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Effect of growing site on the fundamental wood properties of natural hybrid clones of *Acacia* in Vietnam

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Abstract We investigated clonal and site variations in wood fiber length, microfibril angle, and specific gravity of seven natural hybrid clones of *Acacia* (*Acacia mangium* × *Acacia auriculiformis*) grown in northern and southern Vietnam. Fiber length did not differ between clones or between sites. The microfibril angle of the S_2 layer did not significantly differ between clones but significantly differed between sites. Clone and site significantly affected specific gravity. The significant effects of genetic × environmental interactions on wood properties indicated the difference in the response of clones to different growing conditions. The trends of changes in fiber length, microfibril angle, and specific gravity from the vicinity of the pith to near the bark were similar for all clones at each site; however, variations in fiber length, microfibril angle, and specific gravity were more visible in northern Vietnam than in southern Vietnam, with a significant effect of genetic factors. This difference may be attributable to winter, which is experienced in northern Vietnam but not in southern Vietnam. For clone selection for plantation in the northern region, combining growth rate with wood properties was recommended. On the other hand, for plantation in the southern region, clone selection depends mainly on the growth rate, taking into consideration the specific gravity.

Key words *Acacia mangium* · *Acacia auriculiformis* · Natural *Acacia* hybrid clone · Genetic × environmental interactions · Growth · Wood properties

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Introduction

With increasing population pressure, large areas of forest have been destroyed in order to supply land for agriculture and raw material for wood industries. Increasing demand for wood and limited wood supply have prompted investigations into the potential of fast-growing species as a new source of material. *Acacia mangium* and *Acacia auriculiformis*, the native species of wood in Australia and Papua New Guinea,[1] are fast-growing multipurpose species and are used widely for timber, fuelwood, agroforestry, and soil improvement, among others. These species have been introduced in some other countries in Asia, including Vietnam. Natural hybrids between the two have been found in Malaysia,[2] Papua New Guinea, Thailand, and Vietnam.[3] The hybrids exhibited heterosis in growth in terms of both height and diameter, and showed adaptation to many soil types having a range of pH values. The wood of the *Acacia* hybrid was reported to be a suitable material for the paper, particleboard, and medium-density fiberboard (MDF) industries. Wood properties of the *Acacia* hybrid are intermediate or better than those of the wood of *A. mangium* or *A. auriculiformis*.[4–7] Some studies have been carried out for 20 years on seedlings, tree morphology and identification,[4] and isozyme analysis to determine the F1 hybrid,[8] vegetative propagation,[2,9] and techniques to produce hybrid seeds by artificial hybridization.[10]

Studies on *Acacia* in Vietnam showed that natural *Acacia* hybrids grew 1.5–4 times faster in terms of volume compared to *A. mangium* and *A. auriculiformis*.[11,12] Moreover, the hybrid has a better stem shape and height below the crown.[4] With regard to soil improvement, Le[13] reported that the quantity and volume of rhizobium nodules (symbiosis between nitrogen-fixing bacteria and the roots of the plant) of *Acacia* hybrids was 2–4 times greater than that of their parents. This indicates that for the next generation, the important characteristics of soil are maintenance and improvability. In some ecological zones, trial forests were established for clone selection of *Acacia* hybrid. From the results of this study, several natural *Acacia* hybrid clones were introduced for plantation depending on their growth ability and adaptation to the environment. For a given site, clone selection is very important because farmers derive benefits only when the annual yield of an *Acacia* hybrid plantation is at least 15 m^3/ha.[14] In our previous study, clones with higher wood specific gravity could be predicted at an early stage when the stump diameter had reached 6 cm.[15] Fiber length and specific gravity of *Acacia* hybrids are also probably improved by artificial hybridization.[16]

With developments in the field of wood processing, the wood of *Acacia* hybrids can be used in other ways than just pulp and paper production such as solid wood and particleboard. However, little attention has been paid to the wood properties of *Acacia* hybrids at different sites. The wood properties of interest include fiber length, microfibril angle, and specific gravity, all of which are important parameters for the rapid evaluation of wood quality. These properties also affect the strength and stiffness of clear wood, pulp yield, and paper quality. The aim of this study was to determine the effects of genetic and environmental factors on wood fiber length, microfibril angle of the S_2 layer, and specific gravity of the wood of seven natural *Acacia* hybrid clones grown in northern and southern Vietnam.

Materials and methods

Materials

A total of 42 trees (7–8 years old) from seven natural hybrid clones of *Acacia* (*Acacia mangium* × *Acacia auriculiformis*) were collected at two trial forests, located in Ba Vi (northern Vietnam) and Bau Bang (southern Vietnam), which are representative of sub-tropical and tropical forests, respectively. The basic information on these sites is listed in Table 1.

The soil at the northern site is ferralitic clay loam (yellow lateritic hill soil), which developed on sandstone with heavy lateritization, and is poor in nutrients and shallow; its depth does not exceed 50 cm. The soil at the southern site is sandy alluvium with a loose and porous structure, and the soil layer is deep. For this study, seven clones were selected, five of which were from Ba Vi (northern provenance), namely, BV5, BV10, BV16, BV32, and BV33, and two from Trang Bom (70 km from Bau Bang) (southern provenance), namely, TB6 and TB12. According to Le,[4] the parents of the clones selected from Ba Vi were identified as (1) *Acacia mangium*; provenance Daintree, Queensland and (2) *A. auriculiformis*, provenance Darwin, Northern Territory. The parents of the clones selected from Trang Bom were (1) *Acacia mangium*; provenance Mossman, Queensland and (2) *A. auriculiformis* of unknown provenance or Oenpelli provenance, Northern Territory (Australia). Each clone was planted in a 500-m^2 plot and next together in a stand (trial forest). Plantlets propagated from branch cuttings were planted with a spacing of 2.5 × 2.5 m. The height and diameter at 1.3 m of each tree were measured after felling. A 15-cm-thick disc was collected from each tree at a height of 1.3 m above the ground in order to measure the length of the wood fiber, the microfibril angle of the S_2 layer, and the specific gravity.

Wood property measurement

Specific gravity

Pith-to-bark strips (radius × 30 × 20 mm) were cut from each disc after air-drying. The strip was divided into small pieces at intervals of 1 cm from pith to bark with a razor blade and the specific gravity was measured by an electronic densimeter (MD-300S).

Lengths of fiber and microfibril angle

Pith-to-bark strips (radius × 10 × 10 mm) were cut from the discs for measurement of fiber length and microfibril angle of the S_2 layer. The strips were then divided into small pieces at intervals of 1 cm from pith to bark with a razor blade. The pieces were macerated by dipping in a 1:1 solution of HNO_3 and distilled water plus $KClO_3$ (3 g/100 ml solution) for 5 days. The pieces were rinsed three times with distilled water. The lengths of 30 fibers were measured by microscope and Winroof software. Small blocks (5 × 5 mm, L × R) at 2-cm interval from pith to bark were also prepared from the strips. These small blocks were boiled for 2 h before cutting. Radial sections of 8 μm thickness were cut by microtone with a piece of wet paper for a covering and then washed in distilled water. The sections were dehydrated in a series of 10%, 30%, 50%, 80%, and 100% ethanol for 5 min each. The sections were then placed on a slide glass and immersed in a 3% solution of iodine-potassium iodide for 2–5 s. One or two drops of 60% HNO_3 were added and a cover-slip was placed over the wetted specimen. Microfibril angles of 20 fibers per small block were measured by a microscope and an image analysis system (Winroof, Mitsuya).

The volume of each tree was estimated by the following formula before the volume of each clone was averaged:

$$V = 1/4\,\pi \times \mathrm{DBH}^2 \times h \times f_{1.3}$$

Table 1. General characteristics of the natural conditions at the northern site (Ba Vi) and the southern site (Bau Bang)

Site	Latitude	Longitude	Soil type	Rainfall (mm)	Raining season >100 mm	Temperature (°C)		
						Mean	Max	Min
Northern site	21°07′N	105°26′E	Ferralitic clay loam	1680	April–October	23.2	40.2	5.3
Southern site	11°15′N	106°38′E	Sandy alluvium	2175	May–November	26.5	38.5	11.5

where V is the volume, DBH is the diameter at breast height, h is the tree height, $f_{1.3}$ is the form factor (0.5).

The data on wood fiber length, microfibril angle, and specific gravity were first tested for variance homogeneity, and then the analysis of variance was conducted using the data of individual trees with the site and the clone as fixed factors at the 5% confidence level. Statistical Package for Social Services (SPSS) 12.0 software was used for all analyses. When significant differences were found within a site, Duncan's multiple range testing was applied to the mean value of fiber length, microfibril angle, and specific gravity in order to identify significant differences between the clones at $P < 0.01$. The mean value is the average values at the all relative distance.

Results and discussion

Growth characteristics

The diameters at breast height and heights of the seven natural hybrid clones of *Acacia* planted in northern and southern Vietnam are listed in Table 2. The diameter at breast height ranged from 10.80 cm (TB6) to 15.33 cm (BV32) at the northern site and from 14.53 cm (BV33) to 18.23 cm (TB6) at the southern site. The tree height varied from 10.1 m (TB6) to 14.5 m (BV32) at the northern site and from 21.17 m (BV16) to 23.67 m (BV32) at the southern site. Thus, the clones from Ba Vi (northern provenance) grew faster at the southern site (1%–22% larger in diameter and 57%–71% taller). Conversely, the clones from Trang Bom (southern provenance) grew much more slowly at the northern site (34%–68% smaller in diameter and 89%–153% shorter). On the whole, the natural hybrids (northern provenance) planted in southern Vietnam grew 61%–155% more in volume than those planted in northern Vietnam. This result was similar to the report of Le[4] that states that for young trees (first 1–3 years), the *Acacia* hybrids (northern provenance) planted in Long Thanh-Dong Nai (the south) grew 1.5–2 times faster than those planted in Ba Vi (the north) with regard to both diameter and tree height. Hence, the natural conditions in southern Vietnam (tropical zone) seem to be more suitable for the growth of *Acacia* hybrids.

Effect of environmental and genetic factors on fiber length, microfibril angle, and specific gravity

The results of analyses of variance for the three parameters of the seven clones at the two sites are presented in Table 3. Average values of fiber length presented no significant differences between clones and sites; whereas, the effect of clone × site interaction on fiber length was significant. The significant effects of clone and site on fiber length have been reported in six *Salix* clones[17] and in poplar hybrid clones;[18] however, Lowe and Greene[19] stated that no significant effects on fiber length could be attributed to provenance or plantations in green ash. Johnson and McElwee[20] also found no significant geographic effects on the fiber length of sweet gum. The average fiber length is possibly affected by interactions between environmental and genetic factors.

Similarly, the average microfibril angles did not significantly differ among the seven natural hybrid clones of *Acacia*. However, the effects of site and interaction of clone with site on microfibril angle were significant (Table 3). Lima et al.[21] also found no significant effect of clone on microfibril angle at the inner and outer positions of *Eucalyptus* hybrids.

For specific gravity, significant differences were found between clones and between sites (Table 3). These results were similar to those stated in some reports on clones of *Salix*,[17] *Fraxinus*,[19] *Eucalyptus*,[22] and *Populus*.[23]

The interactions between clone and site significantly influenced fiber length, microfibril angle, and specific gravity. This suggests that clones responded differently to different

Table 2. Diameter at breast height (DBH) and height of seven natural hybrid clones of *Acacia* from the northern site (Ba Vi) and the southern site (Bau Bang)

Clone	DBH (cm)		Height (m)		Volume (m^3/tree)	
	Northern site	Southern site	Northern site	Southern site	Northern site	Southern site
BV5	14.67	16.37 (+12)	14.17	22.50 (+59)	0.1197	0.2367 (+98)
BV10	12.70	15.50 (+22)	12.67	21.67 (+71)	0.0802	0.2044 (+155)
BV16	13.47	15.90 (+18)	13.20	21.17 (+60)	0.0940	0.2102 (+123)
BV32	15.33	17.70 (+15)	14.50	23.67 (+63)	0.1338	0.2912 (+117)
BV33	14.33	14.53 (+1)	13.60	21.33 (+57)	0.1097	0.1768 (+61)
TB6	10.80 (−40)	18.23	10.10 (−57)	23.33	0.0462 (−85)	0.3044
TB12	11.80 (−25)	15.83	11.60 (−47)	22.00	0.0634 (−71)	0.2165

Increment (+) and decrement (−) of DBH and height in percent when clone was planted out of provenance are given in parentheses

Table 3. Analysis of variance of fiber length, microfibril angle, and specific gravity of seven natural hybrid clones of *Acacia* at two sites

Source of variation	df	Fiber length		Microfibril angle		Specific gravity	
		MS	F	MS	F	MS	F
Clone	6	0.00291	2.027 (ns)	1.359	2.001 (ns)	0.00279	4.855**
Site	1	0.00061	0.117 (ns)	95.906	141.168**	0.04345	98.085**
Clone × Site	6	0.00424	3.542*	2.674	3.936**	0.00204	3.347*
Error	28	0.00129		0.679		0.00101	

ns, not significant; df, degrees of freedom; MS, mean squares; F-test of significance in ANOVA
* $P \leq 0.05$; ** $P \leq 0.01$

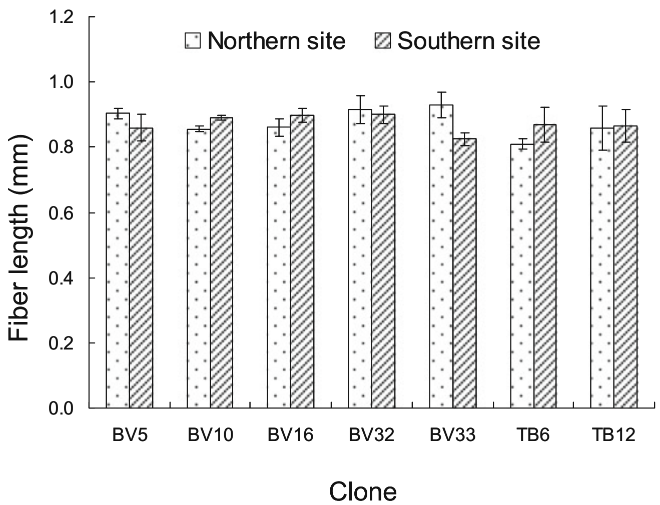

Fig. 1. Mean and standard deviation of fiber length of seven natural hybrid clones of *Acacia* from the northern site (Ba Vi) and the southern site (Bau Bang)

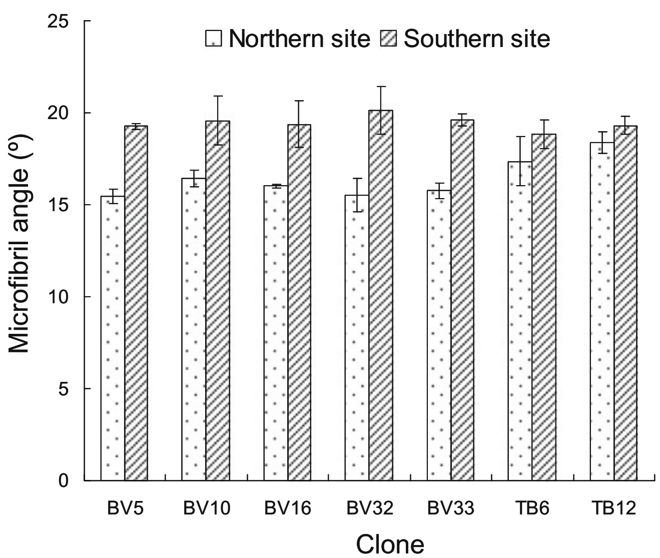

Fig. 2. Mean and standard deviation of microfibril angle of seven natural hybrid clones of *Acacia* from the northern site (Ba Vi) and the southern site (Bau Bang)

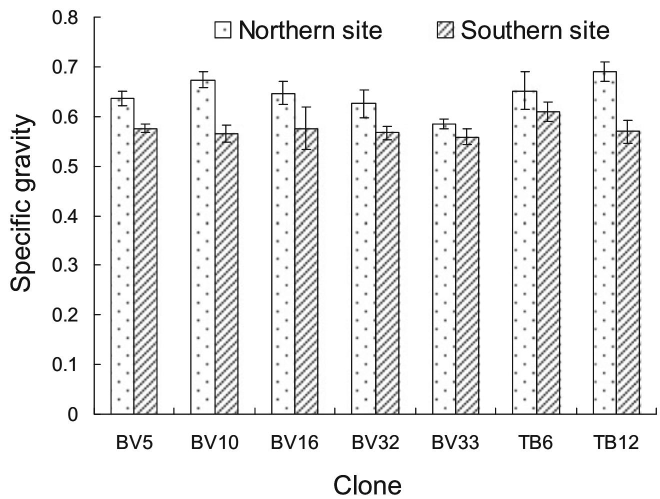

Fig. 3. Mean and standard deviation of specific gravity of seven natural hybrid clones of *Acacia* from the northern site (Ba Vi) and the southern site (Bau Bang)

plantation sites (Figs. 1–3). Breeding programs tend to be more internationally oriented, and their aim is to find clones suitable for different environments, because a plant's phenotype is the result of an interaction between genotype and environmental conditions. Good trees or clones need either a good genotype or a favorable environment, or both. Thus, the interaction between these factors can be related to the differences between the clones with regard to their adaptability to unfavorable or stressful conditions at a given site. Because of the clone × site interaction, clone selection should be carried out separately for each site.

Variation in fiber length, microfibril angle, and specific gravity within sites and between clones

The mean values of fiber length, microfibril angle, and specific gravity of the seven natural *Acacia* hybrid clones at the two sites are shown in Figs. 1–3, respectively. Fiber length ranged from 0.81 mm (TB6) to 0.93 mm (BV33) in the clones planted at the northern site, and from 0.82 mm (BV33) to 0.90 mm (BV32) in those planted at the southern site. The greatest change in fiber length was observed in BV33 because the fibers were the longest at the northern site and the shortest at the southern site. The fiber lengths of BV5, BV32, and BV33 clones decreased 4.4%, 2.2%, and 10.7%, respectively while those of BV10 and BV16 clones increased 3.5% and 1.2% respectively when these clones of northern provenance were planted at the southern site. The fiber of TB6 was 6.8% shorter, while that of TB12 remained constant when these clones of southern provenance were planted at the northern site (Fig. 1). Significant differences in fiber length were found between TB6, BV32, and BV33 at the northern site. Meanwhile, the mean values of fiber length were similar in all the clones grown at the southern site.

The average values of microfibril angle varied from 15.5° (BV5) to 18.4° (TB12) and from 18.9° (TB6) to 20.1° (BV32) in the clones planted at the northern and southern locations, respectively. Figure 2 shows a significant increase (19%–29%) in the microfibril angle of clones of the northern provenance that were planted at the southern site, as against a slight decrease (5%–9%) in the microfibril angle of clones of southern provenance grown at the northern site (Fig. 2). At the northern site, microfibril angle was significantly different between TB12 and BV5 and between TB12 and BV32, whereas there were no differences between clones at the southern site.

Specific gravity values varied from 0.59 (BV33) to 0.68 (TB12) at the northern site and from 0.56 (BV33) to 0.61 (TB6) at the southern site. The range of specific gravity was in agreement with that found in a study on natural *Acacia* hybrids by Nguyen[5] (0.56 g/cm^3 for a 5-year-old tree) but it was slightly higher than that stated in the report of Le[4] (0.54 g/cm^3 for a 5-year-old tree) and Nguyen[7] (0.5 g/cm^3 for a 7-year-old tree). Clone BV33 had the lowest specific gravity at both sites. The specific gravity of BV10 considerably decreased when this clone was planted in the southern region. On the other hand, the specific gravity of TB6 increased considerably when this clone was planted in the northern region. The specific gravities of BV33 and TB12 grown at the northern site significantly differed, while those of the clones grown at the southern site were similar (Fig. 3).

Radial variations in fiber length, microfibril angle, and specific gravity at the two sites are shown in Figs. 4–6, respectively. The trends from the pith to the bark of fiber length, microfibril angle, and specific gravity were similar for all clones at each site. Fiber length was shortest at around 0.5 mm near the pith and increased toward the bark, reaching 1.1–1.2 mm and 1.0–1.1 mm near the bark at the northern

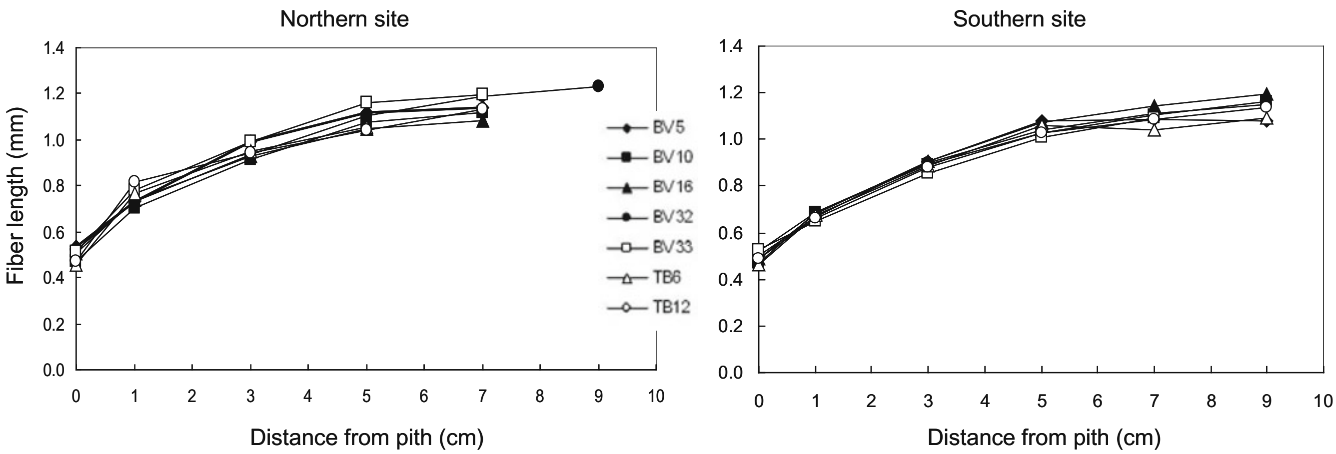

Fig. 4. Profile of length of fibers in the radial direction of seven natural hybrid clones of *Acacia* from the northern site (Ba Vi) and the southern site (Bau Bang)

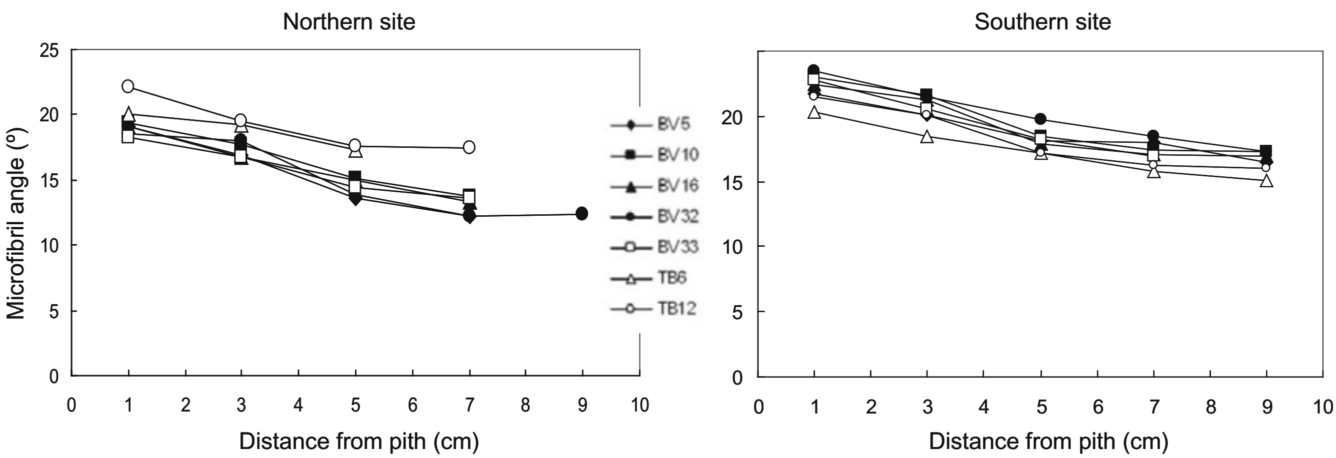

Fig. 5. Profile of microfibril angle in relation to distance from the pith of seven natural hybrid clones of *Acacia* from the northern site (Ba Vi) and the southern site (Bau Bang)

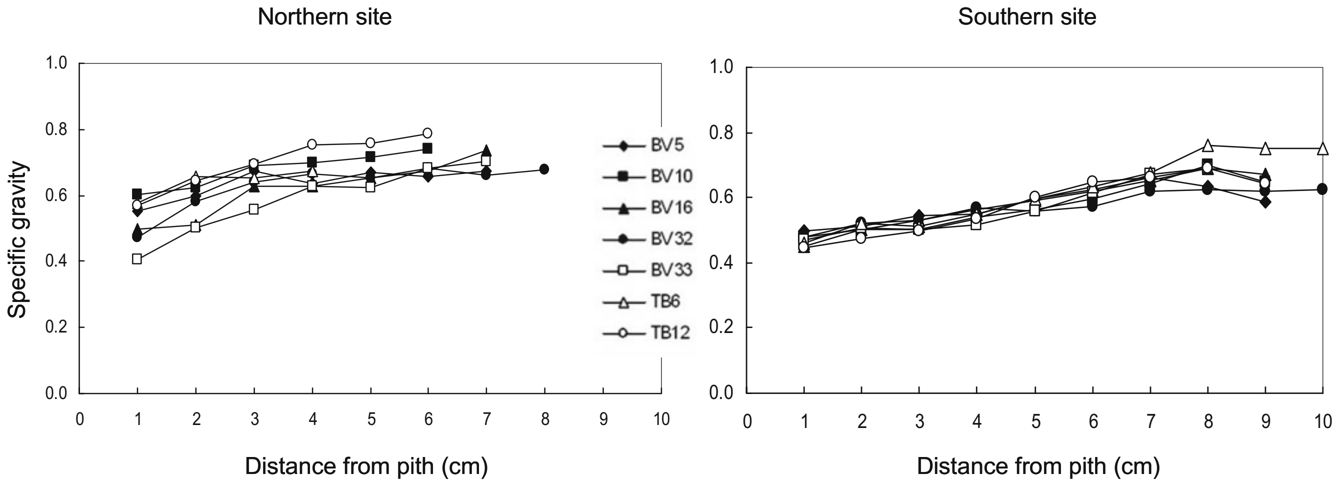

Fig. 6. Profile of specific gravity in the radial direction of seven natural *Acacia* hybrid clones from the northern site (Ba Vi) and the southern site (Bau Bang)

site and at the southern site, respectively (Fig. 4). This may be because the samples collected at the southern site were 1 year younger. Microfibril angles of wood of clones decreased from in the vicinity of the pith to near the bark. Microfibril angles of clones of southern provenance planted at the northern site were larger than those of clones of northern provenance. Conversely, microfibril angles of similar clones planted at the southern site were not significantly different (Fig. 5). The values of specific gravity of clones at both sites increased from the pith to the bark. At the northern site, specific gravity varied from clone to clone and increased quickly with distance from the pith from 0.4–0.6 at 1 cm to 0.55–0.65 at 3 cm, and then increased slightly toward the bark. In contrast, at the southern site, specific gravity was similar among clones until 7 cm from the pith, but significant differences among clones were found from that point to the bark (Fig. 6). This means that clones with higher specific gravity can be selected at individual sites.

Thus, wood properties such as higher specific gravity and lower microfibril angle in northern Vietnam are better than those in southern Vietnam. Significant differences between clones with regard to fiber length, microfibril angle, and specific gravity were found only at the northern site. These differences were attributed to the differences between the clones of northern provenance and those of southern provenance.

Implications for tree improvement

Almost all *Acacia* hybrid plantations are established with the purpose of supplying raw material to the pulp and paper industries. Therefore, the aim of tree breeding programs is to improve the growth rate of trees. Due to the use of *Acacia* wood for different purposes, attention should be paid to the implications of genetic benefits in terms of wood quality and quantity. The results of this study indicate that for a natural *Acacia* hybrid, wood specific gravity is under sufficient genetic control, responding well to selection in a tree-improving program. The effect of clone on fiber length and microfibril angle was not significant; however, a significant effect of the interaction between clone and site on these wood properties indicated that there is potential for improvement in these traits by clone selection for a particular site. For clone selection for the northern region, combining growth rate with wood properties is recommended. In the southern region, growth rate is the main trait and specific gravity should be also considered for clone selection because the most important factor is not volume increment but weight increment. Furthermore, clones with higher specific gravity can be selected at a young age when the tree diameter reaches 6 cm at 0.3 m height.[15] In Vietnam, clones BV5, BV32, and BV33 and clones BV5, BV32, and TB6 were selected for plantation in the northern and southern region, respectively. The relation between wood properties (fiber length, microfibril angle, and specific gravity) and growth rate (stem diameter and height) was weak to moderate,[15,16] indicating that clone selection carried out at the same site for volume improvement does not decrease the length of fiber or specific gravity. These results will be useful for breeders because good clones can be selected with improved growth rate and wood quality.

Conclusions

Genetic and environmental factors influenced to different extents the fiber length, microfibril angle, and specific gravity of seven natural hybrid clones of *Acacia* planted in northern and southern Vietnam. Differences in the average fiber length between clones and between sites were not significant. The effect of the clone on the mean microfibril angle was not significant, but that of site was significant. Clone and site significantly affected specific gravity. The natural hybrid clones of *Acacia* responded differently to different site conditions due to the significant effects of site and of the interaction between clone and site on the three wood properties. Clone selection at a specific site is recommended.

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