IMPACTS OF FOREST MANAGEMENT ACTIVITIES ON SELECTED HARDWOOD WOOD QUALITY ATTRIBUTES: A REVIEW

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ABSTRACT

Hardwoods are increasingly being viewed as an important raw material component of the forest products industry, and this has spurred awareness of the impact of forest management on tree and wood quality. The impacts of various forest management activities on tree and wood quality in hardwoods are presented from the standpoint of the activities themselves rather than that of the wood properties. These silvicultural activities include genetic manipulation, intensive culture, fertilization and/or irrigation, pruning, thinning, weed control, and prescribed fire. A broad literature cited section is included as an aid to future scientists.

Keywords: Hardwoods, wood quality, forest management, silviculture.

In the past several decades, considerable attention has been devoted to measuring, manipulating, and improving wood quality in several softwoods, notably Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), the southern pines (*Pinus* spp.), and redwood (*Sequoia sempervirens* (D. Don) Endl.). However, the same level of attention has not been paid to hardwoods except perhaps for *Populus* and *Eucalyptus* on a global scale. At one time, the United States Forest Service North Central Forest Experiment Station had a major research effort in wood quality of fine hardwoods (white ash, white oak, and black walnut), but this was dropped in a reorganization. Purdue University is now the home of the Hardwood Tree

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Improvement and Regeneration Center (HTIRC), a relatively new effort focusing on genetic improvement of fine hardwoods (Woeste and Michler 2000). The HTIRC is a partnership among state, federal, and private organizations and agencies.

The increased emphasis being placed on hardwood utilization requires that we focus on improving all aspects of hardwood growth and utilization. Luppold et al. (2002) noted that hardwood roundwood consumption has been increasing since the 1960s in all regions of the United States. In this paper we review efforts in wood quality improvement and manipulation in (primarily) North American hardwoods. While the majority of the research cited in this paper is post-1970, there were several pioneering studies predating this that deserve special notice. These include the efforts of Benson H. Paul, USDA Forest Service Silviculturist (Paul 1929 through 1963).

WOOD QUALITY

Wood quality is measured by several parameters whose importance varies from end-user to end-user. Briggs and Smith (1986) indicated that wood quality ''is a measure of aptness of wood for a given use.'' Larson (1969) views wood quality as a concept and further indicates that

> . . . wood quality encompasses the whole of the wood, and when certain characteristics are segregated for measurement or evaluation, it must be recognized that the evaluation is arbitrary and the segregation artificial.

The characteristics or parameters Larson referred to might include cell length, density or specific gravity, growth rate, earlywood-latewood ratio, heartwood color, etc. They may also include such items as lumber grade where hardwood lumber is to be cut into smaller pieces to be remanufactured into furniture (as an example). Until recently, strength had usually not been a concern in hardwood utilization since the majority of the wood had been used for decorative veneers and furniture. Recent research has resulted in the inclusion of aspen, yellow-poplar, red oak, and maples in the National Design Specification (Blankenhorn et al. 1999).

The efforts in wood quality manipulation can be broadly defined as whatever actions the landowner undertakes that influence the growth of the trees and/or the stand. In forestry, this falls under the broad aegis of silviculture. Silviculture is both an art and a science and has been defined as the art of applying science to control forest stand quality (Nyland 2002). This includes no action as well since, as we will see, failure to control weeds or to remove diseased trees or to thin will influence the growth of the stand just as much as overt action does. One of the problems in looking at the effects of forest management activities on tree and wood quality is that all too often tree growth (diameter and/or height) is assumed to be a proxy for wood quality and specific measures of wood quality are left unmeasured.

A study of the literature indicated that the body of knowledge is lacking in many areas. While there have been many examples of guidebooks discussing hardwood stand management—USDA General Technical Report NC-38 by Schlesinger and Funk (1977) or UK Forestry Commission Handbook Number 9 by Kerr and Evans (1993) as examples—few, if any, of these discuss wood quality. The index in Johnson et al.'s recent book on oak ecology and silviculture lists neither tree nor wood quality (Johnson et al. 2002). There are some noteworthy exceptions to this, however. In the Fourth Black Walnut Symposium, Phelps (1989) addressed the tree growth-wood quality relationship from the wood properties perspective. Cutter et al. (1997) reviewed the impact of management activities on walnut growth and wood quality in the Fifth Black Walnut Symposium. Zhang et al. (1997) organized a workshop on timber management and wood quality/end product value. Nepveu (1999) led a workshop on modeling the relationships between silviculture and wood quality.

In wood utilization texts, three general sources of variation in wood and wood properties are listed: genetics, tree (cambial) age, and environment (Panshin and de Zeeuw 1980; Bowyer et al. 2003). Environmental factors are typically thought of as climate, soil fertility, moisture, photoperiod, etc. However, forest management activities undertaken by the landowner constitute an environmental impact as well. Typical or traditional forest management activities—e.g., silvicultural activities—might include thinning, pruning, fertilization, irrigation, etc. Atypical activities might include mechanical agitation by shakers to hurry nut drop such as is common in harvesting English walnuts or pecans (Reid 1993). Another atypical management activity might be agroforestry alleycropping where alleyways are used for rowcrops and grazing lanes (Garrett et al. 1991).

This paper is somewhat unusual in that we address primarily the effects of forest management activities on hardwood tree and wood quality rather than looking at specific wood quality measures. By no means should this paper be considered a complete and exhaustive compilation. We recognize that some citations will be overlooked. We will begin by briefly reviewing some of the literature on the other two sources of wood quality variation—genetics and tree age.

GENETICS

One of the glaring areas where noticeable effort has been lacking has been in the area of genetic improvement of hardwood quality. The establishment of the Hardwood Tree Improvement and Regeneration Center will address some of this. Several years ago there were efforts to improve sugar content in sugar maple for better syrup production (Kriebel 1967; Kriebel and Gabriel 1969). There has been considerable effort expended in poplar improvement by both the government and private industry beginning with Stout and Schreiner in the 1930s (Farmer 1972; Schreiner 1959, 1971; Smith 1967; Stout and Schreiner 1933) and continuing with private industry such as MeadWestvaco (Robison private communication). These efforts have been geared towards improved fiber production for pulp and paper usage and continue today. In recent years, willows (*Salix* spp.) have also received considerable attention because of their increased growth potential (Volk et al. 2001) as has river birch (*Betula nigra* L.) (Hicks et al. 1975).

When it comes to using hardwood for something other than a fiber or energy source, the efforts and results have been more modest. Farmer (1972) indicated that there were tree improvement efforts underway in yellow birch (*Betula alleghaniensis* Britton), northern red oak (*Quercus rubra* L.), sugar maple (*Acer saccharum* Marsh.), sweetgum (*Liquidambar styraciflua* L.), white ash (*Fraxinus americana* L.), sycamore (*Platanus occidentalis* L.), and yellow-poplar (*Liriodendron tulipifera* L.) Many of these early efforts were geared towards improvement in height and diameter growth and not necessarily wood quality parameters per se (Farmer et al. 1983).

In Europe, there have been several studies aimed at genetic improvement and breeding programs primarily in oaks and birches (Nepveu 1976, 1982; Nepveu et al. 1978; Sesbou and Nepveu 1978). Nepveu (1984) indicated that there was a high broad-sense heritability in several oaks (*Quercus petraea* (Matt) Liebl., *Quercus robur* L. and *Q. rubra* L.) for wood basic density, intermediate heritability for volumetric change, and low or insignificant heritability for growth and shrinkage anisotropy. Nepveu and Velling (1983) looked at genetic variability in *Betula pendula* and found that there was sufficient variation that selection for increased wood basic density was possible. Guilley et al. (1999) found that there was some degree of genetic control over spiral grain in *Q. petraea.* There has been some work done with evaluating genetic variation in Indian teak (*Tectona grandis*) as well (Varghese et al. 2000)

The one species where there have been concerted efforts in North America is eastern black walnut (*Juglans nigra* L.). Considerable time and effort have been expended over the years in black walnut tree improvement programs with modest results (Beineke 1985; Bey 1973; Chenowerth 1995; Rink 1987; Rink and Phelps 1989; Rink et al. 1994a, b). Most of the work has been aimed at improving either growth and form or at increasing nut yield (Garrett et al. 1994; Jones et al. 1995). Rink et al. (1994a) evaluated wood quality in a thinning of plantation-grown walnut and found that selection for timber growth showed modest genetic advantage. Rink (1987) has also found low heritability for heartwood color in black walnut suggesting that environmental and/or management factors play a significant role in determining this important wood quality parameter. Woeste (2002) evaluated a 35-year-old walnut progeny test and found that there was significant opportunity for gain for heartwood area.

Chen et al. (1995) examined knots, pin knots, and pin knot clusters in black walnut boards cut from logs obtained from a precommercial thinning of a walnut-agroforestry plantation. They found no advantage over selection for either nut or timber characteristics with respect to knots, pin knots, or pin knot clusters. They suggested that retention of suppressed buds was controlled by environmental factors, not genetics.

While not actual genetic manipulation, there were early efforts to produce figured walnut by grafting (Lamb 1940). Walters (1951) reported that trees grafted had more figure in the outer section of the stem then the inner section. There have also been attempts to graft for birdseye grain in sugar maple, again with limited success (Kriebel and Gabriel 1969).

TREE AGE

Tree age has become increasingly important with the emphasis on short-rotation forestry that surfaced during the 1970s. Again much of the emphasis has been either for fiber production (see Blankenhorn et al. 1988, 1992a, b; Holt and Murphey 1978; Murphey et al. 1979 for example) or biomass energy crops (Geyer 1981; Geyer and Walawender 1994, 1997, 1999; Geyer et al. 2000). In most tree species, the early years of growth produce wood that is variously termed ''immature wood'' or ''juvenile wood'' (Panshin and de Zeeuw 1980, Haygreen and Bowyer 1996). This wood has also been referred to as ''crown-formed wood'' since it is associated with the live crown section of the tree stem. Typically, this wood is characterized by shorter cells, steeper S_2 cell-wall microfibril angles, and altered chemical composition. As a result of these changes, some physical and mechanical properties are altered as well—increased shrinkage, decreased density, decreased strength. Walnut does not appear to be an exception. Cutter and Garrett (1993) found that fiber length was increasing from pith to bark in a study of 15-year-old thinnings from an agroforestry plantation. Zhang et al. (1993, 1994a, b) looked at density variation in European oaks and were able to develop regression equations that related wood density and shrinkage to cambial age and ring width.

FERTILIZATION AND/OR IRRIGATION

As a rule, fertilization and irrigation increase ring width (Klem 1968). In hardwoods, most of this increase seems to occur in the latewood. Murphey et al. (1973b) found that red oak latewood growth increased significantly as a result of fertilization/irrigation with sewage effluent. This resulted in an overall increase in specific gravity. Mitchell (1971) found a slight increase in specific gravity following fertilization. Insofar as improving the growth and vigor of the trees, it is difficult to say that either of these practices would be detrimental to tree and/or wood quality. Certainly, based on the results from other species, one could infer that the results would likely be favorable (Murphey et al. 1973a, b; Scowcroft and Stein 1986). When fertilization is specifically discussed, it is usually with respect to the effect on nut yield (Jones et al. 1995).

There have been several studies conducted where nutrient levels were altered or controlled to determine what if any effect nutrition had on wood anatomy and or quality. Foulger and Hacskaylo (1968) found that potassium-deficient *Populus deltoides* Bartr. seedlings had shorter, narrower fibers and narrower ring widths in their lower stems and narrower vessel elements in the upper stems. Foulger et al. (1971, 1972) stated that more information on specific nutrients was necessary. Cutter and Murphey (1978), Murphey and McAdoo (1969), and Murphey et al. (1962) all found that depriving seedling or cuttings of adequate potassium resulted in higher wood specific gravity.

GRAZING

While grazing is not what many people consider a recommended forest management practice, many times cattle are grazed in forests or woodlots. Some agencies explicitly recommend against grazing (Hershey 1991; Williams 1933). However, in many areas of the United States, forest grazing of cattle is a common practice (Lundgren et al. 1983). Much of the evidence cited against grazing appears to be either anecdotal or based on uncontrolled grazing of not only cattle, but hogs, sheep, goats, etc. and is related to soil erosion and watershed degradation (Patric and Helvey 1986). Cutter et al. (1996) found that controlled grazing with cattle had no influence on tree grade in slash pine. Lehmkuler et al. (1998) indicted that controlled grazing of cattle was not harmful to walnut over the short run. The emphasis in both studies was on control of the duration, intensity, and timing of the grazing.

PRUNING

Pruning is done for several reasons including the production of a clear stem, corrective pruning for tree form, and (in agroforestry alleycropping regimes) removal of low branches that might impede the access of agricultural equipment. While there have been numerous studies showing the proper way to prune to minimize bole damage (Armstrong et al. 1981; Shigo et al. 1978), it is important to remember that pruning is a deliberate wounding of the tree, regardless of the desirability of the end result. The general recommendation that may be made is that pruning should be done at an early age and limited to small-diameter branches (say less than 1-inch diameter). Early pruning will allow the production of the maximum amount of clear wood.

While pruning is frequently done to correct a misshapen stem, Reeves (1984) found that the tree will try to correct this on its own, and, if left alone, will do a very good job. The time of year that pruning occurs has been shown to play a role in both wound healing and scarring. Armstrong et al. (1981) and Smith (1980) found that fall pruning/wounding produced more scarring and discoloration in walnuts than did late winter–early spring pruning. Studies by Clark and several of his co-workers indicated that pruning, while stimulating growth, sometimes produced undesirable results including epicormic branching (Clark 1955, 1961; Clark and Seidel 1961). Indeed, even 25 years following pruning, the pruning wounds had not healed on some stems in one study (Shigo et al. 1978, 1979). Shigo and his numerous co-workers noted that dark bands of discolored heartwood were associated with pruning wounds. If the production of clear, uniform color wood is the desired result, this is clearly undesirable.

Minckler (1967) indicated that pruning and thinning could improve stem quality in white oak, but no direct measure of wood quality was examined. Dwyer and Lowell (1988) and Lowell and Dwyer (1988) showed that, while pruning may appear to improve log grade and therefore lumber quality, the time and effort may not be economically worthwhile over the rotation cycle. This was a study of black and scarlet oak (*Quercus velutina* Lam. and *Q. coccinea* Muench, respectively) growing on an upland site in the Missouri Ozarks. DeBell et al. (2002) found that pruning had no significant impact on wood quality in nine-year old *Populus* stems.

THINNING

Typically, thinning is thought of as removal of poorly formed trees, low vigor trees, diseased trees, etc. From a traditional forest management standpoint, thinning is either precommercial (i.e. the cut trees are left on the ground) or commercial (the removed trees are large enough for product recovery—also known as harvesting or logging). In either event, the result is increased water and nutrient availability for the residual stand. In some instances, there have been reports of increased levels of limb-related defects associated with heavily thinned hardwood stands (Sonderman 1986). It is well recognized that thinned stands have a tendency towards epicormic branch proliferation. In another study, gum spots were found in the wood of black cherry (*Prunus serotina* Ehrh.) following a partial harvest (Rexrode and Smith 1990). There has also been some indication in the literature that thinnings increased the tendency towards sun scald and frost cracks in certain climates, although mechanical injury from equipment could not be ruled out (Phelps 1976).

It should be obvious that there is some damage to the residual stand as a result of thinnings. The damage can occur either from the falling trees damaging limbs or stems of the residual stand or basal damage from skidding, or—more insidious—root damage from soil compaction, which may translate to stem damage.

Cutter et al. (1991) indicated that there was a differential response to thinning between black oak and scarlet oak in the Missouri Ozarks. The black oak responded immediately to the release, while the scarlet oaks lagged some six to seven years behind.

Paul (1943) reported that open-grown black walnut had higher density than did forest-grown walnut. Open-grown was defined at that time as ''trees growing singly or in small scattered groups in pastures and relatively open farm woodlots.'' This might be analogous to stand densities seen in many agroforestry configurations. In a latter paper, Paul (1963) recommended that management practices producing conditions similar to those where open-grown walnut occurs be followed. On the other hand, Landt and Phares (1973) suggested that open-grown walnut would tend to be forked and limby while forest-grown walnut would have a straight, clear stem. According to them, the forest-grown stems would have a dark-colored heartwood with a narrow sapwood band while open-grown trees would have lighter heartwood and wider sapwood rings.

Phelps and Chen (1989) found that—while plantation-grown black walnut grew faster—lumber quality was lower in logs from the plantation-grown trees. They attributed this to the presence of numerous knots in the boards. Phelps and Workman (1992) compared vessel element area in naturally-grown walnut against plantation-grown walnut trees. They found that the faster-growing plantation trees had wider growth rings, which in turn have wider latewood zones. This results in a reduction in vessel area in the cross-section, which results in poorer wood texture. On the other hand, stand management favors a more uniform wood texture.

Phelps and Chen (1991) examined wood and drying properties in white oak (*Quercus alba* L.) lumber from thinned and unthinned stands. They found that tree size had a greater influence on lumber grade than any other variable. There were no significant differences in amounts of heartwood, specific gravity, and board width shrinkage. There was a significant difference in thickness shrinkage between thinned and unthinned wood.

Other literature suggests that trees growing in a crowded stand may have greater height: diameter ratios. In a study of the effect of stand density, Holbrook and Putz (1989) found that sweetgum (*Liquidambar styraciflua* L.), which like walnut is a light-demanding tree, apparently allocated more wood to height growth than to diameter when grown in dense stands.

Zhang et al. (1993) studied wood density in two European oaks (*Q. petraea* (Matt) Liebl.

and *Q. robur* L.) and developed a model that allowed prediction of wood density based on cambial age and ring width. They suggested that application of (what they termed) dynamic silviculture might result in denser and more uniform oak than did conventional silviculture.

Bragg et al. (1997) suggested that management activities—such as thinning—may reduce the occurrence of ''birdseye'' figure in sugar maple.

PRESCRIBED FIRE OR WILDFIRE

While wildfire is not a management tool, prescribed fire is—and it is becoming more common in some areas (Van Lear 2000). In either event, fire may impact tree growth and therefore wood quality. In a prescription (or prescribed) fire, the impact on tree growth and wood quality may be minimized by proper burning techniques. Wendel and Smith (1986) indicated that a single prescribed fire in a central Appalachian oak-hickory stand resulted in a major reduction in butt log quality. The basal scars that result from fire damage are the result of the cambium being heated for a known length of time to a lethal temperature—typically cited as 60°C (140°F) for 30 s or 64°C (147°F) for instantaneous cambial death (Brown and Davis 1973). Obviously this is a function of bark thickness as well and many hardwood species are (relatively) thin-barked. Paulsell (1957) noted that post oak (*Quercus stellata* Wangenh.) and hickory (*Carya* spp.) had thicker bark than more desirable species and therefore were more resistant to basal scarring. Many times the scar is only part way around the tree because of fuel loadings and wind currents (Hare 1965; Gill 1973). Loomis (1973, 1977) and Wendel and Smith (1986) indicated that the chance of tree mortality was a function of tree diameter as well. In the case of wildfires, the damage may include complete destruction of the tree. There is some indication in the fire literature (Van Lear and Waldrop 1989, for example) that seasonal timing of the fire may have a major impact on the likelihood of basal scarring which is of most interest to the forest products community.

WEED CONTROL

This could also be termed ''competing vegetation control'' since, under some scenarios, the competing vegetation that landowners need to control may be rowcrops or other tree species. Numerous papers have shown that vegetation control during establishment phases of walnut stands is necessary for optimum growth response (Schlesinger and Van Sambeek 1986; Van Sambeek et al. 1989). What many do not realize is that the competition for available nutrients and water continues once the tree is into the sapling or pole stage. If the competing vegetation is other trees, be they walnut or some other species, then vegetation control is termed thinning. If the competing vegetation is an annual (such as corn or soybeans) or a perennial (such as clover or lespideza), then the tree line may need to be kept vegetation-free in order for the tree to successfully compete for water and nutrients. This could be done through either chemical or mechanical means (Jones et al. 1990). Cutter and Garrett (1993) indicated that declining growth in an agroforestry plantation on an exceptional site (SI = 90+) was coincident with conversion of the alleyways to a perennial cover crop. SI refers to site index, commonly defined as the height of the dominant and co-dominant trees at age 50.

OTHER ASPECTS OF WOOD QUALITY

By focusing this review on the impacts of management on tree and wood quality, we have neglected some important hardwood quality issues. One that immediately comes to mind is tension wood and its development (Scurfield 1973). Tension wood in hardwoods has been the subject of numerous studies (Isebrands and Bensend 1972; Isebrands and Parham 1974; Schumann and Pillow 1969, for example). In many species, the amount of tension wood present in a stem has been linked directly to the degree of lean in a tree while in other species, tension wood develops regardless of lean (Reeves 1984). In either event, tension wood is not considered a desirable trait in many products!

Color has been examined in a number of studies to attempt to describe the quality of wood from that perspective. Wood color is an elusive trait, primarily because the importance of it (from a quality standpoint) varies from species to species and from market to market (Bistline 1981; Blomgren 1965). There are differences within a species as well. Anecdotally, there are reputed to be black walnut buyers who claim that walnut from certain regions has a reddish hue in color and is therefore less desirable. As previously noted, Rink (1987) suggested that environmental/management factors play a significant role in determining this important wood quality parameter.

In the early 1990s, Phelps and colleagues conducted a series of studies to evaluate the potential for using color-measuring instruments in matching colors in white oak panels destined for the kitchen door market. The color value for lightness (L*) was found to be the most influential in determining color separation between dimension parts in a door panel (Phelps et al. 1994). Little difference was found within individual panel parts, leading to the observation that very few measurements per part were necessary. In a subsequent study (Stokke et al. 1995), the distribution of lightness values within dimension parts was found to be statistically normal, suggesting that there may be an opportunity to examine the source of the raw material for selection of panel dimension parts. The third study in this series examined the potential for pre-sorting dimension parts prior to assembly (Pugel et al. 1995). The pre-sort was shown to have potential for improving the quality and value of the final panel product, but there were increased costs due to the added step in processing.

Obviously there is considerable interest in producing high quality hardwoods. This interest has been spurred by indications that hardwoods are going to play an increased role in providing fiber for the 21st century and beyond. As a closing note, the literature section of this paper is labeled as a ''Partial Bibliography.'' We recognize that not all references on the broad subject we have attempted to review will be included in this section. By the same token, many of the references listed in this section are not cited in this paper but are included to facilitate future use. The relative ease of searching electronic databases and accessing online journals has on one hand simplified life but has also complicated it. However, we have attempted to include a broad cross-section of new as well as older literature to facilitate the efforts of future researchers.

PARTIAL BIBLIOGRAPHY

ARMSTRONG, J. E., W. H. KEARBY, AND E. A. MCGINNES, JR. 1979. Anatomical response and recovery of twigs of *Juglans nigra* following oviposition injury inflicted by the Two-spotted Treehopper, *Enchenopa biontata*. Wood Fiber 11:29–37.

———, A. L. SHIGO, D. T. FUNK, AND E. A. MCGINNES, JR., AND D. E. SMITH. 1981. A macroscopic and microscopic study of compartmentalization and wound closure after mechanical wounding of black walnut trees. Wood Fiber 13:275–291.

BEINEKE, W. F. 1985. Characteristics of Purdue University's patented black walnut trees. Purdue University Cooperative Extension Service FNR-115. West Lafayette, IN. 7 pp.

BENDTSEN, B. A. 1978. Properties of wood from improved and intensively managed trees. Forest Prod. J. 28(10): 61–72.

BEY, C. F. 1973. Growth of black walnut trees in eight midwestern states—A provenance test. USDA Forest Service Research Paper NC-91. St. Paul, MN. 7 pp.

BISTLINE, G. P. 1981. Consumer attitudes and perception of black walnut interior paneling. M.S. thesis, University of Missouri-Columbia, Columbia, MO.

BLANKENHORN, P. R., T. W. BOWERSOX, C. H. STRAUSS, G. L. STIMLEY, L. R. STOVER, AND M. L. DICOLA. 1988. Effects of management strategy and site on selected properties of first rotation *Populus* hybrid NE-388. Wood Fiber Sci. 20:74–81.

———, ———, ———, K. R. KESSLER, W. R. KILMER, AND M. L. DICOLA. 1992a. Effects of management strategy and site on specific gravity of a *Populus* hybrid clone. Wood Fiber Sci. 24:274–279.

———, ———, ———, ———, L. R. STOVER, AND M. L. DICOLA. 1992b. Chemical composition of second rotation *Populus* hybrid NE-388. Wood Fiber Sci. 24: 280–286.

———, P. LABOSKY, J. J. JANOWIAK, H. B. MANBECK, D. A. WEBB, AND R. T. BAILEYS. 1999. The development of preservative treatment recommendations for red oak and red maple glued-laminated timber bridge members. Forest Prod. J. 45(5):87–93.

BLOMGREN, G. W., JR. 1965. The psychological image of wood. Forest Prod. J. 15(4):149–151.

BOAKYE-YIADOM, K. 1986. Properties of the wood of black walnut (*Juglans nigra* L.) at the limb-bole interface zone. M.S. thesis, University of Missouri–Columbia, Columbia, MO.

BOWYER, J. L., R. SHMULSKY, AND J. G. HAYGREEN. 2003. Forest products and wood science, 4th ed. Iowa State University Press. Ames, IA. 484 pp.

BOYCE, S. G. 1965. Improved hardwoods for increased utilization. Pages 1–6 in Proc. 8th Southern Conference on Forest Tree Improvement) June 16–17, 1965. Savannah, Georgia. Macon, GA.

———, M. KAEISER, AND C. F. BEY. 1970. Variations of some wood features in five black walnut trees. Forest Science 16:95–100.

BRAGG, D. L., G. D. MROZ, D. D. REED, S. G. SHELTON, AND D. D. STOKKE. 1997. Relationship between ''birdseye'' sugar maple (*Acer saccharum*) occurrence and its environment. Can. J. Forest Res. 27:1182–1191.

BRESNAN, D. T., W. A. GEYER, AND G. RINK. 1996. Variation among green ash of differing geographic origins outplanted in Kansas. J. Arborculture 22(3):113–116.

———, G. RINK, K. E. DIEBEL, AND W. A. GEYER. 1994. Black walnut provenance performance in seven 22-year-old plantations. Silvae Genetica 43:246–252.

BRIGGS, D. G., AND W. R. SMITH. 1986. Effects of silvicultural practices on wood properties of conifers—A review. *In* C. Oliver, D. Hanley, and J. Johnson, eds., Douglas-fir: Stand management for the future. University of Washington Press, Seattle, WA.

BRINKMAN, K. A. 1955. Epicormic branching in oaks in sprout stands. US Forest Service Central States Forest Experiment Station Technical Paper 146.

BROWN, A. A., AND K. P. DAVIS. 1973. Forest fire control and use, 2nd ed. McGraw-Hill, New York, NY. 686 pp.

CARMEAN, W. H., AND S. G. BOYCE. 1974. Hardwood log quality in relation to site quality. USDA Forest Service North Central Forest Experiment Station Research Paper NC-103. St. Paul, MN. 7 pp.

CHEN, P. Y. S., AND J. E. PHELPS. 1989. Effects of selected management practices on number grade and drying properties of two central hardwood species. Pages 46–52 *in* Proceedings—Western Dry Kiln Clubs. Oregon State University, Corvallis, OR.

———, R. E. BODKIN, AND J. W. VAN SAMBEEK. 1995. Variation in pin knot frequency in black walnut lumber cut from a small provenance/progeny test. Page 488 *in* K. W. Gottschalk and S. L. C. Fosbrike, eds. Proc. 10th Central Hardwood Forest Conference. USDA Forest Service General Technical Report NE-197. St. Paul, MN.

———, G. ZHANG, AND J. W. VAN SAMBEEK. 1998. Relationships among growth rate, vessel lumen area, and wood permeability for three central hardwood species. Forest Prod. J. 48(3):87–90.

CHENOWERTH, B. 1995. Black walnut. Sagamore Publishing, Champaign, IL.

CLARK, F. B. 1955. Black walnut responds to pruning. J. Forestry 53:362–365.

———. 1961. Climatic injury found on planted black walnut in Kansas. Central States Forest Experiment Station Note 147. Columbus, OH. 2 p.

———, AND K. W. SEIDEL. 1961. Growth and quality of pruned black walnut. Central States Forest Experiment Station Technical Paper 180. Columbus, OH. 11 pp.

CUTTER, B. E. 1991. Tree and wood quality in 15-year-old eastern black walnut (*Juglans nigra* L.) grown in agroforestry regimes. Pages 116–123 *in* H. E. Garrett, ed. Proc. The 2nd Conference on Agroforestry in North America, August 18–21, 1991, Springfield, MO. School of Natural Resources, University of Missouri, Columbia, MO. 403 pp.

———, AND W. K. MURPHEY. 1978. Effects of potassium on growth and wood anatomy of a *Populus* hybrid. Wood Fiber 9(4):282–288.

———, AND H. E. GARRETT. 1993. Wood quality in alleycropped eastern black walnut. Agroforestry Systems 22:25–32.

———, K. E. LOWELL, AND J. P. DWYER. 1991. Thinning effects on diameter growth in black and scarlet oak as shown by tree ring analyses. Forest Ecol. Mgmt. 43:1–13.

———, J. E. PHELPS, AND D. D. STOKKE. 1997. The silviculture-wood quality connection in eastern black walnut. Pages 224–230 *in* J. W. Van Sambeek, ed. Proc. 5th Black Walnut Symposium. July 28–31, 1996, Springfield, MO. USDA Forest Service General Technical Report NC-191. St. Paul, MN.

———, K. HUNT, AND J. D. HAYWOOD. 1998. Tree/wood quality in slash pine following long-term cattle grazing. Agroforestry Systems 44:305–312.

DEBELL, D. S., R. SINGELTON, C. A. HARRINGTON, AND B. L. GARTNER. 2002. Wood density and fiber length in young *Populus* stems: Relation to clone, age, growth rate, and pruning. Wood Fiber Sci. 34(4):529–539.

DIERAUF, T. A., J. W. GARNER, AND J. A. SCRIVANI. 1995. A study of diameter growth in black walnut stands. Virginia Department of Forestry. Occasional Report #118. Charlottesville, VA. 10 pp.

DUNHAM, R. A., A. D. CAMERON, AND J. A. PETTY. 1999. The effect of growth rate on the strength properties of sawn beams of silver birch (*Betula pendula*). Scand. J. Forest Res. 14(1):18–26.

DWYER, J. P., AND K. E. LOWELL. 1988. Long-term effects of thinning and pruning on the quality, quantity, and value of oak lumber. Northern J. Appl. Forestry 5(4): 258–260.

ENGLERTH, G. H. 1966. Machining and other properties of fast- versus slow-grown trees. Pages 77–82 *in* Black walnut culture. USDA Forest Service North Central Forest Experiment Station. St. Paul, MN.

EWALD, D., G. NAUJOKS, AND H. PIEGERT. 2000. Performance and wood quality of in vitro propagated hybrid curly birch (*Betula pendula* × *Betula pendula* var. *carelica* SOK.) clones. Silvae Genetica 49(2):98–101.

FARMER, R. E., JR. 1972. Genetic improvement of hardwood fiber production in the North Central Region: Potentials and breeding alternatives. Pages 9–15 *in* Joint Proceedings of the Tenth Lake States Tree Improvement Conference and the Seventh Central States Forest Tree Improvement Conference, September 22–24, Madison, WI, 1972. St. Paul, MN.

———, P. E. BARNETT, E. THOR, AND J. C. RENNIE. 1983. Heritability estimates for height growth of Tennessee yellow-polar. Silvae Genetica 32(1-2):15–18.

FOULGER, A. N., AND J. HACSKAYLO. 1968. Stem anatomy variations in cottonwood under nutrient-deficient conditions. USDA Forest Service Research Paper NC-23. St. Paul, MN. Pp. 41–47.

———, E. A. SHIRE, AND R. FREESE. 1971. Effect of nutrient concentraiton on the stem anatomy of eastern cottonwood seedlings. Wood Fiber 2:340–346.

———, R. FREESE, AND E. A. SHIRE. 1972. Effect of nutrient concentration on the stem anatomy of white ash seedlings. Wood Fiber 4:112–114.

GARRETT, H. E., AND W. B. KURTZ. 1982. Nut production—a valuable asset in black walnut production. Pages 53–56 *in* Black walnut for the future. USDA Forest Service General Technical Report NC-74. St. Paul, MN.

———, AND ———. 1983. Silvicultural and economic relationships of integrated forestry-farming with black walnut. Agroforestry Systems 1:245–256.

——, AND ———. 1987. Nut production and its importance in black walnut management. Pages 23–28 *in* 78th Annual Report of the Northern Nut Grower's Association.

———, C. NEELAN, AND J. E. JONES. 1994. Incidence of yellow-bellied sapsucker damage under walnut agroforestry. Pages 25–28 *in* Proc. 3rd N.A. Agroforestry Conference, August 15–18, 1993. Ames, IA.

———, J. E. JONES, W. B. KURTZ, AND J. P. SLUSHER. 1991. Black walnut (*Juglans nigra* L.) agroforestry—its design and potential as a land-use alternative. Forestry Chronicle 67:213–218.

———, E. F. LOWENSTEIN, J. E. JONES, AND G. RINK. 1995. The importance of selecting gain in walnut agroforestry management. Pages 374–376 *in* Proc. 8th Biennial Southern Silviculture Conference. USDA Forest Service General Technical Report SRS-1, Asheville, NC. 646 pp.

GEYER, W. A. 1981. Growth, yield and woody biomass characteristics of seven short-rotation hardwoods. Wood Science 13(4):209–215.

———, AND W. P. WALAWENDER. 1994. Biomass properties and gasification behavior of young black locust. Wood Fiber Sci. 26(3):354–359.

———, AND ———. 1997. Biomass and gasification of young catalpa trees. Wood Fiber Sci. 3(1):95–100.

———, AND G. RINK. 1998. Interaction effects of seed source, culture and pest management on growth of *Juglans nigra* in plantations. Silvae Genetica 47(1):51–58.

———, AND W. P. WALAWENDER. 1999. Biomass properties and gasification behavior of young silver maple trees. Wood Fiber Sci. 29(1):85–90.

———, J. DEWYKE, AND W. P. WALAWENDER. 2000. Biomass and gasification properties of young *Populus* clones. Wood Fiber Sci. 32(3):375–384.

GILL, A. M. 1974. Toward an understanding of fire-scar formation: Field observation and laboratory simulation. Forest Science 20:198–205.

GOMINHO, J., J. FIGUEIRA, J. C. RODRIGUES, AND H. PEREIRA. 2001. Within-tree variation of heartwood, extractives and wood density in the Eucalyptus hybrid urograndis (*Eucalyptus grandis x. E. Europhylla*). Wood Fiber Sci. 33(1):3–8.

GOTTLEIN, A. 1994. The price of veneer oak as influenced by stem dimension, site characteristics, and wood quality. [German]. *Forstwissenschaftliches Centralbatt.* 113(6):354–366.

GUILLEY, E., M. LOUBERE, AND G. NEPVEU. 1999. Identification en forêt de cheñes sessiles (*Quercus petraea*) présentant un angle du fil du bois intrinsèquement faible. Translated: Identification of trees with a weak spiral wood grain angle in a sessile oak forest (*Quercus petraea*). Can J. Forest Res. 29(12):1958–1965.

HARE, R. C. 1965. Bark surface and cambium temperatures in simulated forest fires. J. Forestry 63:437–440.

HERSEY, F. A. 1991. The extent, nature, and impact of domestic livestock grazing in Missouri woodlands. Pages 248–255 *in* H. E. Garrett, ed. Proc. 2nd Conference on Agroforestry in North America. August 18–21, 1991, Springfield, MO. School of Natural Resources, Univ. of Missouri, Columbia, MO. 403 pp.

HICKS, R. R., JR., G. RINK, AND B. E. CUTTER. 1975. Variation and heritability of seedling height in East Texas sycamore and river birch. Pages 133–137 *in* Proc. 25th Northeast Forest Tree Improvement Conference, Bangor, ME.

HILLER, C. H., F. FREESE, AND D. M. SMITH. 1972. Relationships in black walnut heartwood between color and other physical and anatomical characteristics. Wood Fiber 4(1):38–42.

HOLBROOK, N. M., AND F. E. PUTZ. 1989. Influence of neighbors on tree form: Effects of lateral shade and prevention of sway on the allometry of *Liquidambar styraciflua* (sweetgum). Am. J. Botany 76:1740–1749.

HOLT, D. L., AND W. K. MURPHEY. 1978. Properties of hybrid poplar juvenile wood affected by silvicultural treatments. Wood Science 10(4):198–203.

ISEBRANDS, J. G., AND D. W. BENSEND. 1972. Incidence and structure of gelatinous fibers within rapid-growing eastern cottonwood. Wood Fiber 4(2):61–71.

———, AND R. A. PARHAM. 1974. Tension wood anatomy of short rotation Populus spp. before and after kraft pulping. Wood Fiber 6(3):256–265.

JOHNSON, P. S., S. R. SHIFLEY, AND R. ROGERS. 2002. The ecology and silviculture of oaks. CABI Publishing, New York, NY. 503 pp.

JONES, J. E., H. E. GARRETT, AND J. K. HAINES. 1990. Production, harvesting, utilization, and marketing of eastern black walnut nuts—An industrial viewpoint. Pages 242–247 *in* Proc. of the Black Walnut Symposium, Carbondale, IL.

———, ———, ———, AND E. F. LOEWENSTEIN. 1995. Genetic selection and fertilization provide increased nut production under walnut-agroforestry management. Agroforestry Systems 29:265–273.

KELLISON, R. C., R. LEA, AND D. J. FREDERICK. 1982. Effect of silvicultural practices on wood quality of southern hardwoods. Proc. TAPPI R&D Conf. Pp. 99–103.

KERR, G., AND J. EVANS. 1993. Growing broadleaves for timber. United Kingdom Forestry Commission Handbook No. 9. 95 pp.

KLEM, G. S. 1968. Quality of wood from fertilized forests. TAPPI 51(11):99A–103A.

KRAJICEK, J. E. 1959. Epicormic branching in even-aged, undisturbed white oak stands. J. Forestry 57:372–373.

KRIEBEL H. B. 1967. Patterns of genetic variation in sugar maple. Ohio Expt. Sta. Res. Bull. 791. 65 pp. Wooster, OH.

———, AND J. W. GABRIEL. 1969. Genetics of sugar maple. USDA Res. Pap. WO-7. Washington, DC. 17 pp.

KURTZ, W. B., H. E. GARRETT, AND W. H. KINCAID, JR. 1984. Investment alternatives for black walnut plantation management. J. Forestry 82:604–608.

LAMB, G. N. 1940. Figure in wood. Northern Nut Growers Association Annual Report. 31:28–33.

LANDT, E. F., AND R. E. PHARES. 1973. Black walnut . . . an American wood. USDA Forest Service Publication No. 270. Washington, DC. 7 pp.

LARSEN, P. R. 1969. Wood formation and the concept of wood quality. Yale University School of Forestry Bulletin No. 74. New Haven, CT. 54 pp.

LEHMKULER, J. W., M. S. KERLEY, H. E. GARRETT, B. E. CUTTER, AND R. L. MCGRAW. 1998. Comparison of continuous and rotational silvopastural systems for established walnut plantations in southwest Missouri, USA. Agroforestry Systems 44:267–279.

LOOMIS, R. M. 1973. Estimating fire-caused mortality and injury on oak-hickory forests. USDA Forest Service Research Paper NC-93. St. Paul, MN. 6 pp.

———. 1977. Wildfire effects on an oak-hickory forest in southeastern Missouri. USDA Forest Service Research Note NC-219. St. Paul, MN. 4 pp.

LOWELL, K. E., AND J. P. DWYER. 1988. Stem form and lumber yield: Long term effects of thinning and pruning. Northern J. Appl. Forestry 5(1):56–58.

LUNDGREN, G. K., J. R. CONNER, AND H. R. PEARSON. 1983. An economic analysis of forest grazing on four timber management situations. S. J. Appl. Forestry 7(3): 19–24.

LUPPOLD, W. R., J. P. PRESTEMON, AND A. SCHULER. 2002. The changing markets for hardwood roundwood. Pages 96–100 *in* D. Zhang, ed. Proc. 2001 Southern Forest Economics Workshop, March 28–29, 2001, Atlanta, GA. School of Forestry and Wildlife Sciences, Auburn University. 203 pp.

LUTZ, J. F. 1958. Color in walnut veneer. Veneers and Plywood 52(11):15, 21–22.

MAEGLIN, R. R., AND N. D. NELSON. 1970. Surface soil properties of black walnut sites in relation to wood properties. Soil Science Soc. America Proc. 34:142–146.

MATYAS, C., AND I. PEZLEN. 1997. Effect of age on selected wood quality traits of popular clones. Silvae Genetica 46(2–3):64–72.

MCGINNES, E. A., JR. 1968. Extent of shake in black walnut. Forest Prod. J. 18:80–82.

——. 1975. Response of black walnut to environmental mishaps. Pages 102–107 *in* 66th Annual Report of the Northern Nut Growers Association. Southwest Missouri State University, August 10–13, 1975, Springfield, MO.

———, C. I.-J. CHANG, AND K. Y.-T. WU. 1971. Ring shake in some hardwood species: the individual tree approach. J Polymer Sci:Part C 36:153–176.

MILLER, R. B. 1976. Wood anatomy and identification of species of *Juglans.* Botanical Gazette 137:368–377.

MINCKLER, L. S. 1967. Release and pruning can improve quality of white oak. J. Forestry 55:645–655.

MIRANDA, I., M. ALMEIDA, AND H. PEREIRA. 2001. Influence of provenance, subspecies and site on wood density in *Eucalyptus globulus* Labill. Wood Fiber Sci. 33(1):9–15.

MITCHELL, H. L. 1971. Effect of fertilization on the growth rate and certain wood quality characteristics of sawlog red oak, yellow-poplar, and white ash. Pages. J1–J15 *in* Proc. Symposium on the Effect of Growth Acceleration on the Properties of Wood, Nov. 10–11, Madison WI.

MITCHELL, R. J., J. P. DWYER, R. A. MUSBACH, H. E. GARRETT, G. S. COX, AND W. B. KURTZ. 1988. Crop tree release of a scarlet and black oak stand. Northern J. Appl. Forestry 5(2):96–99.

MURPHEY, W. K., AND J. C. MCADOO. 1969. Effect of nutrient deficiencies on tensile properties of *Robinia pseudoacacia* L. Forest Science 15:151–153.

———, J. HACSKAYLO, AND F. M. LAMB. 1962. The anatomy of Liquidambar styraciflua grown in nutrient-deficient regimes. Paper presented at the Annual Meeting, Forest Products Research Society, San Francisco, CA.

———, R. L. BRISBIN, W. J. YOUNG, AND B. E. CUTTER. 1973. Anatomical and physical properties of red pine and red oak sprayed with municipal wastewater. Pages 295–310 *in* W. E. Sopper and L. T. Kardos, eds, Recycling treated municipal wastewater and sludge through forest and cropland. The Pennsylvania State University Press, University Park, PA.

———, W. J Young, and B. E. Cutter. 1973b. Effects of sewage effluent irrigation on various physical and anatomical characteristics of northern red oak. Wood Science 6(1):65–71.

———, T. R. Bowersox, and P. R. Blankenhorn. 1979. Selected wood properties of young *Populus* hybrids. Wood Science 11(4):263–267.

Nelson, N. D. 1975a. Extractives produced during heartwood formation in relation to amounts of parenchyma in *Juglans nigra* and *Quercus rubra*. Can. J. Forest Res. 5:291–301.

———. 1975b. Important influences on heartwood formation and heartwood-sapwood proportions in black walnut. Pages 156–160 *in* 66th Annual Report of the Northern Nut Growers Association. Southwest Missouri State University, August 10–13, 1975, Springfield, MO.

———. 1976. Gross influences on heartwood formation in black walnut and black cherry trees. USDA Forest Service Research Paper FPL-268. Madison, WI. 12 pp.

———. 1978. Xylem ethylene, phenol-oxidizing enzymes, and nitrogen and heartwood formation in walnut and cherry. Can. J. Botany 56:626–634.

———, R. R. Maeglin, and H. E. Wahlgren. 1969. Relationship of black walnut wood color to soil properties and site. Wood Fiber 1(1):29–37.

Nepveu, G. 1976. Croissance et qualité du bois de Framire. Évolution de la largeur de cerne et des conposantes densitometriques en fonction de l'âge. Translated: Variability of growth and quality of *Terminalia ivorensis* wood; Correlations between characters; Evaluation of width of age-rings and density components in function of age. *Bois Forets Trop* (Jan/Feb 1976):39–58.

———. 1982. Variabilité clonale de l'infreadensité chez *Quercus petraea*. Premiers résultats obtenus sur boutures d'un an. Translated: Clonal variability of basic density in *Quercus peltraea*. First results in one-year-old cuttings. *Annales des sciences forestieres.* 39(2):151–164.

———. 1984. Contrôle héréditaire de la densité et de la retractibile duk bois de trios espèces de chêne (*Quercus petraea, Quercus robur* et *Quercus rubra*). Translated: Hereditary control of density and shrinkage of three species of oak (*Quercus petraea, Quercus robur* and *Quercus rubra*). Silvae Genetica 33(4-5):110–115.

———. 1999. Connection between silviculture and wood quality through modelling approaches and simulation software. Proceedings, Third Workshop, September 5–12, 1999. La Londe-les-Moures, France INRA (*Institut national de la recherche agronomique*) Nancy, France. 644 pp.

———, and P. Velling. 1983. Variabilité génetique individuelle de la qualité du bois chez *Betula pendula* Roth. Silvae Genetica 32(1-2):37–49.

———, R. Keller, and E. Teissier Du Cros. 1978. Selection juvenile pour la qualité du bois chez certains peupliers noirs. Translated: Juvenile selection for wood quality in *Populus nigra* and *Populus euramerican.* Ann. Sci. For. 35(1):69–92.

Niese, J. N., T. F. Strong, and G. G. Erdmann. 1995. Forty years of alternative management practices in second-growth, pole-size northern hardwoods. II. Economic evaluation. Can. J. Forest Res. 25(7):1180–1188.

Nyland, R. D. 2002. Silviculture: Concepts and applications. McGraw-Hill. New York, NY. 682 pp.

Omolodun, O., B. E. Cutter, E. A. McGinnes, Jr., and G. F. Krause. 1991. Anatomical variation in *Hildegardia barteri* (Mast.) Kossern—An African tropical pioneer species. Wood Fiber Sci. 23(4):419–435.

Osorio, L. F., T. L. White, and D. A. Huber. 2001. Age trends of heritabilities and genotype-by-environment interactions for growth traits and wood density from clonal trials of *Eucalyptus grandis* Hill ex Maiden. Silvae Genetica 50(3-4):108–116.

Panshin. A. J., and C. DeZeeuw. 1980. Textbook of wood technology, vol. I. McGraw-Hill. New York, NY. 722 pp.

Patric, J. H., and J. D. Helvey. 1986. Some effects of grazing on soil and water in the eastern forest. USDA Forest Service. NE-GTR-115. Broomall, PA. 25 pp.

Paul, B. H. 1929. The relation of growth to the production of white wood in hickory trees. U.S Forest Service Forest Products Lab. Report 1605. Madison, WI. 2 pp.

———. 1929. The quality of Appalachian hickory. Southern Lumberman 135(1749):29–32.

———. 1941. Quality comparisons of hardwoods from the southern Appalachians with that of northern origin. Wood Products 46(7):16–18.

———. 1942. Variation in the porosity of twelve species of oak. Southern Lumberman March 15, 1942.

———. 1943. Black walnut for gunstocks. Southern Lumberman 166(2089):32–33.

———. 1952. Second-growth southern hardwood timber. USDA Forest Service. Forest Products Lab. Report No. R1120. Madison, WI. 5 pp.

———. 1959a. Second-growth oak, part 1. Southern Lumber Journal and Building Material Dealer January, 1959.

———. 1959b. Second-growth oak, part 2. Southern Lumber Journal and Building Material Dealer February, 1959.

———. 1963. The application of silviculture in controlling the specific gravity of wood. USDA Forest Service Technical Bulletin No. 1288. Madison, WI. 97 pp.

Paulsell, L. K. 1957. Effects of burning on Ozark hardwood timberlands. University of Missouri Agricultural Experiment Station Research Bulletin 640. Columbia, MO. 24 pp.

Phelps, J. E. 1976. Anatomical studies of radial cracks in black oak (*Quercus velutina* Lam.) M.S. thesis, University of Missouri–Columbia, Columbia, MO.

———. 1989. How management practices influence black walnut wood properties. Pages 21–29 *in* The Continuing Quest for Quality, Proc Fourth Black Walnut Symposium, July 30–August 2, 1989, Carbondale, IL. Walnut Council, Indianapolis, IN.

———, AND E. A. MCGINNES JR. 1983. Growth-quality evaluation of black walnut wood, part III—An anatomical study of color characteristics of black walnut veneer. Wood Fiber Sci. 15(3):212–218.

———, AND P. Y. S. CHEN. 1989. Lumber and wood properties of plantation-grown and naturally grown black walnut. Forest Prod. J. 39(2):58–60.

———, AND ———. 1991. Wood and drying properties of white oak from thinned and unthinned plantations. Forest Prod. J. 41(6):34–38.

———, AND E. C. WORKMAN, JR. 1992. Vessel area studies in black walnut (*Juglans nigra* L.). Wood Fiber Sci. 24(1):60–67.

———, D. D. STOKKE, AND A. D. PUGEL. 1994. Color analysis of white oak, edge-glued furniture panel stock. Forest Prod. J. 44(2):35–38.

———, E. A. MCGINNES, JR., H. E. GARRETT, AND G. S. COX. 1983. Growth-quality evaluation of black walnut wood. Part II—Color analyses of veneer produced on different sites. Wood Fiber Sci. 15(2):177–185.

PUGEL, A. D., J. E. PHELPS, AND D. D. STOKKE. 1995. Improving visual color sorting of dimension stock. Forest Prod. J. 45(11/12):57–60.

REEVES, G. B. 1984. Selected wood properties of self-straightening black walnut trees. Ph.D. dissertation, University of Missouri–Columbia, Columbia, MO.

REID, W. 1993. Mid-summer shaking reduces alternative bearing. Quandong 19:10–12.

REXRODE, C. O., AND H. C. SMITH. 1990. Occurrence of gum spots in black cherry after partial harvest cutting. USDA Forest Service Research Paper NE-634. Broomall, PA. 7 pp.

RINK, G. 1987. Heartwood color and quantity variation in a young black walnut progeny test. Wood Fiber Sci. 19(1):93–100.

———, AND J. E. PHELPS. 1989. Variation in heartwood and sapwood properties among 10-year old black walnut trees. Wood Fiber Sci. 21:177–182.

———, F. H. KUNG, AND B. E. CUTTER. 1994a. Selection effectiveness for black walnut nuts and timber. Pages 101–105 *in* R. C. Schultz, and J. P. Colletti, eds. Opportunities for agroforestry in the temperate zone worldwide. Proc. Third North American Agroforestry Conference, August 15–18, 1993. Iowa State University, Ames, IA.

———, G. ZHANG, Z. JINGHUA, F. H. KUNG, AND E. R. CARROLL. 1994b. Mating parameters in *Juglans nigra* L. seed orchard similar to natural population estimates. Silvae Genetica 43:261–263.

ROBERGE, M. R. 1975. Effect of thinning on the production of high quality wood in a Quebec northern hardwood stand (*Betula alleghaniensis, Acer saccharum*). Can. J. Forest Res. 5(1):139–145.

SAUCIER, J. R., AND A. F. IKE. 1972. Response in growth and wood properties of American sycamore to fertilization and thinning. Proc. Symp. Effect of growth acceleration on the properties of wood. USDA Forest Service Forest Products Laboratory, Madison WI.

SCHLESINGER, R. C., AND D. T. FUNK. 1977. Manager's handbook for black walnut. USDA Forest Service General Technical Report NC-38. St. Paul, MN. 22 pp.

———, AND J. W. VAN SAMBEEK. 1986. Ground cover management can revitalize black walnut trees. Northern J. Appl. Forestry 3:49–51.

SCHMIDT, T. L. 1998. Comparing grazed and ungrazed forests in Kansas. Northern J. Appl. Forestry 15(4):216–221.

SCHREINER, E. J. 1959. Production of poplar timber in Europe and its significance and application in the United States. USDA Forest Service Agricultural Handbook No. 150. Washington, DC. 123 pp.

———. 1971. Genetics of eastern cottonwood. USDA Forest Service Research Paper WO-11. Washington, DC. 19 pp.

SCHUMANN, D. R. 1973. Mechanical, physical, and machining properties of black walnut from Indiana and Missouri. Wood Fiber 5(1):14–20.

———, AND M. Y. PILLOW. 1969. Effect of tension wood on hard maple used for manufactured parts. USDA Forest Service Research Paper FPL-108. Madison, WI.

SCOWCROFT, P. G., AND J. D. STEIN. 1986. Simulating growth of stagnated *Acacia koa* by thinning and fertilizing. USDA Forest Service Research Note PSW-380. Berkeley, CA. 8 pp.

SCURFIELD, G. 1973. Reaction wood: Its structure and function. Science 179:647–655.

SENDAK, P. E., W. B. LEAK, AND W. B. RICE. 2000. Hardwood tree quality development in the White Mountains of New Hampshire. Northern J. Appl. Forestry 17(1): 9–15.

SESBOU, A., AND G. NEPVEU. 1978. Variabilité infraspécifique du retrait avec collapse et de la densité du bois chez *Eucalyptus camaldulensis* Translated: Infraspecific variability of shrinkage with collapse and wood density in *Eucalyptus camaldulensis. Annales des sciences forestieres.* 35(3):237–263.

SHIGO, A. L., N. F. ROGERS, E. A. MCGINNES, JR., AND D. T. FUNK. 1978. Black walnut on Kansas stripmine soils. Some observations 25 years after pruning. USDA Forest Service Research Paper NE-393. Broomall, PA. 14 pp.

———, E. A. MCGINNES, JR., D. T. FUNK, AND N. F. ROGERS. 1979. Internal defects associated with pruned and nonpruned branch stubs in black walnut. USDA Forest Service Research Paper NE-440. Broomall, PA. 27 pp.

SMITH, D. E. 1980. Abnormal wood formation following fall and spring injuries in black walnut. Wood Sci. 12: 243–251.

SMITH, W. J. 1967. The heritability of fibre [sic] characteristics and its application to wood quality improvement in forest trees. Silvae Genetica 16(2):41–50.

SONDERMAN, D. L. 1986. Changes in stem quality on young thinned hardwoods. USDA Forest Sevice Research Paper NE-576. Broomall, PA. 9 pp.

———, AND E. D. RAST. 1988. Effect of thinning on mixed-oak stem quality. USDA Forest Service Research Paper NE-618. Broomall, PA. 8 pp.

STOKKE, D. D., A. D. PUGEL, AND J. E. PHELPS. 1995. Variation of lightness of white oak dimension stock. Forest Prod. J. 45(10):51–56.

STOUT, A. B., AND E. J. SCHREINER. 1933. Results of a project in hybridizing poplars. J. Heredity 24:216–229.

STRONG, T. F., G. G. ERDMANN, AND J. N. NIESE. 1995. Forty years of alternative management practices in second-growth, pole-size northern hardwoods. I. Tree quality development. Can. J. Forest Res. 25(7):1173–1179.

SZOPA, P. S., H. E. GARRETT, AND E. A. MCGINNES, JR. 1980. Growth-quality evaluation of black walnut wood, part I—Specific gravity, growth rate, and percent extractables for trees grown on three different sites in Missouri. Wood Science 13:95–98.

VAN LEAR, D. H. 2000. Recent advances in the silvicultural use of prescribed fire. Pages 183–189 *in* W. K. Moser and C. F. Moser, eds. Fire and forest ecology: Innovative silviculture and vegetation management. Proc. Tall Timbers Fire Ecology Conference. Tall Timbers Research Station, Tallahassee, FL.

———, AND T. A. WALDROP. 1989. History, uses, and effects of fire in the Appalachians. USDA Forest Service General Technical Report SE-54. Asheville, NC. 20 pp.

VAN SAMBEEK, J. W., AND G. RINK. 1981. Physiology and silviculture of black walnut for combined timber and nut production. Pages 100–107 *in* 72nd Annual Report of the Northern Nut Growers Association.

———, R. C. SCHLESINGER, P. L. ROTH, AND I. BOCUMA. 1989. Revitalizing slow-growth black walnut plantings. Pages 108–114 *in* Proc. Seventh Central Hardwood Conference. USDA Forest Service General Technical Paper NC-132. St. Paul, MN.

VARGHESE, M., A. NICODEMUS, P. K RAMTEKE, G. ANBAZHAGI, S. S. R. BENNET, AND K. SUBRAMANIAN. 2000. Variation in growth and wood traits among none populations of teak in peninsular India. Silvae Genetica 49(4-5):201–205.

VOLK, T. A., L. P. ABRAHAMSON, AND J. L. BALLARD (compilers). 2001. Proc. Short-Rotation Woody Crops Operations Working Group, Third Conference, October 10–13, 2000. Syracuse, NY. 200 pp.

WALTERS, C. S. 1951. Figured walnut propagated by grafting. J. Forestry. 49:917.

WENDEL, G. W., AND H. C. SMITH. 1984. Effects of a prescribed fire in a central Appalachian oak-hickory stand. USDA Forest Service Research Paper NE-RP-594. Broomall, PA. 8 pp.

WILLIAMS, W. K. 1933. Protect hardwood stands from grazing. U.S. Department of Agriculture. Leaflet No. 86. Washington, DC. 3 pp.

WOESTE, K. E. 2002. Heartwood production in a 35-year-old black walnut progeny test. Can. J. Forest Res. 32: 177–181.

———, AND C. H. MICHLER. 2000. The history, mission, plans, and accomplishments of the Hardwood Tree Improvement and Regeneration Center. Pages 76–81 *in* Northern Nut Growers Association 91st Annual Report, Grantham, PA.

WRIGHT, J. A. AND M. ENDO. 1993. Wood density of four-year-old clones of *Eucalyptus grandis* from sixteen trials in Columbia. Wood Fiber Sci. 25(4):333–338.

YANG, K. C. 1987. Wood properties, wood qualities, and silvicultural treatments. Quart. J. Chinese Forestry 20(2):7–28.

ZASADA, J. C., AND R. ZAHNER. 1969. Vessel element development in the earlywood of red oak (*Quercus rubra*). Can. J. Botany 47:1965–1971.

ZHANG, S. Y., G. NEPVEU, AND R. E. OWOUNDI. 1994a. Intratree and intertree variation in selected wood quality characteristics of European oak (*Quercus petraea* and *Quercus robur*). Can. J. Forest Res. 24(9):1818–1823.

———, G. NEPVEU, AND F. MOTHE. 1994b. Modeling intratree wood shinkage in European oak by measuring wood density. Forest Prod. J. 44(10):42–46.

———, R. GOSSELIN, AND G. CHAURET. 1997. Timber management toward wood quality and end-product value. Proc. CTIA/UFRO International Wood Quality Workshop, August 18–22, 1997, Quebec City, Canada.

———, R. E. OWOUNDI, G. NEPVEU, F. MOTHE, AND J. F. DHOTE. 1993. Modelling [sic] wood density in European oak (*Quercus petraea* and *Quercus robur*) and simulating the silvicultural influence. Can. J. Forest Res. 23(12):2587–2593.