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NOTE

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Radial variations of wood properties in *Casuarina equisetifolia* growing in Bangladesh

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Abstract Radial variations of wood properties (basic density, fiber length, vessel element length, and compression strength) in plantation-grown *Casuarina equisetifolia* in Bangladesh were investigated for effective utilization of the wood. Samples disks at breast height were randomly collected from trees in a 10-year-old plantation in Cox's Bazar Forest Division, Bangladesh. The basic density showed a near-constant value up to 30 mm from the pith and then rapidly increased up to 60 mm from the pith. The fiber length and vessel element length gradually increased from the pith to bark. When radial variation of wood properties was determined according to relative distance from the pith, similar radial patterns were observed among the sample trees, indicating that the wood properties in *C. equisetifolia* may be related to the growth rate. The compression strength parallel to the grain (CS) increased from the pith to bark. A significant positive correlation was found between the air-dried density and the CS. The results obtained indicated that wood around the pith has a relatively low density, and wood outside the pith area has a relatively high density, suggesting that it could be used as structural lumber.

Key words *Casuarina equisetifolia* · Basic density · Fiber length · Vessel element length · Compression strength

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Introduction

Trees belonging to Casuarinaceae are fast growing and can grow in poor soil throughout coastal and mountainous areas in subtropical and tropical regions.[1] *Casuarina equisetifolia*, one of the Casuarinaceae plantation species, is naturally distributed in Southeast Asia and the Western Pacific, including northern Australia.[2]

A short rotation species, *Casuarina equisetifolia* is listed among the national priority species of the Forest Department Plantation Program in Bangladesh.[3] In addition, it has been planted extensively along the coast for sand dune stabilization in Bangladesh.[4] Besides coastal plantation, this species is also recommended for agroforestry systems in Bangladesh.[5] Most of the *C. equisetifolia* plantations in Bangladesh are approaching their economic maturity in size and vigor and should be used for maximum economic return.[6]

The wood of *C. equisetifolia* has been used for firewood, boat building, house construction, and furniture making.[7,8] In addition, this species is a suitable raw material for the production of chemical and semichemical pulps.[9] The supply of this wood may be increased in Bangladesh, because plantation area has been increased as described above. Therefore, further research is needed for effective utilization of wood from this species, such as production of structural lumber. However, only a few reports on the wood properties of *C. equisetifolia* are available.[6,10] In order to achieve the best utilization of this species, much more information is required. On the other hand, when the wood properties were analyzed transversely across the radius, around the perimeter, or longitudinally along the stem, the wood varies in its chemical, mechanical, and anatomical properties.[11] Therefore, research on the radial variation of wood properties of this species is needed.

The objective of this study was to obtain information about the basic wood properties of plantation-grown *C. equisetifolia* in Bangladesh for effective utilization of the wood. In this study, radial variations in basic density, fiber length, vessel element length, and compression strength parallel to the grain were investigated.

Materials and methods

Samples were collected from trees growing in a 10-year-old beach plantation in Cox's Bazar Forest Division, Bangladesh. The area's average monthly rainfall and temperature indicate a monsoon climate with a dry season (from November to April) and a wet season (from May to October). The plantation was established under the coastal afforestation program of the Forest Department of Bangladesh. The spacing of trees in the plantation was 2 × 2 m. Seedlings, which are widely used for plantations in Bangladesh rather than breeding materials, were used to establish this plantation.

Twenty trees were randomly selected in the plantation for sample collection. After the trees were harvested, 20 disks (10 disks 50 mm thick and 10 disks100 mm thick) were collected at 1.3 m from ground level. One sample had excessive tension wood and so was eliminated. Excluding the bark, the diameter of the 19 collected trees at 1.3 m from ground level ranged from 12.1 to 18.1 cm (mean ± standard deviation = 14.8 ± 2.2 cm).

Due to indistinct growth rings in the sample, the radial variation of wood properties except for compression strength was analyzed at 1-cm intervals from pith to bark. For the measurement of wood properties, radial strips (20 mm in width, 20 mm in thickness) were taken from each disk. The obtained radial strips were divided into small sample blocks at 1-cm intervals from pith to bark. These sample blocks were used to measure the wood properties (basic density, fiber length, and vessel element length). The basic density was determined by the water displacement method. To determine the fiber length and vessel element length, small blocks were macerated with Schulz's solution. Fifty fibers and 30 vessel elements in each sample were measured under a microprojector (Nikon, V-12) with a digital slide caliper (Mitutoyo, CD-30C).

For compression tests, small specimens [23 (R) × 23 (T) × 50 (L) mm] were prepared from 9 of the 19 collected logs at 25-mm intervals from pith to bark. The compression tests were conducted on a universal testing machine (Shimadzu, DCS-5000). The load speed was adjusted to 1 mm/min. The mean moisture content of the specimens was 9.1% ± 0.3%. The compression strength parallel to the grain (CS) was calculated by dividing the maximum load by the specimen area.

In the present study, the radial variation of wood properties determined by the relative distance from the pith was also examined. The calculation method for the value of the wood properties determined by the relative distance from the pith is shown in Fig. 1.

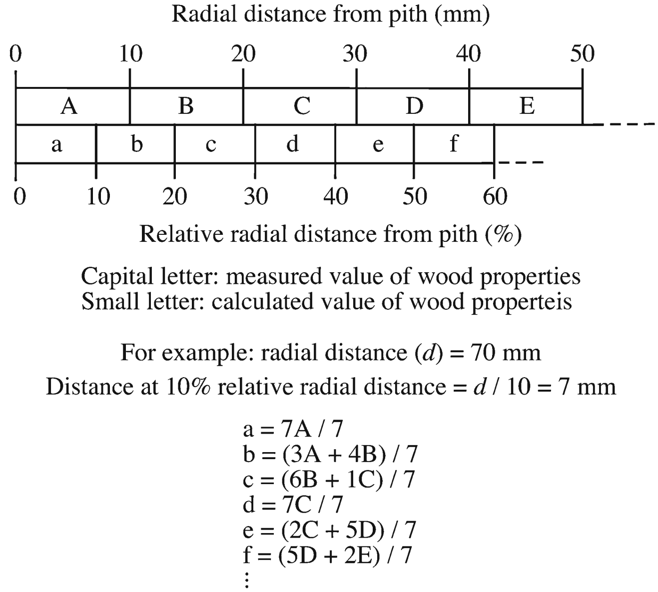

Fig. 1. Method of calculation of wood properties with respect to relative distance from the pith

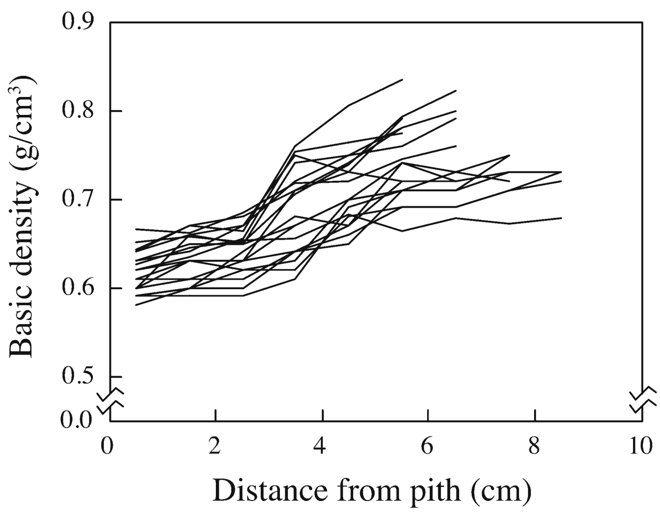

Fig. 2. Radial variation of basic density with respect to distance from pith

Results and discussion

Figure 2 shows the radial variation of basic density. The basic density showed an almost constant value (ca. 0.63 g/cm^3) up to 30 mm from the pith and then rapidly increased to 60 mm (0.74 g/cm^3) toward the bark. In trees with a large diameter at breast height (DBH), thereafter, it again showed an almost constant value (ca. 0.73 g/cm^3) toward the bark. The mean value of the basic density from pith to bark was 0.68 ± 0.02 g/cm^3. This value obtained in this study was lower than the mean basic density (ca. 0.84 g/cm^3) of 25-year-old *Casuarina equisetifolia* (200 mm DBH) grown in Chittagong, Bangladesh.[6] On the other hand, when seedlings of seven different seed provenances were planted in one stand located in Sadival, India, the wood densities (oven-dried condition) of 4.5-year-old trees varied from 0.59 to 0.71 g/cm^3.[8] In addition, significant differences in wood density were found among the provenances: one provenance (provenance Seventeen Seventy) had 16% higher wood density than those of Iluka and local provenances.[8] This result suggests that the density of *C. equisetifolia* was different according to the provenance of seedling. On the other hand, Ishiguri et al.[12] reported that the basic density of *Paraserianthes falcataria* grown in Indonesia could be divided into two groups. In the present study, it can be said that the basic density of *C. equisetifolia* may also be divided into two groups according to distance from the pith, the border being at a distance of 20–30 mm.

The radial variation of fiber length is shown in Fig. 3. The fiber length gradually increased from pith to bark. As shown in Fig. 4, although the vessel element length had almost the same pattern as that of the fiber length from pith to bark, the increase was very gradual. The mean values of fiber length and vessel element length were 1.04 ± 0.07 mm and 0.31 ± 0.03 mm, respectively. In 10-year-old *C. equisetifolia* trees grown at four different locations, the mean fiber length and vessel element length varied from 0.90 to 1.23 mm and from 0.29 to 0.43 mm, respectively.[13] Our results for the mean values of fiber length and vessel element length were similar to those obtained by other researchers.[8,13]

Honjo et al.[14] reported that an increase in fiber length accompanied by radial growth could be divided into two components, the fusiform initial length and the fiber length increment. Bailey[15] suggested that the vessel element length could be taken as a substitute because vessel elements show little elongation after differentiation from the fusiform initial cell. Honjo et al.[14] also demonstrated that the boundary between juvenile wood and mature wood in *Acacia mangium* was determined by using a differential fiber length increment: juvenile wood and mature wood could be divided at around an age of 3 to 4 years, when 0.5% and 0.3% differential fiber length was used as the boundary point. In the present study, therefore, the fiber length increment was calculated by subtracting the vessel element length from the fiber length at the same sampling position, according to the procedure of Honjo et al.[14] to find out whether Honjo's definition of juvenile wood and mature wood could be used in hardwood species. As shown in Fig. 5, fiber length increment gradually increased. According to the results of Honjo et al.,[14] almost all woods used in this study may be regarded as "juvenile wood." In addition, as shown in Fig. 2, basic density may be divided into two groups: the border between them was 20–30 mm from the pith. From the results obtained, it may be considered that wood near the pith area may be considered as low quality wood, such as juvenile wood. However, the definition of juvenile wood in hardwood species grown in the tropics as well as in temperate zones is still not clear. Thus, further accumulation of data is needed to define juvenile wood in hardwood species.

In the present study, the diameters of the sample trees varied from 12.1 to 18.1 cm, indicating that the trees may have different growth rates. Therefore, the radial variation of wood properties determined by the relative distance from the pith was also examined (Figs. 6–8). Figure 6 shows radial variation of basic density with respect to relative dis-

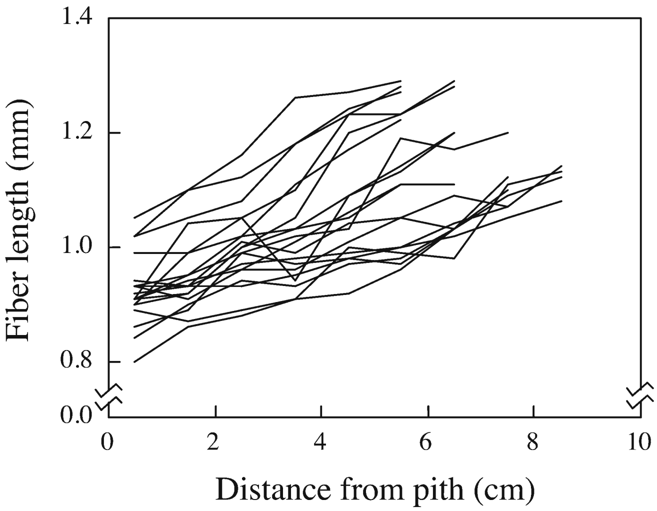

Fig. 3. Radial variation of wood fiber length with respect to distance from pith

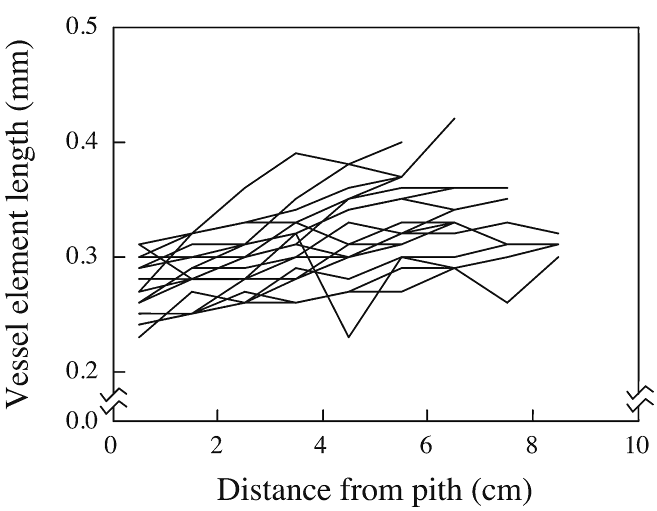

Fig. 4. Radial variation of vessel element length with respect to distance from pith

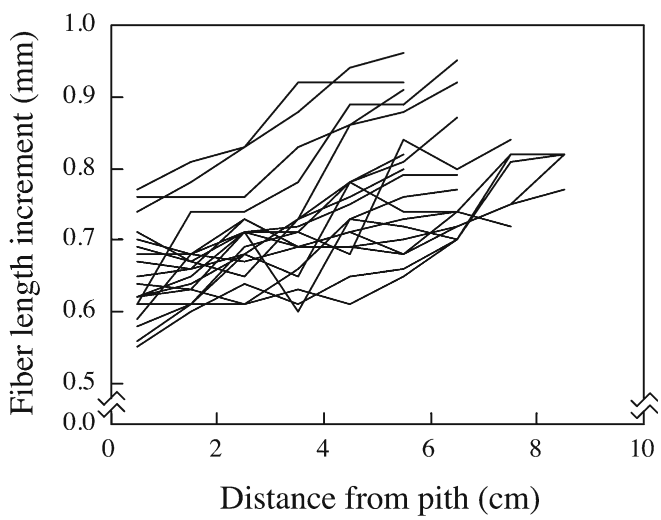

Fig. 5. Radial variation of fiber length increments with respect to distance from pith

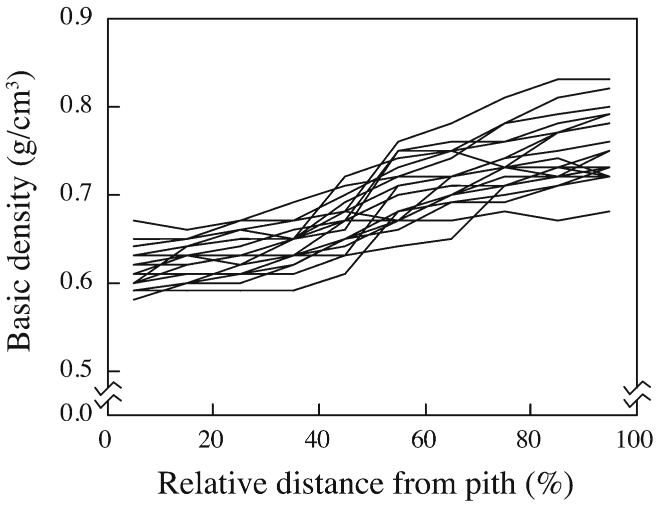

Fig. 6. Radial variation of basic density with respect to relative distance from pith

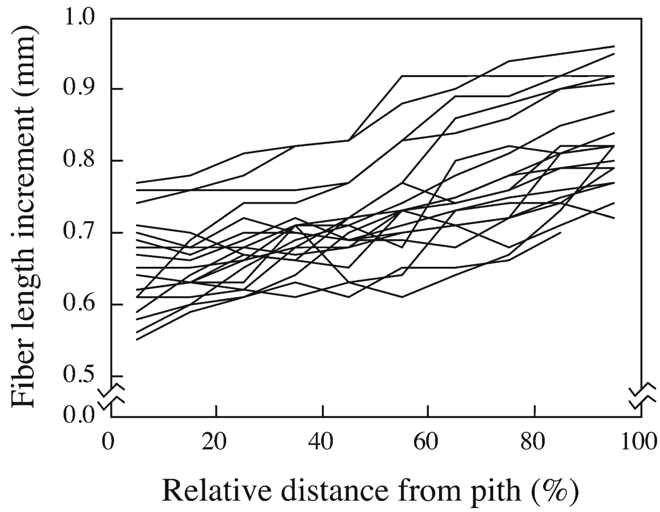

Fig. 8. Radial variation of fiber length increments with respect to relative distance from pith

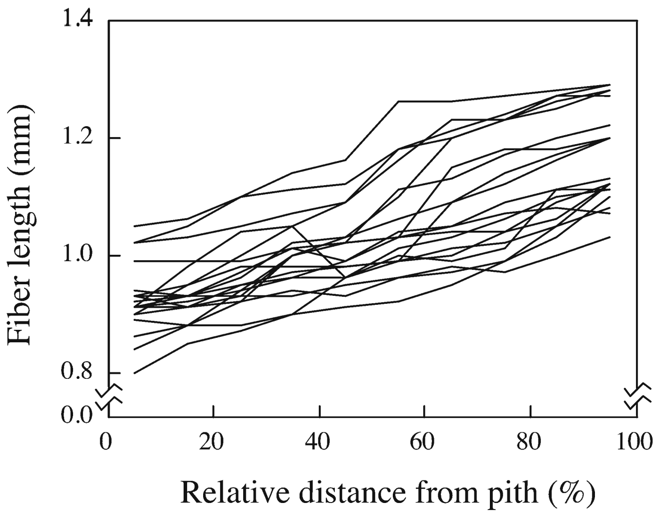

Fig. 7. Radial variation of fiber length with respect to relative distance from pith

tance from the pith. The radial variation pattern of the basic density determined by the relative distance from the pith was slightly different from the pattern for the radial distance from the pith (Fig. 2). The basic density determined by the relative distance from the pith increased from 40% relative distance from the pith to 100%. Radial variations by the relative distance from the pith in fiber length and fiber length increment were similar to the patterns for the radial distance from the pith (Figs. 3 and 5). In addition, when radial variation in basic density, fiber length, and fiber length increment were determined by the relative distance from the pith, almost all sample trees showed the same radial variation pattern. These results indicated that variation of wood properties among the sample trees might be affected by the difference of growth rate among the sample trees.

Table 1. Radial variation of compression strength parallel to grain

Position	*n*	Air-dried density (g/cm^3)		CS (MPa)	
		Mean	SD	Mean	SD
I	11	0.73	0.07	44.9	5.0
II	17	0.81	0.05	59.1	10.0
III	4	0.87	0.01	63.7	3.2
Total	32	0.79	0.07	54.8	10.8

n, Number of samples; CS, compression strength parallel to grain; SD, standard deviation; I, 0–25 mm from pith; II, 25–50 mm from pith; III, 50–75 mm from pith

Table 1 shows the radial variation of the CS, which gradually increased from pith to bark. The mean value of the CS was 54.8 ± 10.8 MPa. A significant correlation was found between the density and the mechanical properties of wood.[16] In *Casuarina* spp., there was a significant correlation between the air-dried density of the specimen and the modulus of rupture in static bending.[10] In the present study, as shown in Fig. 9, a significant correlation coefficient was found between the air-dried density of the specimen and the CS. Therefore, the mechanical properties of *C. equisetifolia*, especially in the CS, can be predicted by density. On the other hand, the density of wood near the pith area (within 30 mm from the pith) was relatively low compared with the other area, as described above. The compression test showed that the CS for position I (0–25 mm from pith) was low. Therefore, it is concluded that low quality wood exists near the pith area.

Conclusions

Radial variations of basic wood properties in 10-year-old plantation-grown *Casuarina equisetifolia* in Bangladesh were investigated for effective utilization of wood. The

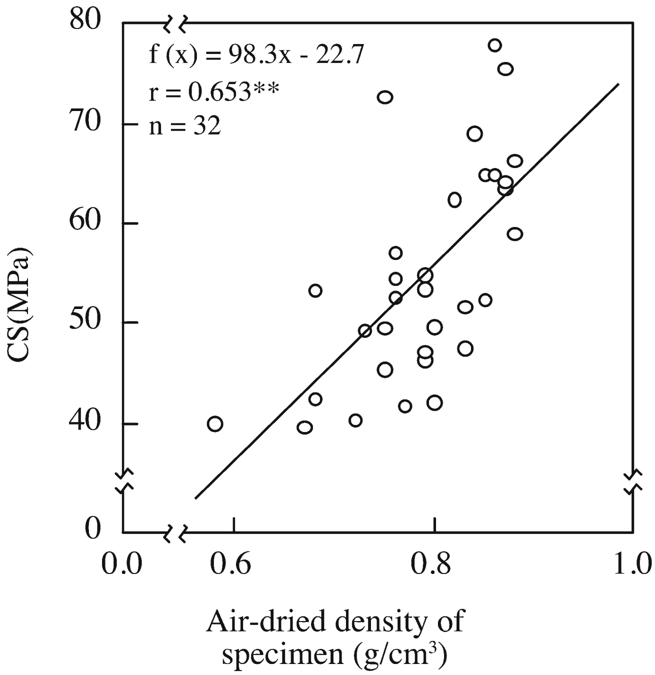

Fig. 9. Relationship between air-dried density of specimen and compression strength parallel to grain (*CS*). *Double asterisk*, significant at 1% level

basic density may be divided into two groups according to distance from the pith, the border being 20–30 mm from the pith. In addition, the variation of wood properties among the sample trees may be related to the growth rate. A significant correlation coefficient was found between air-dried density of the specimen and the CS. From the results obtained, it can be concluded that the wood near the pith area with relatively low density could be used as nonstructural lumber, and the wood with relatively high density could be used as structural lumber.

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