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EFFECT OF THINNING REGIME ON WOOD QUALITY OF *ACACIA SALICINA* TREES GROWING IN SAUDI ARABIA

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ABSTRACT

This study, based on a high initial-density plantation of *Acacia salicina* trees, which was later thinned to facilitate high individual-tree growth suitable for saw-timber production, investigates the effect of thinning on some wood quality parameters. Trees were planted in 1998, at a density of 6400 trees ha^{-1} (with spacing of 1.25 x 1.25 m). Annual mechanical thinning, started after two years in half of the population, was continued till 2003. From 2004 to 2010, the densities of 400 and 3200 trees ha^{-1} were maintained for the thinned and unthinned stands, respectively. In 2010, five trees selected randomly from each of the two stands were felled and disk samples obtained to determine wood specific gravity, fiber length, shrinkage behavior, sapwood-heartwood ratio, and growth-ring width. Tree thinning increased the width of annual growth rings by 155-185 % in comparison with growth rings in unthinned population. At a given height level, production of sapwood and heartwood was 4-5 times and 4-6 times higher in thinned population than in unthinned population. Fibre length showed no significant change, but the impact of thinning on fibre length varied with position across the radius of the wood disc. However, thinning caused specific gravity of wood to decline form 0.523 in unthinned population to 0.503 in thinned population (3.8 % reduction). Tangential shrinkage of wood in thinned trees exhibited a clear variation pattern along the radius, with the highest mean value (8.24 %) recorded near the periphery of the wood disc and the lowest (7.28 %) near the centre (pith region).

KEYWORDS: Thinning regime, tree density, specific gravity, fiber length, wood shrinkage, growth-ring width, sapwood-heartwood ratio.

INTRODUCTION

The raw-material base for forest products is increasingly shifting from old-growth forests to short-rotation plantation-stock (Kennedy 1995). The change in the raw-material source is bothersome for manufacturers of forest products (lumber, panel products, pulp and paper), since the properties of young stock are not desirable for most of the end uses. Little is known about variations in the stem characteristics of trees grown in the managed short-rotation stands.

Many cultural practices like the initial tree spacing, respacing /thinning, pruning and fertilization affect wood quality, i.e. the suitability of wood logs for conversion into useful products (Joza and Middleton 1994). Wood quality stems from interplay between tree genotype, environment and silvicultural operations (Lasserre et al. 2008, 2009). Wood properties that are closely linked to the end-product performance include the specific gravity, fiber length, shrinkage, growth-ring width and sapwood-heartwood ratio. Reducing tree density, after initial plantation in a stand, is important for reducing inter-tree competition and promoting rapid growth of the left over trees (Evans and Turnbull 2004). Early thinning, prior to canopy closure, affects wood quality, as does the initial spacing (Moore et al. 2009). Thinning at the age of 7-8 years is the most successful growth-promoting practice in eucalypts plantations being managed for solid-wood production in Australia (Glencross et al. 2011).

Wood density has a positive relationship with desirable mechanical properties of wood. Structural timber needs high density and strength, while low-density wood is suitable for pulp and paper products (Barnett and Jeronimidis 2003). Wood shrinkage, on the other hand, is important for dimensional stability of wood. Excessive shrinkage during drying causes warping, cracking and angular deformation of wood (Ormarsson et al. 1998). The processed wood also expands or shrinks in service according to the ambient moisture levels. Therefore, wood with low-shrinkage habit is highly desirable for sawn-timber production and solid-wood products (Walker 2006). Wood-fiber length is also important for timber products; longer fibers result in greater resistance against buckling of wood beams. Fibre length influences paper and timber strength through improved bonding due to more numerous cell-to-cell contacts (Via et al. 2004).

Trees of *Acacia salicina* Lindley, grown at high initial density to restrict early branch development, and subsequently subjected to thinning to ensure high individual stem growth, have been examined earlier for biomass production and stem characteristics (Hegazy et al. 2013). The present study evaluates the effect of thinning on the physical properties of wood of the same stand of *A. salicina* and analyzes the variation in wood properties along the radius of the wood log at breast-height level.

MATERIAL AND METHODS

Field operations

Six-month-old seedlings of *Acacia salicina* Lindley were planted in the field in October 1998, accommodating 330 seedlings in 15 rows, with 22 plants in each row. The space between and within the rows was 1.25 x 1.25 m, with a starting density of 6400 trees ha^{-1}. The plantation was irrigated once a week in winter and twice a week in summer.

In February 2000, the planted area was divided into three blocks, each comprising of two plots, using a randomized complete block design. Three plots were then chosen randomly and subjected to mechanical thinning, in which each second tree was removed from the rows to reduce the plot density to 3200 trees ha^{-1}. These plots were thinned twice again in the next two years to reduce tree density to 800 trees ha^{-1}. El-Juhany (2003) studied the effect of early thinning on tree growth and biomass production in this plantation, when it was 4.5-year-old.

For producing high-quality logs suitable for solid wood, these plots were re-thinned in 2004 to a final density of 400 trees ha^{-1}, while unthinned plots had a density of 3200 trees ha^{-1} with 2.5 x 1.25 m spacing. Both these stand densities were maintained till the end of experiment.

In 2010, five trees from each tree-density stand were selected randomly and felled (at 10 cm above ground level) to determine the total tree height, bole diameter at breast height (1.4 m), number of branches above 1.4 m height, diameter of each branch at its base (above the base swell), and distance of each branch from tree base. Stems were cut into logs, first at breast height and then successively at each one-meter interval.

Preparation of wood samples

Two disks from each of the logs taken at breast height were machine-sawed. One disk, about 2 cm thick, was assigned for specific gravity (SG) and fiber length (FL) determination, and the other, about 12 cm thick, for shrinkage determination.

A 2.5 cm thick radial strip, free from any visible defects, was machine-cut from the small disk and made into a number of specimens along the wood radius from pith to the bark. Sample specimens taken at five locations across the radius (at 20, 40, 60, 80 and 100 % distance from pith) were divided radially into two matched specimens, one for SG and the other for FL determination.

Fiber length determination

Thin chips obtained from the specimens assigned for fiber-length determination were macerated in a 1:1 (by volume) solution of glacial acetic acid and 30 percent hydrogen peroxide at 60°C for 48 hours. After delignification was completed, the macerated fibers were washed several times, with mild shaking in distilled water, and then stained with Safranin. Lengths of 50 randomly selected fibers from each sampling specimen were measured in wet condition to the nearest 0.01 mm, using projection microscope connected to TV screen.

Specific gravity determination

Specific gravity was determined based on oven-dry weight and green volume of wood specimens. The volume was determined by water displacement, following the method of American Society for Testing Materials (ASTM D 2395, 1989).

Shrinkage determination

Shrinkage samples were taken only from the thinned trees, as they had a larger radius to allow for a convenient sampling. A cross-sectional disk of 15 cm thickness (at breast height) was used for shrinkage determination. Two perpendicular radial strips of wood with 2.5 cm tangential thickness (and 10 cm in vertical length) were marked and removed from bark to bark. These strips were further marked to obtain a total of twelve specimen covering three groups, each of four specimens from positions 2 cm away from pith, at the middle of the radius, and near the bark.

Care was taken to prepare samples with true radial and tangential surfaces having 2x2x10 cm dimensions in the radial, tangential, and longitudinal direction, respectively. Samples used for shrinkage measurement were saturated under vacuum pressure and the wet dimensions of the radial, tangential and longitudinal surfaces were measured to the nearest 0.01 mm using a digital caliper. The samples were then oven-dried at 103 ± 2°C to constant weight and re-measured for the same dimensions. Shrinkage values were determined as the ratio of the change in dimensions from the swollen condition to oven-dry condition, and expressed as percentage (Panshin and De Zeeuw 1980). Volumetric shrinkage was estimated by multiplying the percentage values of shrinkage in the tangential, radial and longitudinal dimensions.

Growth rings were counted in each disk, and the average ring width was calculated by dividing the average disk radius by the number of rings. For studying the effect of thinning on annual growth ring width and heartwood-sapwood ratio, a transparent plastic sheet was used to mark the outer borders of each disk and the circumference of heartwood portion. The total disk area and heartwood area were then determined using a planimeter device (to the nearest mm). Sapwood area was calculated by subtracting the heartwood area from the total disk area. Wood-disk diameter inside bark was measured first along the largest diameter and then perpendicular to it.

Statistical analysis

Analysis of variance test was applied to the data obtained, using the SAS computer software (SAS 2004). Means were compared by the L.S.D. test ($P<0.05$).

RESULTS

The effects of thinning on selected wood properties of *Acacia salicina* are described below.

Annual radial growth and sapwood-heartwood ratio

In order to know the effect of thinning on the extent of radial growth per year, average width of annual growth rings was calculated by the dividing the length of wood radius by the number of growth rings in each disk (Tab. 1). The average growth-ring width for the first four disks of the thinned tree was 1.01, 0.94, 0.86 and 0.86 cm, respectively. These values were 0.57, 0.51, 0.54 and 0.56 cm, respectively, for unthinned trees. Thus, in our case, thinning resulted in 155 - 185 % higher annual ring-width values, as compared with corresponding values from unthinned trees.

Thinned trees with larger crowns (higher foliage biomass) had larger sapwood areas. The mean values of sapwood area in the first four disks (at 0.1, 1.4, 2.4, and 3.4 m from ground level) were 261.1, 198.7, 178.7 and 160.3 cm^2, respectively, for thinned trees and 71.2, 47.6, 43.0 and 32.2 cm^2 respectively, for unthinned trees (Tab. 1). It is well known that the percent heartwood area decreases from bottom to top of the tree. Observations revealed that the mean values for heartwood proportion were a little higher in samples taken from thinned trees in comparison to those from unthinned trees, being 51.0, 49.1, 47.2 and 46.1 % for the first four disks, respectively, from trees of thinned population, and 49.4, 44.3, 42.0 and 41.0 % for the same disks, respectively,

Tab. 1: Effect of early tree thinning on the average wood growth rate, total cross sectional area of stem disks, sapwood and heartwood area and heartwood proportions in the thinned (400 stems ha^{-1}) and unthinned (3200 stems ha^{-1}) populations of A. salicina trees at the age of 12 years.

Disk level (m)	Thinned trees						Unthinned trees					
	Annual rings		Total area (cm^2)	Heart area (cm^2)	Sap area (cm^2)	Heart wood %	Annual rings		Total area (cm^2)	Heart area (cm^2)	Sap area (cm^2)	Heart wood %
	No	Thickness (cm)					No	Thickness (cm)				
0.1	12	1.01	532.5	271.4	261.1	51.0	12	0.57	140.6	69.4	71.2	49.4
1.4	12	0.94	390.5	191.8	198.7	49.1	10	0.51	85.4	37.8	47.6	44.3
2.4	12	0.86	338.2	159.5	178.7	47.2	9	0.54	74.2	31.2	43.0	42.0
3.4	11	0.86	297.5	137.2	160.3	46.1	8	0.56	54.6	22.4	32.2	41.0
4.4	10	0.85	248.1	116.1	132.0	46.8	7	0.57	40.8	13.0	27.8	31.9
5.4	10	0.85	213.6	96.3	117.3	45.1	6	0.52	36.5	11.0	25.5	30.1
6.4	9	0.85	188.7	63.4	125.3	33.6	5	0.58	33.5	10.0	23.5	29.9
7.4	9	0.83	171.8	62.5	109.7	36.4	5	0.54	24.0	6.0	18.0	25.0
8.4	8	0.83	125.7	37.4	88.3	29.8	--	--	--	--	--	--
9.4	7	0.72	91.1	27.4	63.7	30.1	--	--	--	--	--	--
10.4	7	0.69	70.1	13.5	56.6	19.3	--	--	--	--	--	--
11.4	6	0.57	60.3	5.3	55.0	8.8	--	--	--	--	--	--
12.4	5	0.52	30.2	0.0	30.0	0	--	--	--	--	--	--

from trees of unthinned stand. The difference between two populations became wider at higher levels along the stem axis (Tab. 1).

Fiber length (FL)

Statistical analysis revealed that tree thinning did not have any significant effect on the average FL values, 0.939 mm and 0.933 mm for the thinned and unthinned trees, respectively.

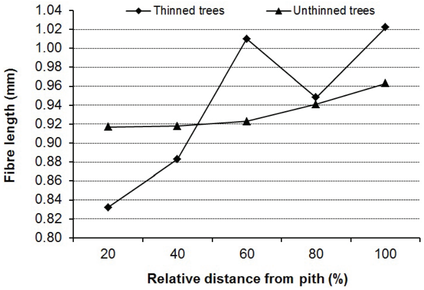

Fig. 1: Effect of tree thinning on wood fiber length variations across the wood-disc radius at breast-height level for Acacia salicina trees of 12-year age.

However, differences in FL values at the selected five locations along the wood-core radius were significant. FL in the outer wood (near bark location) had the highest mean values in both populations. The unthinned trees showed a steady but slow centrifugal increase (0.917, 0.918, 0.923, 0.942 and 0.964 mm) for FL in 5 pith-to-bark samples. In the thinned trees, the otherwise constant increase in FL dropped slightly at the fourth location from the pith, showing 0.832, 0.884, 1.01, 0.949 and 1.02 mm values along the wood-core radius (Fig. 1).

Specific gravity (SG)

In general, tree thinning strongly influenced the between-treatments and within-tree variations of specific gravity (both P > 0.0001). Statistical analysis demonstrated that the mean value of SG was significantly higher (0.523) in unthinned trees than in the thinned trees (0.503), showing a reduction of 3.8 % due to thinning treatment. On the other hand, the SG mean values for the samples taken at five points (20, 40, 60, 80 and 100 % from pith; respectively) across the radial direction, showed almost a regular centrifugal increase (with a sharper rise in unthinned trees) up to about 80 % of the radial distance in both populations, followed by a decline near the bark (Fig. 2). The SG mean values at these five locations were 0.492, 0.515, 0.523, 0.551 and 0.532; respectively, for unthinned trees, whereas 0.506, 0.499, 0.506, 0.512 and 0.492, respectively, for thinned trees at the corresponding distances mentioned above.

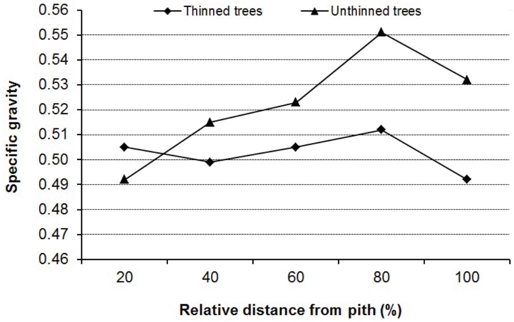

Fig. 2: Effect of tree thinning on wood specific gravity variations across the wood-disc radius at breast-height level for Acacia salicina trees of 12-year age.

Shrinkage

As mentioned earlier, samples for calculating shrinkage were taken from thinned trees only. Statistical analysis revealed highly significant differences (P > 0.0001) among the shrinkage mean values for three (near pith, middle point, and near bark) sampling locations across the wood-core radius. Fig. 3 presents data on shrinkage, expressed as the percent change in tangential, radial and longitudinal directions. Tangential shrinkage was the highest (7.28- 8.24 %), followed by the radial (3.66 – 5.43 %), and then the longitudinal (0.54 – 0.60 %) ones. Samples from peripheral (near bark) wood area underwent the maximum shrinkage (8.24 %), followed by samples from the mid-radius (7.75 %) and the central (7.28 %) locations (Fig. 3). On the other hand, shrinkage in radial direction attained the highest mean value (5.43 %) near the pith and the lowest (3.66 %) in the middle of the radius. The longitudinal shrinkage followed the trend of radial shrinkage, with 0.604, 0.539 and 0.543 % values at the three pith-to-bark locations, respectively. The volumetric shrinkage was relatively too high, i.e. 23.72, 15.32 and 18.30 % (not included in figure) at selected positions along the wood-core radius.

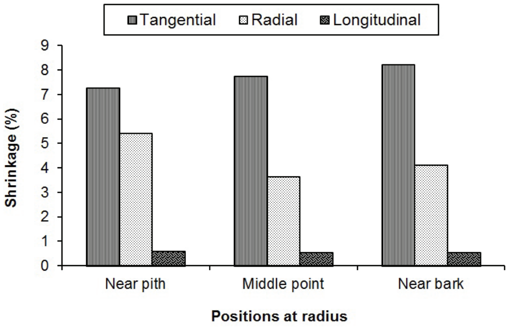

Fig. 3: Variation in three-dimensional shrinkage of wood across the wood-disc radius at breast-height level in thinned population of Acacia salicina trees of 12-year age, showing that the shrinkage is the maximum in tangential direction, relatively less in radial direction and the minimum in longitudinal direction.

DISCUSSION

Changes in stem volume and diameter, tree height, branch characteristics and biomass distribution of *Acacia salicina* in relation to thinning regimes have been discussed earlier (Hegazy et al. 2013). Importance of thinning with reference to growth rings, sapwood-heartwood ratio, fiber length, wood shrinkage and specific gravity is elucidated below.

Radial growth and sapwood-heartwood ratio

Growth rate of individual tree influences wood quality. Seasonal changes in the timing, rate and duration of secondary growth affect the properties and proportions of earlywood and latewood (Downes and Drew 2008). Faster growth rates, desirable for volume-yield optimization, may be accompanied by greater earlywood portions, thus lowering the wood density and affecting the wood quality. Short-rotation tree species (less than 20-30 yr), with fast early-growth rates, often develop internal growth stresses and tension wood that lead to end-splitting at harvest and limit the recovery of wood during processing (Washusen 2011). Growth rate generally declines after a certain age and size of the tree. Hein et al. (2008) found high portions of sapwood in young trees and in young parts of old trees. In *A. salicina* trees, heartwood production begins at a fairly young age, as early as 6-7 years.

The proportion of heartwood increases with tree age; therefore longer rotations will increase the proportion of heartwood for a given stand volume. Practices (like wide spacings or fertilization) that encourage rapid growth and greater leaf area would likely increase the proportion of heartwood on individual tree basis (Whitehead et al. 1984) and possibly per hectare basis (DeBell and Lachenbruch 2009). Trees with wider spacings produce greater amounts of sapwood and heartwood in hardwoods (Gominho and Pereira 2000) and softwoods (DeBell and Lachenbruch 2009). In *A. salicina*, the sapwood and heartwood areas in thinned trees might be 4-5 times and 4-6 times larger, respectively, than in the unthinned trees. This information can be combined with knowledge of cultural effects on stem diameter and form, heartwood durability, and total volume production to develop silvicultural approaches that ensure the best output.

Fiber length

The fiber or tracheid length has a strong, direct effect on tear index, bending stiffness, and pulp yield (Wimmer et al. 2002). It shows positive correlation with the plant age and negative correlation with the width of annual growth ring. Low stocking densities (trees/ha) are related to shorter fiber lengths, while higher stocking densities result in decreased radial growth at juvenility (Watson et al. 2003). Higher stocking densities cause faster longitudinal (primary) growth due to increased competition for light. Lindstrom (1997) found the tracheid length to be dependent on a logarithm of cambial age and growth-ring width. Thinning generally causes decrease in fiber length, tracheid length and wood density (Barbour et al. 2003); however, no differences due to thinning were found for tracheid length in *Taiwania cryptomerioides* Hay, which can likely be due to the young age of trees studied (Chiu et al. 2005).

Wood density

Basic wood density (kg.m^{-3}), defined as the ratio of dry mass to green volume and determined by cell-wall thickness, cell size and shape, and the ratio of latewood to earlywood (Swenson and Enquist 2007), is influenced by tree age and different variables of secondary growth. Wood density has a direct bearing on many wood attributes including strength, shrinkage and yields (Joza and Middleton 1994), which determine the suitability of timber to be processed into lumber, panel products, or pulp and paper. In a study of *Eucalyptus* trees, wood density alone accounted for 81 percent of the variation in their MOE (Yang and Evans 2003). Wood density could be reduced by thinning only slightly; heavy thinning applied to 40-50 year old trees did not alter wood quality in certain conifer stands (Schneider et al. 2008).). Jane et al. (2012) reported that thinning at an early age of 6 years had no significant effect on wood density or the intra-annual cycle of wood density of 22-year-old *Eucaluptus nitens* plantations in Australia. Thinning of *A. salicina* trees in our study reduced wood density by 3.8 % only.

Variation in wood density along the radius of the disk, which generally shows a rising trend with tree age, as in the case of eucalypts (Hein and Brancheriau 2011), has a key role in solid-wood applications (Kim et al. 2008). Radial variation of density in the diffuse-porous hardwoods is attributed to the proportionate volumes of vessel and fiber cell-wall substance (Panshin and De Zeeuw 1980), and specifically to the thickness of the S2 layer of the cell wall (Walker and Butterfield 1996). Radial variations in density are linked to radial changes in strength and shrinkage traits (Walker 2006). Large changes in basic density from pith to bark as well as within the annual growth are generally undesirable for solid-wood processing and silvicultural interventions such as thinning and fertilizing that aim to maintain a relatively continuous individual tree growth throughout the rotation so as to produce wood with homogenous density (Drew et al. 2011)

Studies on relationship between growth rate and wood density have often given inconsistent results. Significant negative correlations were noted in poplar trees (Hernandez et al. 1998), while no correlations were detected in some other species (Zhang 1995). Radial variations in the wood density of *A. salicina* trees resembled those in the 14-year-old *Acacia mangium* (Lim and Gan 2000), attaining the peak around 80% of the radial distance from the pith and then declining near the bark.

Wood density across the growth ring

Average wood density of *A. salicina* was relatively low (0.503) in thinned stand and slightly high (0.523) in unthinned stand, while the average growth rate was high (0.94 cm per year) and low (0.51 cm per year) in trees of these stands respectively. Heavy thinning had a significant positive effect on annual radial growth, with little effect on wood density, in black spruce (Queju et al. 2011), Japanese cedar (Lin et al. 2012) and *Pinus elliottii* (Luo et al. 2012). This negative correlation between wood density and growth rate agrees to some earlier studies (Watson et al. 2003) and contradicts few others (Persson et al. 1995). The relationship between ring width and wood density was negative when thin-walled earlywood dominated the ring width in Norway spruce. It turned out positive when environmental factors promoted development of thick-walled latewood cells (Wimmer and Downes 2003). Evidence suggests that suppressed and intermediate trees have higher wood densities than the co-dominant and dominant trees within the same stand (Lindström, 1996, Duchesne et al. 1997). In *Picea abies*, wood density showed correlation with tree characteristics like tree height, stem taper and mean ring width, and with stand characteristics such as stocking density and thinning regime (Lindström 1996).

Shrinkage

The extent of wood shrinkage differs in tangential, radial and longitudinal directions. The wood normally shrinks about twice as much tangentially as radially, and by a very small amount in longitudinal direction (Zobel and Van Buijtenen 1989), and the same applies to *A. salicina*. Transverse (radial and tangential) shrinkage is less in low-density juvenile wood than in the mature wood (Bowyer et al. 2003). This concept fits our study also, where tangential shrinkage is less near the pith and increased gradually towards the bark. Within-tree stability and homogeneity with regards to shrinkage are desirable characters, because a high coefficient of anisotropy (the ratio between tangential and radial shrinkage) causes cupping, cracking and angular deformation in wood during drying (Chauhan and Aggarwal 2004). Longitudinal shrinkage, and its variations over cross-sections of studs, can cause unlikable springing and/or bowing (Johansson 2002).

Wood density has a positive relationship with the radial and tangential shrinkage but a negative one with longitudinal shrinkage (Pliura et al. 2005). It thus facilitates shrinkage predictions (Leonardon et al. 2010). Koubaa et al. (1998) found significant positive correlations between basic wood density and the radial, tangential as well as volumetric shrinkages in *Populus* x *euramericana* hybrid clones. In Japanese cedar (*Cryptomeria japonica*), effect of 45 % thinning intensity was not significant on wood density and shrinkage (Luo et al. 2012).

CONCLUSIONS

The wood produced for lumber production would ideally have a high density, long fibers, high percentage of heartwood and low variability in wood density and shrinkage across the radius. For developing these traits, trees should have a close initial spacing, followed by thinning so as to decrease competition between trees. In *A. salicina*, influence of thinning is non-significant on average fiber length, but significant on fibre-length variation across the radius of the wood disk. Proper thinning significantly decreases tangential shrinkage and specific gravity of wood. It increases the annual-ring-width values by 155-185 %, sapwood area by 4-5 times and heartwood area by 4-6 times, compared with those in unthinned population.

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