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Review on the Effects of Silivicultural Practices on Some Selected Wood Properties of Softwoods and Hardwoods Species

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Abstract: The aim of this review was to know and highlight the effects of silivicultural practices such as, thinning, pruning, stand density, fertilizer application, growth period and rate on some selected wood properties. The review work will help to highlight the positive and negative effects of applying growth accelerating treatments on the different wood properties. Wood properties like fiber length, cell wall thickness, growth ring, earlywood and latewood ratio, density and modulus of elasticity are affected by the different silivicultural practices. Accelerated growth rate of trees due to various silivicultural practices resulted in lower quality wood products. Tree grown with wider spacing produced wider growth rings, which indirectly decrease the density of wood because wider rings contain more earlywood. On the other hand, as the stand density increases, competition for light occurs causing crown recession and delayed crown development, which could cause a growth rate reduction and lower production of juvenile wood. Application of fertilizer and irrigation might have both negative and positive impact. In the density study of nitrogen fertilized *Pinus radiata* found that earlywood and latewood densities were significantly affected throughout the tree, a significant reduction in latewood formation compared to unfertilized *P. radiata*. Early thinning is an increase in the size of juvenile core through greater ring width in this zone. Early thinning can also cause the juvenile period to be extended, results in a broader transition zone. To the extent that the proportion of juvenile wood in stem is increased as a result of thinning, wood can be expected to have lower density and strength, shorter fiber, higher longitudinal shrinkage upon drying and a greater proportion of lignin.

Key words: Fiber Length · Cell Wall Thickness · Growth Ring · Earlywood and Latewood Ratio · Density and Modulus of Elasticity · Microfibril Angle

INTRODUCTION

Siliviculture has been defined as the practice of tending and cultivating forest trees. In forest plantations, different silivicultural practices, including fertilization, thinning, pruning and spacing are applied in order to maximize the amount of harvestable wood [1]. Silivicultural manipulation can either alert wood directly through physiological change within the tree or it can change the tree form, which in turn may have an effect on wood properties [2]. Several studies [1, 3-8] indicated that accelerated growth rates of trees due to various silivicultural practices resulted in lower quality wood products, because fast growth encourages trees to produce a high proportion of juvenile wood. At the same time, as the growth rate is increased the proportion of latewood becomes lower compared to the earlywood proportion [9].

On the other hand, some investigators found that wood qualities are changed positively as a result of silivicultural manipulations. For the southern hardwoods, Kellison *et al*. [10] make abroad statement that silivicultural practices applied to natural stands and plantations improve the growth and form without adversely affecting wood properties. Therefore in this paper, many studies related to the silivicultural effects on wood properties have been reviewed and from these will broadly summarize how various silivicultural manipulations can cause variation in wood properties.

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Effects of Stand Density on Wood Properties: The amount of space in which a tree grows is an extremely important determinant of growth rate and thus of wood properties. The spacing between trees and the extent of surrounding vegetation define the degree of competition for such critical growth elements as nutrients, water and sunlight. Wider spacing between trees decreases the competition for nutrients, moisture and light and increases their growth rate. The growth rate, however, has a great influence on wood properties. Tsoumis [11] reported that trees grown with wide spacing produce wider growth rings, which indirectly decreases the density, because wider rings contain more earlywood. On the other hand, as the stand density increases, competition for light occurs causing crown recession and delayed crown development, which could cause a growth rate reduction [8] and a lower production of juvenile wood. Zhu *et al.* [12] reported that as the population density increases, the ring widths of the trees decreases. The modulus of elasticity (MOE) is also highly affected by the initial spacing in the plantation [1]. Wider spacing encourages early diameter growth with large crowns, which favors the formation of large diameter knots [13-15]. Knots interrupt the fiber grain and reduce its flexibility and therefore the MOE. Waghorn *et al.* [14] reported that the MOE increased linearly with the stand density in *P. radiata*. Their results showed an increase of MOE from 5.4 GPa to 7.2 Gap as the stand density increased from 209 stems ha^{-1} to 835 stems ha^{-1}.

The faster diameter growth of trees planted at sparse spacing's results in higher juvenile wood contents, wider annual rings and thicker branches that remain longer on the stem [16]. A study of jack pine (*Pinus bankisana* Lamb) stem spaced 2.7m with comparable diameter at breast height to stems spaced 1.5m, observed density decreases of 4-18% [17]. Thus, trees growing at wider spacing's and/or fertile sites have lower basic density than those growing at narrow spacing's and/or poor sites. On the other hand studies on *Pinus radiata* spaced 2500stems/ha, produced a 12% increase in fiber length compared to an 833 stems/ha spacing [18].

Effects of Fertilization on Wood Properties: Additional nutrients and optimum soil moisture through supplementary irrigation accelerates the growth rate of trees [1, 19]. In most cases the application of nutrients and water is directly focused on harvesting a larger volume of biomass with reduced rotation periods [1, 3]. Bowyer *et al.* [1] pointed out that if wood properties are studied, the application of fertilizer and irrigation might have both negative and positive impacts. In a density study of nitrogen fertilized P. radiata, Beets *et al.* [20] found that earlywood and latewood densities were significantly affected throughout the tree. They noted a significant reduction in latewood formation compared to unfertilized P.radiata, especially at a younger age, below 15 years. Bowyer *et al*. [1] reported that growth accelerating treatments, such as fertilization and irrigation, affect the average fiber length differently in softwoods and hardwoods. They also reported a reduction in fiber length in softwoods but an increase in fiber length in hardwoods.

Watt *et al.* [21] on the other hand, reported that fertilization had an insignificant influence on MOE in *P. radiata*. In a density study of phosphate fertilized *P. radiata* in Australia by Rudman and Mckinnell [22] indicated that the density dropped after fertilization; in these studies decreases of nearly 20% were recorded in plantations treated with phosphate fertilizers. Experiments performed in New Zealand by Cown [23] on P. radiata showed that fertilizers reduce the wood density by 10% when compared to unfertilized site. Cown [23] indicated that this reduction is due to a decrease in the proportion of latewood in the ring. Bisset *et al*. [24] also found that tracheid length was about 33% shorter in P. radiata when fertilized with phosphates. Posey [25] presented a comprehensive study on the effects of fertilization on wood properties of 12 and 16 years Pinus taeda growing in Northern Carolina. He found that fertilizer application increased ring width, decreased specific gravity, latewood percentage, tracheid length and cell wall thickness.

A summary of 44 studies with 16 conifer species showed that fertilizer reduced the basic density of timber and that nitrogen caused the greatest change in wood properties [26]. According to Larson [2] fertilization of young trees not only increases the area of juvenile wood but can also delay the transition to mature wood. Similar study by Borders *et al*. [27] indicated that fertilizer applied to a loblolly pine (*P. taeda* L.) plantation caused a one year extension of the transition from juvenile to mature wood. McGrath *et al*. [28] also reported that the improved growth associated with the application of N, in combination with P, reduced basic wood density temporarily. The application of fertilizer frequently increased the percentage of earlywood and often did not affect the latewood. It was found that N often increased the period of juvenile wood production [20]. In all studies the increased volume from the application of fertilizer more than compensated for the adverse change in wood properties [26].

Effects of Growth Period and Rate on Wood Properties: The microfibril angle (MFA) is affected by the duration of the growth period andgrowth rate. Longer growth period and higher growth rates results in higher MFA values [3]. Saren [5] reported that the increased growth may cause intrusive growth where the tips of cells may curl more than in slow growing trees, resulting in a larger MFA. A higher MFA was observed during the early growth period than during the later period [3, 5]. The faster growth rate due to the use of improved genetic material and adjustment of silivicultural practices to the prevailing environmental conditions was found to result in the reduction of rotation length but at the same time it increased the proportion of juvenile wood and decreased the quality of wood [15]. These findings were supported by Saren [5] who found that fast growing trees produce shorter cells with thinner cell walls that tend to be round in their cross-sections. Jyske [7] reported that wood density, fiber length and cell wall thickness decreased on average by 2-7%, 0-9% and 1-17%, respectively in Norway spruce due to fast growth rate. Rotation age also affects the average fiber length in a tree [1]. In shorter rotation cycles, more juvenile wood is formed compared to the mature wood, which contains shorter fibers. Wimmer [2] stated that trees should grow to larger diameters to reduce the proportion of juvenile wood; otherwise the average fiber length would be too small.

Kojima *et al*. [29] agreed with these findings that fast growing trees contain large proportions of juvenile wood with unstable properties. Moore *et al*. [30] reported a negative relationship between growth rate and MOE of Picea sitchensis. As the growth rate increased the latewood proportion decreased and with it the density and MOE also decreased.

Effects of Thinning on Wood Properties: Trees remaining when surrounding trees are removed by thinning or partial cutting respond to the more open environment by stimulated crown development and formation of wider growth ring along the bole. Because of the impact on crown development and growth rate, thinning may adversely affect some wood properties for example; Bowyer *et al.* [1] indicated that, early thinning is an increase in the size of juvenile core through greater ring width in this zone. Early thinning can also cause the juvenile period to be extended, resulting in a broader transition zone; To the extent that the proportion of juvenile wood in stem is increased as a result of thinning. Thus, wood can be expected to have lower density and strength, shorter fiber, higher longitudinal shrinkage upon drying and a greater proportion of lignin.

Larger branch diameters and subsequently larger knots are produced after thinning [31, 32]. Again the larger branch formation and increased crown vigor may cause increased compression wood production in the live crown [32].

In Sweden, thinning from above, in which the thickest trees and wolf trees are removed, has been discuses as an option to improve timber quality and increase early profits. Co-dominant and dominant trees remaining after thinning from above may have better timber quality in terms of thinner branches, narrower annual rings and higher timber density [33].

Pape [34-36] compared effects of thinning regimes on various quality properties in Norway spruce and found that thinning from above resulted in slightly higher basic density and lower ring width than thinning from below when the same percentage of basal area was removed.

Effects of Pruning on Wood Properties: Pruning is the practices of trimming branches from chosen portions of standing trees to reduce the occurrence of knots in subsequently produced wood [1]. When a branch is removed from the bole of a tree, the sheath of new growth will eventually cover the stub, producing knots-free wood thereafter. Such wood has markedly higher value than knotty wood for solid wood products and veneer because of increased strength and improved appearance [1]. The effects of pruning and thinning on the number of growth units per year, internodes length, number of branches and branch diameters was analyzed in managed and unmanaged stands of *P. radiata* grown in Chile. When used jointly, these practices generated larger individual tree volumes (135% more) and clear wood in the pruned logs; however, they also reduced the sawn wood quality of the un-pruned stem sections for some years after the silivicultural interventions. The managed trees showed more growth units per annual shoot and shorter internodes, thus generating more knotty wood. Moreover, managed trees showed more tapering. As trees of the managed stand restore the foliar biomass lost due to pruning, managed and unmanaged stands approach the same level of canopy closure and differences minimize.

A study of hybrid aspens (*Populus tremula* L. & *P. tremuloides* Michx.) found that the time between pruning and clear wood formation was approximately three years, while un-pruned trees continually produced lower quality wood due to dead branches [37]. Therefore, the benefit of clear wood has some delay, but the benefits are continuous thereafter. Pruning regimes for *Tectona grandis* are expected to produce approximately 40% of knot-free volume for a 20 year rotation [38].

Table 1: Effect of an increase of external factors on various wood properties

Wood/Fiber Properties	Moisture/ irrigation	Fertilization/ Soil Fertility	Thinning	Initial Stand density	Pruning	Temperature	Wind	Altitude	Tree age
Fiber length	Shorter[25]	Shorter	Shorter[1, 3]	Longer[18]	-	Longer[8]	-	Shorter[42]	Longer [1, 48]
Fiber diameter	Wider [6]	Wider[6]	Wider[1]	Smaller[1, 11]	-	Smaller[22]	-	Wider[1, 11, 45]	Wider [1]
Cell-wall thickness	Thinner[5, 7]	Thinner[25]	Thinner[1]	Thicker[1, 11]	-	Thicker[1, 11, 45]	-	Thinner[1, 11, 45]	Thicker[1, 45]
Lumen diameter	Larger[43]	Larger[25]	Larger[1]	-	-	Smaller[44, 8]	-	-	Lower[1, 11, 45]
Earlywood ratio	Higher[46]	Higher[23]	Higher[1]	Lower[1, 11, 45]	Lower[1]	Lower[1, 11, 45]	-	Higher[1, 11, 45]	Lower[1, 11, 45]
Latewood ratio	Lower[9, 43]	Lesser[23]	Lower[47]	Higher[1, 11, 45]	Higher[1]	Higher[1, 11, 45]	-	Lower[1, 11, 45]	Higher[48]
Ring width	Wider[3]	Wider[25]	Wider[1]	Narrow[8, 12]	-	Narrow[12]	-	-	Narrow[1, 48]
Juvenile wood ratio	Higher[3]	Higher[5, 6]	Higher[1]	Lower[8]	Lower[26]	Lower [1, 11, 45]	-	-	Lower[1, 11, 45]
Mature wood ratio	Lower[9]	Lower[6]	Lower[1]	Higher [1, 11, 45]	Higher[49]	Higher[1, 11, 45]	-	-	Higher[1, 11, 45]
Wood density	Lower[50]	Lower[25]	Lower[8, 6]	Higher[11]	Higher[49]	Higher[44]	Higher[51]	-	Higher[1]
MOE	Lower[52]	Lower[52]	Lower[1]	Higher[14]	-	Higher[15]	-	Lower[30]	Higher[18]
MOR	Lower[11]	Lower[52]	-	-	-	-	-	-	-
Reaction wood	Higher[1]	Higher [1]	Higher [1]				Higher [1]		

The effect of pruning on density, microfibril angle and tracheid length is somewhat unclear. Density is generally observed to increase after pruning [30]. This relationship is mostly agreed upon, but some studies observed no significant change [26, 39]. Gartner [40] studied the effect of pruning, either 3.4 or 5.5 m, on trees age 13, 16 and 18. Ten years after the pruning, Gartner [40] tested the trees and found that density had only increased in the live crown of the youngest trees. No decreases in density were observed in any other areas.

Again Gartner [40] observed 3-4 years of increased fiber length for the youngest Douglas fir trees; however, he concluded that pruning has little or no effect on fiber length. A study of pruning trees used for structural lumber found higher MOE and MOR and a reduced variability for both properties in managed trees and attributed the higher quality to relatively lower knot occurrence [41]. Table 1 shows the expected effects of various external factors on wood and fiber properties.

CONCLUSION AND RECOMMENDATIONS

Stand density, fertilizer application, growth period and rate, thinning and pruning affects the various wood properties such as tracheid length, cell wall thickness, density and specific gravity of wood, early and latewood proportion, ring width, juvenile wood proportion, micro fibril angle (MFA) and modules of elasticity. Silivicultural practices have great potential to regulate wood structural characteristics and mechanical properties, apparently due to the influences of the green crown and growth rate on the vascular cambium, the strength of which vary throughout the rotation period.

The quality of wood produced when utilizing silivicultural treatments is highly dependent upon the intended end use of the raw material. The most common goal in silivicultural treatment reviewed was to increase the amount of harvestable wood. Wood grown for lumber production would ideally have a high density, low microfibril angle and less/no knot, juvenile and compression wood; Planting trees for this purpose should have close initial spacing and be re spaced to ensure healthy and vigorous trees growth. For lumber production during growth increasing of stand density is important because competition for light occurs causing crown recession and delayed crown development, which could cause a growth rate reduction [8] and a lower production of juvenile wood. Subsequently growth accelerating treatments, such as fertilization application reduced latewood percentage and wood density, so that application of accelerating treatments for lumber production not preferable. On the other hand slow growth rate with long rotation period recommended for quality lumber production. Moderate thinning should be performed once canopy closure has been established. Crown size will be maintained more easily when a relatively high stand density is used. Also pruning will force crown recession and promote clear wood development. Both choices reduce the amount of juvenile wood production. Lastly researches on the various silivicultural techniques that will/can improve wood quality must be continued.

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