A REVIEW OF RELATIONSHIPS BETWEEN WOOD QUALITY AND SILVICULTURAL PRACTICES

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ABSTRACT

The effect of silviculture on wood quality has been approached from different perspectives. This relationship is being a critical concern of forest managers, landowners and also researchers. Reliable information is needed to support forest managers in predicting the consequences of various silvicultural practices in terms of quantity and wood quality.

Wood has been used for a variety of products. Each product has particular requirements regarding quality. The variation of wood quality requirement allows industries to decide to use timber resources appropriate for their products. Silvicultural practices cover all treatments applied in forest stand management especially to improve the quality of stand, including manipulation of the availability of sunlight, nutrient and water by using several treatments such as thinning, control of spacing, fertilizing, and pruning. The quality of stand is aimed to achieve particular forest management objectives including higher wood quality.

There is no broad generalization regarding the relation between silvicultural practice and wood quality. Many investigators showed positive results in relation to producing high quality of wood products, while other researchers revealed negative effects. Reliable information is needed to support forest managers in predicting the consequences of various silvicultural practices in relation to the wood quantity and quality. Continuous research is needed to find methods of producing wood of high quality based on silvicultural practices and genetic improvement which can be used in wider area by considering limitation including environment and geographic variation.

Keywords: *wood quality, silviculture, forest management*

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INTRODUCTION

There has been a strong interest in timber as a worldwide commodity. In fact, timber has been an important material to the beginning of existence of human beings themselves. It is sometime said that timber utilizations have been replaced by other materials because of the price and the impacts on forest destruction. However, the demand for timber has increased. This is supported by Sedjo and Lyon (1996) in Evans and Turnbull (2004) who prophesized that the average annual demand of wood would increase from 1700 million m^3 in 1995 to approximately 2300 million m^3 in 2045. For this reason, Brown (1947) and Desch & Dinwoodie (1996) stated that although there are some substitutes for timber, such as plastic, fibres, and steel, timber remains competitive versatile material because of strength-to-weight ratio, workability, excellent non conductor of heat, and artistic and architectural design.

Timber resources have been transferred to plantation forest with the increase in conservation of natural forests. In addition, remoteness, inaccessibility, and poor quality of natural forest may be other reasons for establishing plantation forest (Savill *et al*., 1997). Globally, the forest area in the world is estimated around 3.95 billion hectares or around 30% of the worlds', and more than 50% of total areas are dominated by the Russian Federation, Brazil, Canada, the United States, and China (FAO 2007). Generally, more than 50% of the area is inaccessible due to conservation or under normal economic perspectives (Sedjo & Simpson 1999). This shift has led to establishing new forest plantations. According to FAO (2001), 48% out of 4.5 million ha new forests are being established for wood processing industries. Unfortunately, specific characteristics of wood products from plantation forest may not be similar to those from old growth forest.

The effect of silviculture practices on wood quality has been approached from different perspectives. This relationship is being a critical concern of forest managers, landowners and also researchers. It is sometimes said that there is an inconsistency correlation between silvicultural treatment and wood properties (Goncalves *et al*., 2004). However, various treatments that may be applied to forest stands to manage and improve their utility for any purpose is a concern of silvicultural practice (Smith, 1986). Silvicultural practices have the potential to influence wood quality of many hardwood and softwood species (Goncalves *et al*., 2004). Silvicultural practise also can be explained as manipulation of forest stand structure and dynamics to achieve particular forest management objectives (Bauhus, 1999). For example, implementing appropriate silviculture technique in Douglas fir plantation has produced a premier wood product with high grade timber (Hermann & Lavender, 1999). Therefore reliable information is needed to support forest managers in predicting the consequences of various silvicultural practices in terms of wood quantity and quality. This paper will review the relationships of silviculture and wood properties with respect to wood production industries.

Silvicultural practice

Silvicultural practice covers all treatments that applied in forest stand management especially to improve the quality of stand. Silvicultural practice can be defined as a method of reproduction regarding to treatments of stand and site during establishment and methods of intermediate cutting refer to treatment at other time during the rotation (Smith, 1986). Basically, silvicultural practice has objectives to increase growth rate and wood quality including manipulation of the availability sunlight, nutrient and water by using several treatments such as thinning, control of spacing, fertilizing, and pruning (Haygreen & Bowyer, 1996).

Control of spacing is important to improve growth and wood quality. Spacing control is based on an assumption that trees should compete to get nutrient, water and sunlight which are usually limited (Haygreen & Bowyer, 1996). In addition, spacing control leads to increase the availability of large diameter stem which are more commercially valuable products, reduce the defect because of knot, and reduce loss of wood because of dying stress in relation to denser stand (West, 2006).

Thinning is a method to support spacing control by changing the stand density. The idea of thinning is to improve the production of larger log. This is because producing big size of lumber will increase stand efficiency and also will produce better value in terms of price. Method of thinning can be classified into four groups: low, crown, selection and geometric (Smith, 1986). Schedule of thinning is also important. The schedule should be based on desired products, benefit and also the condition or type of vegetation (Smith, 1986). Improper thinning application might lead to useless treatment and costly. For example, larger branches may develop along the stem following thinning which might lead to increase the size of knot (West, 2006).

WOOD QUALITY

Wood has been used for a variety of products. Each product has its particular requirements regarding quality. The variation of wood quality requirements allows industries to decide to use timber resources which are appropriate for their products. Walker (1993) illustrated that sawmills may prefer to pay more for large logs than an equivalent volume of small logs due to the economic perspective that large logs can produce a better grade of timber, while mechanical pulp and particleboard factories are satisfied with chips from small top logs.

Wood quality can be defined as a concept of the characteristic of wood that affects the properties of the product manufactured from it (Haygreen & Bowyer, 1996). There are two types of wood properties: microscopic and macroscopic. The appropriateness of trees for producing certain wood products is influenced by the variation of macroscopic properties. There are several criteria of wood that should be considered with respect to high quality material by the wood industry or forestry company such as wood density, uniformity, heartwood and sapwood, presence of juvenile wood, reaction wood, knots, grain orientation, fibre length and content.

There are some microscopic properties within wood cell which are important in determining wood quality. Wood cells can be defined as a structural element of wood tissue which has various sizes and shapes and are fairly cemented together (Miller, 1999). These properties are fibres, proportion of vessels, and rays. The properties are usually important in pulp manufacture. The characteristics of vessel proportion might cause difficulties in producing high surface qualities of paper due to less conducive to develop strong intra-element bond while fibre length has influences on tear resistance and tensile, fold, and burst strength (Haygreen & Bowyer, 1996).

Grain orientation is important in wood industries due to its effects on mechanical properties, machining properties, and dimensional stability. Haygreen and Bowyer (1996) summarized that silvicultural practices such as irrigation and pruning may produce spiral grain. Generally, there is a relationship between accelerating growth and grain orientation.

Growth ring has been used to determine growth characteristics of trees. For some tropical species, growth is characterized as rapid in wet season and slow in dry season. Subsequently, there are two types of wood formation: earlywood and latewood. Earlywood refers to the inner part of the growth ring which is formed first in the growing season while latewood refers to the outer part formed later in the growing season (Miller, 1999). Latewood tissues show greater density which are built by small radial cells with thick walls and small lumen (Haygreen & Bowyer, 1996).

Basic density is commonly used to determine wood quality. This is because density of wood is the main determinant of strength and both of them have direct relationships (Benddsten, 1978; Bootle, 1983; Haygreen &Bowyer, 1996; Walker, 1993). Density of wood is the ratio of dry wood mass to unit of volume (Desch & Dinwoodie, 1996; Haygreen &

Bowyer, 1996). Understanding the basic density of species allows the consumer to decide the appropriateness of wood utilization. For example, teak (*Tectona grandis*), meranti (*Shorea* sp), and keruing (*Dryobalanops* sp) are preferred as a construction material while tusam (*Pinus merkusii*), sengon (*Paraserianthes falcataria*), and ramin (*Gonystilus bancanus*) may be used as interior product or furniture. However, it should be realized that there may be variation within species because of genetic improvement, site or silviculture technique. The variation of density between and within trees (radial and tangential) exists according to growth rate, climate, silviculture and breeding (Downes *et al*., 1997; Haygreen & Bowyer, 1996; Repola, 2006).

Mechanical properties are important in structural wood products. Strength is usually used as general sense to refer mechanical properties. Strength can be defined as the ability of substance to hold certain load or forces (Haygreen & Bowyer, 1996). As orthotropic material, wood has unique characteristics in that its mechanical properties are influenced by the direction of three mutually perpendicular axes: longitudinal (parallel to fibre), radial (perpendicular to fibre in the radial direction) and tangential (perpendicular to fibre in the tangential direction) (Green *et al*., 1999). Mechanical properties can be grouped into two major groups: strength properties (bending strength, compression strength, tension strength, shear strength, toughness, resilience, side hardness) and elastic properties (modulus elasticity and Young's modulus; Haygreen & Bowyer, 1996).

The proportion of heartwood and sapwood influences the quality of solid wood due to several reasons. Heartwood refers to the inner part of stem which is physiologically inactive, darker in colour than sapwood and mainly responsible for providing mechanical support to tree (Desch & Dinwoodie, 1996). In some species heartwood indicates the existence of the natural preservative which makes wood less susceptible to fungi and insect. In addition, in terms of artistic perspective, a high proportion of heartwood will be desired as a valuable product. For example, a lack of well developed heartwood in species such as walnut, cherry, or rosewood would have a negative effect of their value (Haygreen & Bowyer, 1996). There are some indications that rotation management can affect the production of heartwood. In addition, pruning regime may influence the occurrence of heartwood.

Uniformity of wood qualities, especially in wood density and other cell structure is also important for quality products. Lack of the uniformity might reduce the quality of product or cause difficulties in wood processing. It should be noted that the uniformity of wood structure might be influenced by growth rate and silvicultural practices (Haygreen & Bowyer, 1996).

Juvenile wood has been known to be affected by growth rate. Juvenile wood is formed during the condition when tree stem is surrounded by live crown (Willcocks & Bell, 1994). High proportion of juvenile wood occurs during the juvenile period when softwood stems grow rapidly. Haygreen & Bowyer (1996) stated that the occurrence of juvenile wood in stems and reaction wood is related to growth condition. Growth is a critical consideration in determining whether planting species in specific location will be worthwhile or not (Booth, 2005). Growth rate is affected by several factors including site quality, silviculture technique and breeding. It is necessary to always concern that silvicultural treatments usually affect growth rate which in turn might be the explanation for the wood variation (Zobel, 1992).

Growth conditions apparently also affect reaction wood formation. Haygreen & Bowyer (1996) noticed that reaction wood and juvenile proportion increase during the rapid growth of young trees. Abundant supplies of auxin may be linked to the rapid growth and compression wood development. In addition, there is an influence of silviculture regime on reaction wood formation. For example, straight trees can be considered as having good quality wood because of the absence of undesireable reaction wood (Downes *et al*., 1997).

Frequency and size of knot are important for wood product, particularly for saw log production and veneer. Knot can be defined as the tissues of branches which are usually playing a part in reducing strength (Bootle, 1983; Desch & Dinwoodie, 1996). The abundance, size and relative posisition of knot influence the stiffness and strength of lumber products (Barbara, 2005). Haygreen and Bowyer (1996) found that knot is also affected by a number of silvicultural practices, such as spacing and time of planting and thinning, treatments to accelerate growth rate, and pruning.

INFLUENCE OF THE SILVICULTURE PRACTICES ON WOOD QUALITIES

Silviculture practices have long been developed to improve growing patterns of plantations for specific objectives especially for wood products. Subsequently, due to the difference in growth performance, wood qualities of the tree might be affected by silvicultural practices. Some research work found that applying silviculture practice might affect growth and other physiological changes without causing differences in wood qualities. For instance, the applied silvicultural practices, i.e. a high forest or coppice-with-standards, do not affect the wood density model of *Quercus petraea* (Guilley *et al*., 2004). However, some investigations reveal contradictory results that wood qualities are influenced by changes of tree performance due to silviculture practices. For example, silvicultural regimes (a dense 85-year-old stand established by direct seeding and a 56-year-old widely spaced stand established by planting, designated Saw Dry Rip (SDR) and Plain-wet-rip (PWR), respectively in the boreal zone of Sweden) have a great potential to regulate wood structural characteristics and mechanical properties of scot pine (*Pinus sylvestris*; Eriksson *et al*., 2006). Stocking management, rotation age, and pruning are some of the principal means available to foresters to affect wood quality and value in stands of coast Douglas fir (*Pseudotsuga menziesii* var. menziesii) in the Pacific Northwest (Fight *et al*., 1995).

The relationship between silvicultural practice and wood qualities is very complex and the influence on wood quality might not be determined by only simple factors. For example, it has been explained in the preceding section that there is unclear interaction between growth rate and wood qualities. There are some detailed reasons which cause the increase of growth rate and influence the quality of stand. One of the reasons is that the stand performance is influenced by certain silvicultural treatments. Generally, silviculture treatment can be classified into 4 groups: nutrient treatment including fertilization, stocking control (initial planting and thinning), pruning, and miscellaneous treatments, such as planting technique, and coppicing (Zoble & Buitjtenen, 1989).

Effect of nutrient and fertilization on wood qualities

Forest companies and forest researchers are concerned with the effect of fertilizer on stand growth and wood quality. Fertilizer is mainly designed to maximize the potential growth of plantations. The objective of applying fertilizer is to stimulate growth by improving nutrient availability, thereby increasing crown development and the size of photosynthesizing surfaces (Haygreen & Bowyer, 1996). Fertilizer frequently increases the percentage of earlywood and often does not affect the latewood. In some instances fertilizer makes earlywood cell wall thicker and latewood cells thinner. However, the influence of fertilizer depends on kind of fertilizer, time of application and the age of trees (Zoble & Buitjtenen, 1989).

Nitrogen and phosphorus have long been investigated in relation to stand growth and wood qualities. Nitrogen influences the greatest change in wood properties and also increases the period of juvenile wood production (Zoble & Buitjtenen, 1989). N and P fertilizer application in *Eucalyptus nittens* have no effect on basic density, lignin content or the concentrations of extractives, but increase the longevity and size of branches thereby leading to an increased occurrence of decay infections (Wiseman *et al*., 2006). In *Populus deltoides*, deficiencies of nitrogen and sulfur result in short fibers and small diameter fibers and vessels (Zoble & Buitjtenen, 1989). Nitrogen may also reduce cell size, wall thickness and specific gravity of conifers, but there are many exceptions especially in the diffuse porous hardwoods (Zoble & Buitjtenen, 1989).

There are specific characteristic differences between conifer and hardwood in relation to the effect of fertilization. As for conifers, the better volume growth following fertilization offsets the wood quality loss except for a few specialty products (Zobel, 1992). Zobel and Buitjtenen (1989) after reviewing a number of publications, found that there are a few generalizations regarding the effect of fertilization on conifer wood properties such as fertilization increases the relative amount of earlywood, has little effect on latewood, and showed lower specific gravity due to fertilization and change in wood conifer. Fertilization also effect on hardwood. For example, fertilizations cause degradation in the quality of solid wood products because of poor stimulation tree form, and epicormic branching, a high specific gravity mineral due to mineral deficiencies such as calcium or phosphorus, reducing cell size, wall thickness and specific gravity because of nitrogen application. There is less impact of fertilization on basic density in hardwood (Haygreen & Bowyer, 1996).

Fertilization also increases wood uniformity which is one of the desirable influences of fertilization. The uniformity of ring width is usually caused by a small difference between the earlywood and latewood. This occurs because wall thickness in thin walled earlywood cells increases while the thickness in latewood decreases (Zoble & Buitjtenen, 1989).

Effect of stocking and thinning nutrient on wood qualities

Stocking and thinning can be used as a control for growth and wood qualities. Larger and better quality of log harvested from thinned plantation has higher wood quality. Thinning might determine wood qualities due to its impact on crown development and growth rate (Haygreen & Bowyer, 1996). In thinned stands the cambium becomes active earlier than in un-thinned stands but latewood productions are delayed (Zobel, 1992).

It is also important to consider the time of thinning. Young trees might respond differently than mature stands in relation to thinning treatment. The occurrence of knots in lower stems can be reduced by delaying thinning treatment. Delay of thinning until the completion of the juvenile period is important, especially for lumber products, to circumvent the

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development of an unduly large juvenile core and produce uniformly denser mature wood (Haygreen & Bowyer, 1996). For instance, timing and intensity of early thinning of Douglas fir plantations in coastal forests in the US Pacific Northwest are critical in determining both stand structure and wood quality (Barbour *et al*., 1997). Light thinning of loblolly pine at 12 years produced a higher specific gravity than earlier stands due to the increase in percentage of latewood for the year following thinning (Smith, 1968). Fertilizer treatment at the end of 4-5 years in radiata pine (*Pinus radiata*) preceded by thinning is economically possible (Nyakuengama *et al*., 2003).

The level of thinning is also a critical issue in intensive management in relation to wood qualities. The wood density of growth rings balsam fir (*Abies balsamea*) tends to decrease following the moderate thinning, due to a decrease of latewood percentage (Koga *et al*., 2002). Heavy thinning during the juvenile wood formation phase on young Douglas-fir reduces latewood fibre length by 26.5% (Bodner, 1984). The decrease of earlywood and increase in latewood also occur in heavy thinning treatments (Moschler *et al*., 1989). In teak large variations in wood properties found under different thinning regimes suggest that at early stages teak stands can be managed under different thinning programs without negatively affecting the quality of wood under humid tropical conditions (Pérez & Kanninen, 2005).

Thinning has more effect on the wood of the ring porous hardwoods than on the conifers or diffuse porous species (Zobel, 1992). In addition, in hardwoods, epicormic branches following thinning can cause a major degradation in wood qualities. The epicormic branches in lower bole are produced especially when the competition within the stand is less (Haygreen & Bowyer, 1996). Specific gravity and tracheid length are not much affected by thinning although a decrease in cell length is also observed (Zobel, 1992).

Effect of spacing on wood qualities

Several wood qualities have been influenced by spacing treatment. This condition might have relation to the availability of nutrient and water. The availability of nutrient and water for trees is influenced by stand density or spacing. The effect of spacing on wood qualities can be explained by the combination of the availability of nutrient, water and maximum sunlight (Haygreen & Bowyer, 1996). However, the influence is often not clear. For example, basic density, heartwood content, modulus of elasticity, modulus of rupture and compression parallel to grain of *Cupressus lusitanica* are not significantly affected by spacing (Malimbwi *et al*., 1992). Spacing also does not significantly influence the presence or size of spike knots (Pfister *et al*., 2007). In addition, there is no evidence that tree spacing and live-branch pruning have a significant effect on the cambial age of transition from juvenile to mature wood in Douglas-fir trees (Gartner *et al*., 2002). On the other hand, there are many investigations that show the influence of spacing on wood qualities.

The influence of spacing is related to a period of juvenile formation and knots. For example, the average diameter of knots is significantly larger in stand with wider initial spacing than closer initial spacing stands (Ishiguri *et al*., 2002). A number of knotty trees increase with wider spacing in a seven year old bilinga (*Nauclea diderrichii* Merril.) stand (Fonweban *et al*., 1994). In the widely spaced stands of 350 stems ha^{-1}, the fraction of trees having spike knots is high (over 50%) while at a density of 1,600 ha^{-1}, the sample trees have somewhat less branches in a whorl compared with the more widely spaced plots (Mäkinen & Hein, 2006).

Spacing treatment also influences wood density, mechanical properties and other wood qualities. For example, it is important to manage planting density of radiata pine in relation to stiffness of wood (Lasserre *et al*., 2004). Initial stand spacing in jack pine (*Pinus banksiana* Lamb.) has a significant effect on wood density, fibre and pulp properties (Kang *et al*., 2004). Kang *et al*. (2004) also suggested managing stand density to improve yield and wood and pulp fibre properties of jack pine plantations. Lower quality value of intrinsic variables important to wood quality such as resin content, cell length and transverse shrinkage are produced in wider spacing due to the increase of juvenile wood (Willcocks & Bell, 1994). In addition, the dynamic Young's modulus, the modulus of rupture, and the modulus of elasticity in static bending increase with the decrease in the initial spacing from 2.6 by 2.6 m to 1.3 by 1.3 m (Ishiguri *et al*., 2002). In areas of low rainfall, more widely spaced trees tend to produce higher wood density (Zobel, 1992).

Effect of pruning on wood qualities

Artificial pruning is necessary when natural pruning does not occur in early stages of growth. Delay in natural pruning might produce a lot of knots which reduce the quality of logs or wood products. Natural pruning can be forced by spacing management. However, artificial pruning using appropriate tool needs to be applied as early as possible to remove lower branches. After removing branches from the bole of tree, the stub is then immediately covered by the sheath of new growth, then produces knot-free wood (Haygreen & Bowyer, 1996).

Basically, pruning should be applied for stand management to produce higher-value clear wood. Larger branches tend to produce bigger knot size and reduce the stem quality, especially in areas with high wind intensity. Trees should be pruned when bole diameter is about 12 cm to allow the formation of enough clean wood outside the knot zone to make the pruning economic (Zobel, 1992; Zoble & Buitjtenen, 1989). In addition, trees having large branches tend to be crooked (Maclaren, 2002). Under an intensive pruning regime, a teak tree at a 20 year - rotation may yield over 40% of knot-free volume (over 60% of the merchantable tree volume) (Víquez & Pérez, 2005). Un-pruned logs from farm sites present intractables problem, particularly unsuited for structural uses, due to short node (Maclaren, 2002). In conifer, pruning is frequently applied to improve the quality of logs especially for lumber or plywood by reducing limbs and the occurrence of knots (Zoble & Buitjtenen, 1989).

The direct effect of pruning on wood properties is that pruning influences juvenile formation which in turn influences other wood qualities such as wood density and mechanical properties. Pruning might accelerate the transition from juvenile to mature wood (Zoble & Buitjtenen, 1989). Pruning treatments in young Douglas-fir influence a small increase of wood density at the upper height (5.3 m) in the youngest age class (for which this 5.5 m pruning would be removing vigorous live branches at this height) but not in the medium age class (for which the pruning would be removing lower live crown at this height) or in the oldest age class (for which there would have been no live branches at 5.5-m) (Gartner *et al*., 2005).

There are also some contradictory results of the effect of pruning. For example, ring width, wood density, and fiber length of clones 47-174 of 9-year old *Populus* stems grown in a silviculture research plantation in Western Washington are not affected significantly by pruning (DeBell *et al*., 2002). There is also no relationship between pruning and occlusion of decay in *E. nittens* plantations (Hermann and Lavender, 1999).

There is a negative impact of pruning especially if not taken properly. The pruning can also affect the properties of the wood itself, especially when the pruning is not done correctly or is too severe (Zobel, 1992). Without correct treatment, pruning will lead to wounds and fungal degradation.

CONCLUSIONS

There is no broad generalisation regarding the relation between silvicultural practices and wood qualities. Many investigators have showed positive results in relation to producing high quality of wood products, while other researchers have revealed negative effects. Reliable information is needed to support forest managers in predicting the consequences of various silvicultural practices with regard to wood quantity and quality. Continuous research is necessary to find methods of producing wood of high quality based on silvicultural practice and genetic improvement which can be used in wider areas by considering limitations including environment and geographic variation.

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