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COMPARING GROWTH RING FEATURES OF MAHOGANY TREES AT THE FOREST'S EDGE AND IN THE INTERIOR

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The aim of this study was to investigate the growth ring features of mahogany (*Swietenia macrophylla*) trees at the forest's edge and in the interior. The results revealed that the trees at the forest's edge exhibited an increase in the average ring width and density components compared to those in the forest interior. The growth rings were found to exhibit a radial trend, with the width decreasing from the pith towards the 7th ring (Rings A), then gradually decreasing towards the 20th ring (Rings B), and finally remaining relatively consistent towards the outer bark (Rings C). Although the specimens from Ring A of trees at the forest's edge did not exhibit more growth than those of trees in the forest interior, Rings B and C specimens of trees at the forest's edge had more growth than those in the forest interior. Furthermore, the ring density of Rings A and C specimens of trees at the forest's edge did not show any significant difference compared to those of trees in the forest interior. Ring B tree specimens at the forest's edge displayed a higher ring density compared to those in the forest interior.

Keywords: Mahogany (*Swietenia macrophylla*), forest edge, forest interior, tree ring features, annual growth increment, wood density

INTRODUCTION

Mahogany (*Swietenia macrophylla*) is an important plantation timber species highly valued for its quality wood properties and processing characteristics (Verissimo et al. 1995, Grogan et al. 2005). Mahogany trees are a significant source for the production of forest products. Since its introduction and cultivation in Taiwan in 1899, mahogany has been partially grown in the plains and mountains of this subtropical region, and has shown good adaptability. Shortages in wood resources have led to the need for sustainable forest operation to meet the future demands for multiple purposes. People involved in forest management and wood utilisation would greatly benefit from understanding the growth patterns and wood quality characteristics of these trees.

Mahogany trees are often selected for plantation due to their favorable adaptability and high-quality wood properties. However, the growth and wood characteristics of mahogany trees can be variable depending on the ecological conditions and management practices of different sites (Mayhew & Newton 1998). While some studies have reported results on wood properties, little attention has been paid to the study of ring growth performances (Francis 2003, Moya & Munoz 2010, Langbour et al. 2011, Lin et al. 2012).

During field investigations of tree growth performance, differences in the diameter of mahogany trees were observed within the forest. Visual inspections revealed that trees at the forest's edge had larger diameters compared to those in the forest interior. However, there is currently no available investigative information to confirm or discuss the reasons for this observation. The interface zone between a forest and an open field develops different microclimatic conditions that differ from those found in the forest interior. Moreover, trees in the edge zone typically have longer green crowns with more foliage compared to trees in the interior (Cienciala et al. 2002).

Tree ring analysis has various applications, and X-ray densitometric scanning techniques can be utilised to investigate the growth and density components of the rings (Lin et al. 2010, 2011). The characteristics of tree rings serve as significant indicators of environment, tree growth and wood density, making them essential for forest management and timber processing (Zobel & van Buijtenen 1989, Alteyrac et al. 2006). This study aims to examine the unique features of tree rings located at the inner and outer parts of mahogany plantations, as well as the variations in tree growth rates and wood density during different growth stages. The findings of this study could serve as a valuable reference for forest management and wood utilisation.

MATERIALS AND METHODS

The experimental site is located in the same location as a previous study, but with different sampled trees (Lin et al. 2012). The trees used in this study are from compartment 4 of the Xinhua Experimental Forest in Tainan County, southern Taiwan, currently managed by National Chung Hsing University. Based on data from the nearest meteorological station from 2004 to 2007, the average annual temperature in the Xinhua Forest area is approximately 24 °C, with a relative humidity of around 80%, average annual precipitation of approximately 2,500 millimeters, and an average elevation of around 94 meters. The study site covers an area of approximately 3 hectares. The mahogany plantation in the Xinhua Forest was established in 1986 with a planting density of 1,500 trees per hectare and has not undergone any artificial silvicultural thinning or pruning treatments to date. By 2008, natural thinning had reduced the average forest stand density to 720 trees per hectare. For this study, 40 sample trees were randomly selected, with 20 from the forest's edge and another 20 from within the dense forest interior, to represent the mahogany plantation in the Xinhua Forest.

In this experiment, an increment corer was used to extract a 5-mm diameter tree core sample from the breast height position of each sample tree in the eastern quadrant, with the direction towards the pith from the bark. The sampling was conducted in late 2012 when the trees were 25 years old. Only complete core samples from the pith to the bark were selected for analysis, and incomplete samples were excluded. All core samples were processed into 2.0 mm thin slices for X-ray scanning to obtain tree ring growth and density characteristics. A total of 40 trees were selected, resulting in 40 core samples for further analysis of 9 tree ring characteristics. In total, 40 trees, 25 tree rings and 9 tree ring characteristics were measured in this experiment, resulting in approximately 9,000 tree ring characteristic values.

In this study, X-ray densitometric method was used to scan and measure the ring characteristics of sampled wooden thin core slices (see Figure 1). Prior to use, the slices were pre-treated with distilled water and an alcohol-benzene solution to extract the volatiles in the samples. The conditioned slices were then placed in a commercial device, the QTRS-01X tree ring analyser and X-ray scanning machine, after being adjusted under controlled temperature and humidity conditions. After scanning, the 9 original values of the ring characteristics were directly read using the built-in software. Each slice was adjusted to approximately 12% moisture content and scanned in the radial direction from the bark to the pith for all the rings.

The QTRS-01X analyser was fitted with an X-ray source within its main unit. A standard collimator, measuring roughly 0.038 mm in width and 1.59 mm in height was included as the detector. The scanning step size of the sample was adjusted in increments of 0.02 mm. The QTRS-01X scanning system calculates density based on the correlation between X-ray attenuation and density [Quintek Measurement System (QMS 1999].

The tree ring analyser employed a collimated X-ray beam with a strictly controlled energy range to measure radiation absorption. The absorption is related to the sample density, following basic radiation attenuation principles. A fixed-density threshold was used to determine the density boundary values for each ring. The position of the earlywood/latewood boundary for each ring was defined by the average of the maximum and minimum density values in the ring, based on the wood's density profile. The tree ring analysis program, integrated with the QMS, confirmed and determines the original data of the wood density profile and ring characteristics. An additional correction program was utilised to confirm the nine ring characteristic values. Firstly, the program confirmed each ring's fixed density threshold, then moved each ring individually to confirm each characteristic value. These ring features included width components [ring (RW), earlywood (EW), and latewood (LW)], mean density components [ring (RD), earlywood (ED), latewood (LD), maximum (Dmax), and

Figure 1 a. Mahogany (*Swietenia macrophylla*) plantation trees, b. core slices and c. Quintek measurement systems (QMS) x-ray machine

minimum (Dmin)], and latewood percentage (LWP) in a ring. All specimens had a moisture content of approximately 12% when converting the ring density components from the degree of X-ray absorption. The wood density value at 12% moisture content served as the density reference value.

RESULTS

Ring width (RW)

A t-test was employed to assess the disparity in average radial growth components between the sampled trees situated at the forest's edge and in the interior. The results presented in Table 1 signify significant variations in the RW components between the trees located at the forest's edge and those in the forest interior. The t-test findings indicate that the average RW, EW and LW of the trees at the forest's edge were considerably greater than those in the forest interior (8.93, 4.35 and 4.58 mm versus 7.38, 3.54 and 3.85 mm, respectively). Consequently, it can be inferred that the tree specimens at the forest's edge exhibited more robust growth than those situated in the forest interior.

Figures 2, 3 and 4 display the radial direction changes in the radial growth components of trees in the mahogany plantation trees. It was observed that RW, EW and LW decreased radially from the pith to approximately the 7th ring, after which they gradually decreased towards the 20th ring. Finally, these components remained almost constant towards the bark. To examine the effects of tree cambium ages on ring characteristics, all rings in the radial variation at breast height position were categorised into three groups: Ring A (from the 1st to the 7th ring), Ring B (from the 8th to the 20th ring), and Ring C (from the 21st ring to the 25th ring). The descriptive statistical analysis of the RW components revealed

Table 1 Ring characteristics averaged from all sampled rings of mahogany trees at the forest's edge and in the interior

Variables	Trees within the forest interior (N = 20)	Trees on the forest edge (N = 20)	Significant (p value by t test)
Width (mm)			
Ring	7.38 (0.22)	8.93 (0.26)	< 0.01
Earlywood	3.54 (0.13)	4.35 (0.19)	< 0.01
Latewood	3.85 (0.16)	4.58 (0.16)	< 0.01
Density (kg m^{-3})			
Ring	466.3 (2.55)	480.4 (2.53)	< 0.01
Earlywood	440.3 (2.55)	457.4 (2.54)	< 0.01
Latewood	492.1 (2.76)	504.7 (2.71)	< 0.01
Highest	581.5 (3.15)	595.8 (3.14)	< 0.01
Lowest	369.9 (2.54)	380.1 (2.49)	< 0.01
LWP (%)	52.1 (1.06)	52.7 (1.05)	0.69

LWP = latewood percentage, number in parentheses is standard error

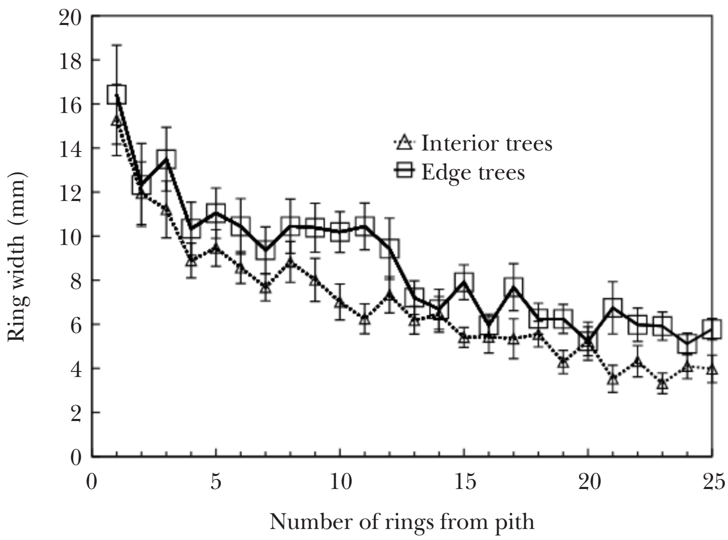

Figure 2 Radial variations in ring width of mahogany trees at the forest's edge and interior based on all rings from pith to bark (I, standard error)

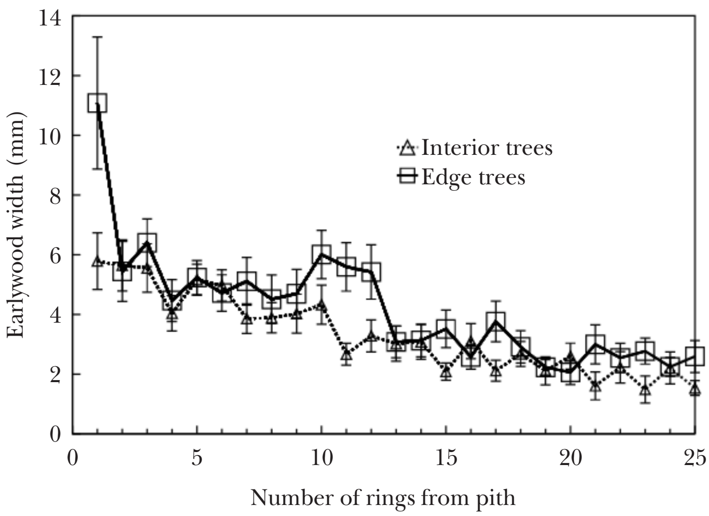

Figure 3 Radial variations in earlywood width of mahogany trees at the forest's edge and interior based on all rings from pith to bark (I, standard error)

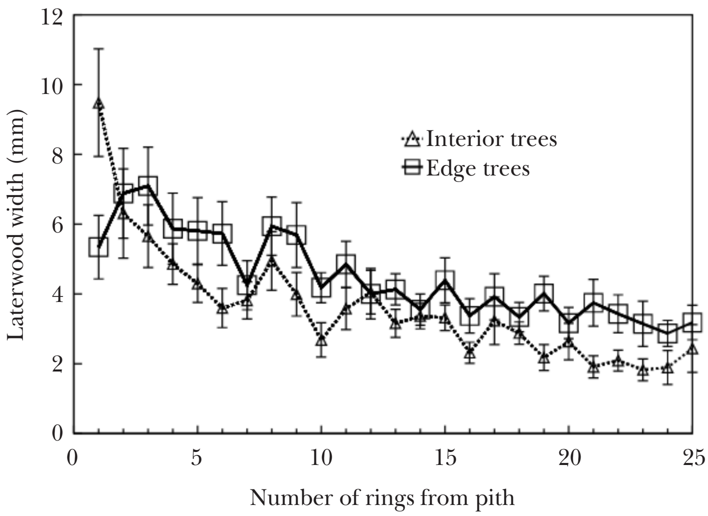

Figure 4 Radial variations in latewood width of mahogany trees at the forest's edge and interior based on all rings from pith to bark (I, standard error)

significant differences among the three radial regions, as shown in Tables 2–4. The analysis indicated that, for both trees at the forest's edge and in the forest interior, the average radial growth (RW) followed the order: Ring A > Ring B > Ring C.

The radial variation in the rings was further categorised into three zones based on the age of the tree cambium, which were juvenile, transition and mature regions. The descriptive statistics of the average RW for each zone showed that the trend was for the juvenile region to have a higher average RW than the transition and mature regions, or immature zones to have a higher average RW than the mature zones. The boundary between juvenile and mature wood in the mahogany stem was approximately located at the 8^{th} to 20^{th} growth ring from the pith. Wider growth rings were produced with immature wood near the pith, while narrower growth rings were typical for mature wood located towards the bark. The differences in average RW components based on Ring A were examined between the sampled trees located at the forest's edge and in the interior using a t-test, and the results are presented in Table 2. It is evident that no significant differences in the RW components were observed between trees at the forest's edge and those in the interior. The t-test analysis revealed that the average RW components of trees at the forest's edge were not significantly larger than those of trees in the forest interior. Therefore, it can be concluded that the Ring A specimens of trees located at the forest's edge did not exhibit greater growth than those of trees in the forest interior.

A t-test was conducted to analyse the differences in average RW components between Ring B and Ring C among the sampled trees located at the forest's edge and in the forest interior, and the results are presented in Tables 3 and 4. It is evident that significant differences in RW components were observed between trees at the forest's edge and those in the forest interior. The t-test analysis revealed that the average RW components of trees at the forest's edge were significantly greater than those of trees in the forest interior. Therefore, it can be concluded that Rings B and C specimens of trees located at the forest's edge exhibited greater growth than those of trees in the forest interior.

Rind density (RD)

A t-test was conducted to examine the differences in average RD components between the sampled trees located at the forest's edge and those in the forest interior, and the results are presented in Table 1. It is evident that significant differences in RD components were observed between trees at the forest's edge and those in the forest interior. The t-test analysis revealed that the average RD components of trees at the forest's edge were significantly larger than those of trees in the forest interior. In general, it can be concluded that the specimens of trees located at the forest's edge had a higher ring density than those of trees in the forest interior.

Table 2 Ring characteristics averaged the 1th through 7th sampled rings of mahogany trees at the forest's edge and in the interior

Variables	Trees within the forest interior (N = 20)	Trees on the forest edge (N = 20)	Significant (p value by t test)
Width (mm)			
Ring	10.43 (0.45)	11.92 (0.59)	0.05
Earlywood	5.00 (0.27)	6.06 (0.44)	0.05
Latewood	5.43 (0.38)	5.85 (0.38)	0.43
Density (kg m^{-3})			
Ring	457.5 (4.6)	467.0 (4.0)	0.12
Earlywood	435.1 (4.7)	447.4 (3.9)	0.05
Latewood	482.3 (4.9)	494.4 (4.9)	0.08
Highest	564.4 (5.3)	580.0 (5.8)	0.05
Lowest	365.0 (4.5)	371.9 (4.0)	0.26
LWP (%)	50.3 (1.9)	48.9 (2.0)	0.60

LWP = latewood percentage, number in parentheses is standard error

Table 3 Ring characteristics averaged the 8th through 20th sampled rings of mahogany trees at the forest's edge and in the interior

Variables	Trees within the forest interior (N = 20)	Trees on the forest edge (N = 20)	Significant (p value by t test)
Width (mm)			
Ring	6.34 (0.22)	8.08 (0.28)	< 0.01
Earlywood	3.04 (0.15)	3.86 (0.20)	< 0.01
Latewood	3.30 (0.15)	4.22 (0.18)	< 0.01
Density (kg m^{-3})			
Ring	469.0 (3.3)	486.6 (3.5)	< 0.01
Earlywood	441.7 (3.4)	461.6 (3.6)	< 0.01
Latewood	495.4 (3.6)	510.0 (3.6)	< 0.01
Highest	589.5 (4.2)	604.0 (4.0)	0.011
Lowest	370.1 (3.4)	384.7 (3.3)	< 0.01
LWP (%)	52.5 (1.4)	54.3 (1.4)	0.37

LWP = latewood percentage, number in parentheses is standard error

Table 4 Ring characteristics averaged the 21st through 25th sampled rings of mahogany trees at the forest's edge and in the interior

Variables	Trees within the forest interior (N = 20)	Trees on the forest edge (N = 20)	Significant (p value by t test)
Width (mm)			
Ring	3.80 (0.27)	5.93 (0.35)	< 0.01
Earlywood	1.80 (0.21)	2.64 (0.22)	0.010
Latewood	2.01 (0.17)	3.29 (0.25)	< 0.01
Density (kg m^{-3})			
Ring	478.0 (7.0)	485.4 (7.1)	0.48
Earlywood	448.7 (6.4)	463.1 (7.2)	0.16
Latewood	504.3 (8.5)	506.5 (7.3)	0.85
Highest	590.8 (10.0)	598.9 (9.0)	0.55
Lowest	383.2 (7.1)	380.7 (7.8)	0.82
LWP (%)	54.8 (3.2)	54.5 (2.7)	0.94

LWP = latewood percentage, number in parentheses is standard error

Figures 5–9 illustrate changes in RD components in the radial direction of mahogany trees, showing a gradual increase in RD components from the pith towards the bark. Descriptive statistics revealed significant differences in RD components among the radial regions, as presented in Tables 2–4. The descriptive statistics also showed that Ring A had lower RD components than Rings B and C. Additionally, the average RD components of the three regions varied, with mature and transition regions exhibiting higher RD components than juvenile regions. These findings indicated the presence of narrower growth increment and higher wood density in mature wood located towards the bark side. In contrast, wider radial width and lower wood density were characteristic of juvenile wood near the pith area.

A t-test was used to analyse differences in the average RD components based on Rings A and C between the sampled trees located at the forest's edge and in the forest interior, and the results are presented in Tables 2 and 4. It is evident that no significant differences in RD components were observed between trees at the forest's edge and those in the forest interior. The t-test analysis revealed that the average RD components of trees at the forest's edge were not significantly larger than those in the forest interior. Therefore, it can be concluded that Ring A and C specimens of trees located at the forest's edge did not exhibit greater ring density than those in the forest interior.

The average RD components based on Ring B were compared between the sampled trees at the forest's edge and in the interior using a t-test.

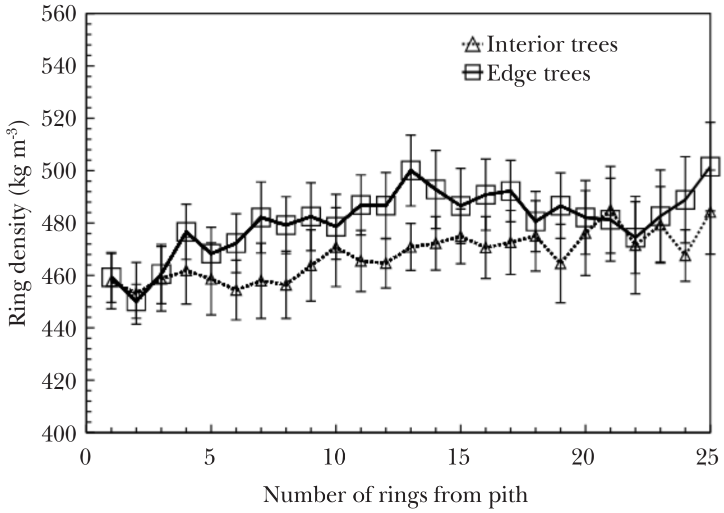

Figure 5 Radial variations in ring density of mahogany trees at the forest's edge and interior based on all rings from pith to bark (I, standard error)

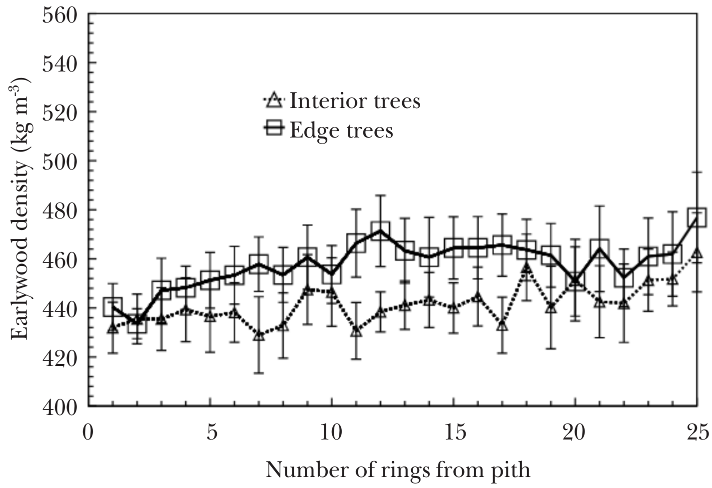

Figure 6 Radial variations in earlywood density of mahogany trees at the forest's edge and interior based on all rings from pith to bark (I, standard error)

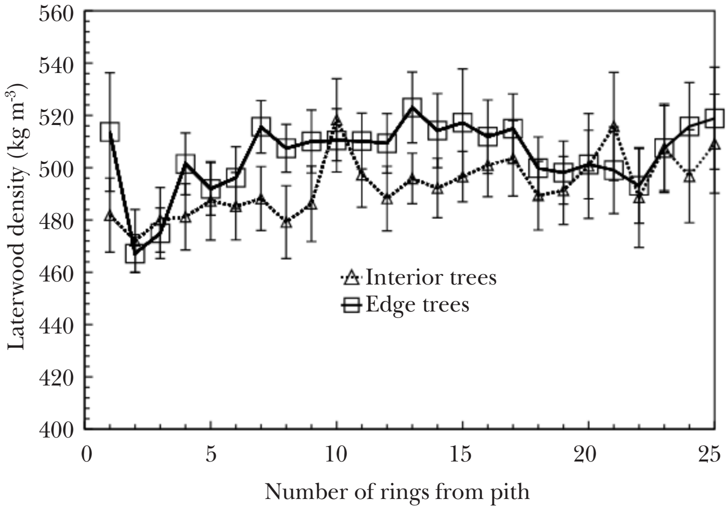

Figure 7 Radial variations in latewood density of mahogany trees at the forest's edge and interior based on all rings from pith to bark (I, standard error)

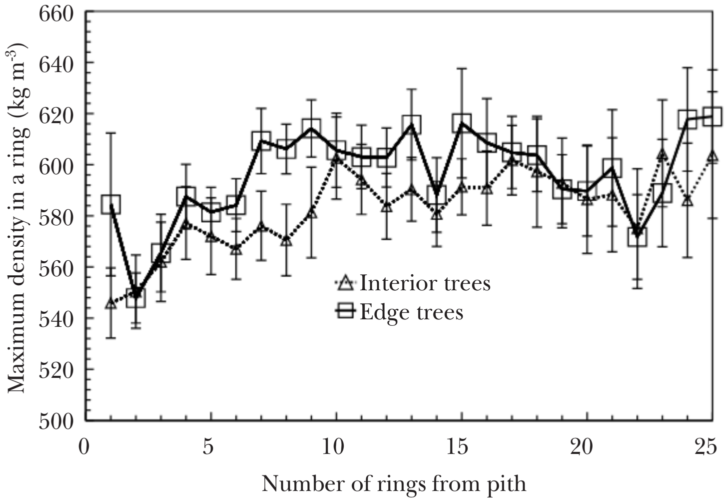

Figure 8 Radial variations in maximum density in a ring of mahogany trees at the forest's edge and interior based on all rings from pith to bark (I, standard error)

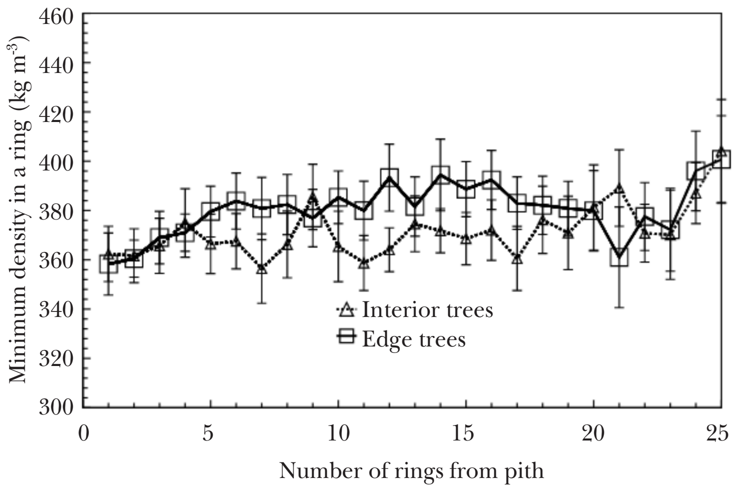

Figure 9 Radial variations in minimum density in a ring of mahogany trees at the forest's edge and interior based on all rings from pith to bark (I, standard error)

The results are presented in Table 3, and it is evident that there were significant differences in the RD components between trees at the forest's edge and in the forest interior. The t-test analysis revealed that the average RD components of trees at the forest's edge were significantly larger than those of trees in the forest interior. Therefore, it can be concluded that Ring B specimens of trees located at the forest's edge exhibited greater ring density than those in the forest interior.

Latewood percentage (LWP)

A t-test was conducted to analyse the differences in average LWP between the sampled trees located at the forest's edge and in the forest interior. The results, presented in Table 1, indicated that there were no significant differences in LWP observed between the trees at the forest's edge and those in the forest interior.

The radial direction change in the LWP of mahogany trees are presented in Figure 10, which demonstrated irregular fluctuations and a slight increase from the pith outward to the bark. T-tests were conducted to examine differences in the average LWP based on all ring numbers, as well as Rings A, B and C specimens, between the sampled trees at the forest's edge and in the interior. The results, presented in Tables 1–4, indicated that no significant differences in LWP were observed between trees at the forest's edge and in the interior.

Relationships among ring characteristics

Tables 5 and 6 display the Pearson correlation coefficients (r) for ring components sampled from both the forest's edge and interior. The most significant factors in determining the overall ring width were the earlywood and latewood widths, with correlation coefficients (r) of 0.75 and 0.73, respectively, regardless of the tree's origin. Additionally, ED, LD, Dmax and Dmin vales in a ring had high correlation values ranging from 0.88 to 0.92, 0.88 to 0.90, 0.81 to 0.82 and 0.79 to 0.81, respectively, and were the most crucial elements in evaluating overall ring density. However, the relationships between ring width and ring density were weak, regardless of whether the trees were from the forest edge or interior.

DISCUSSION

In this experiment, it was found that the average ring width of 25-year-old mahogany trees was higher (7.38-8.93 mm, as shown in Table 1) compared to that of 30-year-old trees reported in a previous study (4.85 mm, Lin et al. 2012). Another study reported the mean ring width of mahogany plantation trees as 3.49 mm (Dünisch et al. 2003). Additionally, the average ring density of the mahogany trees in this study was 466–480 kg m^{-3} (Table 1), which was lower than the value of 525.0 kg m^{-3}, was reported by Lin et al. (2012). The wood densities (at 12% moisture

Table 5 Pearson correlation coefficients between ring characteristics of mahogany trees in the forest interior (N = 20)

	RW	EW	LW	RD	ED	LD	Dmax	Dmin	LWP
RW	1.00	0.75**	0.73**	-0.18**	-0.06	-0.21**	-0.12*	-0.13**	-0.06
EW		1.00	0.17**	-0.27**	-0.07	-0.14**	-0.16**	-0.19**	-0.65**
LW			1.00	0.00	-0.02	-0.22**	-0.02	-0.02	0.59**
RD				1.00	0.88**	0.90**	0.82**	0.79**	0.20**
ED					1.00	0.75**	0.67**	0.88**	-0.00
LD						1.00	0.84**	0.65**	-0.07
Dmax							1.00	0.54**	0.10*
Dmin								1.00	0.10*
LWP									1.00

EW = earlywood width, LW = latewood width, RW = ring width, ED = earlywood density, LD = latewood density, RD = ring density, Dmin = minimum density in a ring, Dmax = maximum density in a ring, LWP = latewood percentage; * and ** indicate significance at 5 and 1% level by F-test

Table 6 Pearson correlation coefficients between ring characteristics of mahogany trees at the forest's edge (N = 20)

	RW	EW	LW	RD	ED	LD	Dmax	Dmin	LWP
RW	1.00	0.75**	0.73**	0.00	0.08	-0.02	0.11*	-0.04	-0.07
EW		1.00	0.16**	-0.17**	-0.02	-0.01	-0.00	-0.18**	-0.67**
LW			1.00	0.18**	0.15**	-0.05	0.14**	0.12**	0.58**
RD				1.00	0.92**	0.88**	0.81**	0.81**	0.27**
ED					1.00	0.77**	0.71**	0.84**	0.11*
LD						1.00	0.86**	0.66**	-0.02
Dmax							1.00	0.55**	0.11*
Dmin								1.00	0.23**
LWP									1.00

EW = earlywood width, LW = latewood width, RW = ring width, ED = earlywood density, LD = latewood density, RD = ring density, Dmin = minimum density in a ring, Dmax = maximum density in a ring, LWP = latewood percentage; * and ** indicate significance at 5 and 1% level by F-test

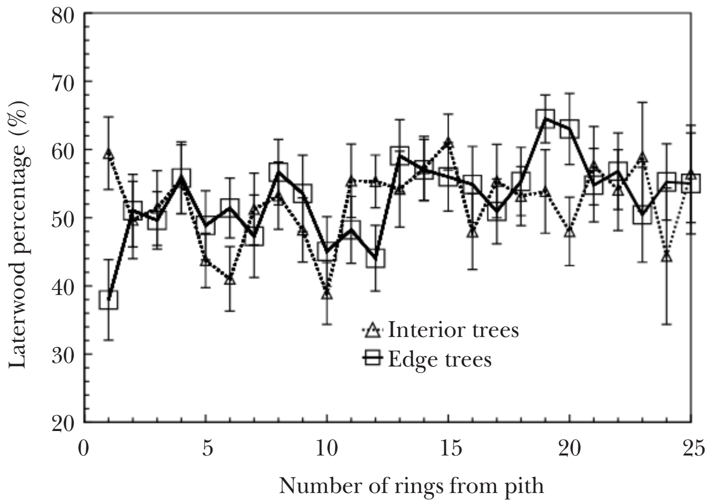

Figure 10 Radial variations in latewood percentage in a ring of mahogany trees at the forest's edge and interior based on all rings from pith to bark (I, standard error)

content) of mahogany plantation trees reported in previous studies ranged from 472–549 kg m^{-3} (Francis 2003, Moya & Muñoz 2010, Langbour et al. 2011). In contrast, another study reported that the air-dried xylem density of 8-year-old mahogany trees in the Philippines ranged from 580–610 kg m^{-3} (Gilbero et al., 2019).

The study found that tree specimens growing at the forest's edge exhibited greater growth and ring density compared to those growing in the forest interior, as shown in Table 1. This observation suggests that trees grown in relatively open spaces have wider annual ring widths. This finding is consistent with the assertion that edge effects can significantly influence growth rates for some species, thereby affecting forest community dynamics (McDonald & Urban 2004). Solar radiation increases near the forest edge due to the reduction in canopy closure, allowing more light to enter the forest compared to the interior, which may explain the wider ring widths of edge-grown trees (Dignan & Bren 2003). Forest edge effects promote significant microclimate shifts that result in greater light exposure, increased air temperature and evapotranspiration rates, and reduced soil moisture, altering stem hydraulic conductivity (Silva da Costa et al. 2020). These abiotic changes can have complex effects that should be considered in forest management and conservation planning.

The most significant load on a tree is created by wind, precipitation or the weight of the crown itself, as suggested by Mattheck and Breloer (2003). These loads can introduce bending stresses near the periphery of the stem, which may either balance or reinforce the tree structure. The values of tree growth and wood density may increase with an increased wind load or external force, indicating that wind, rain and crown weight could induce the growth of reaction wood in trees. As a result, wider annual ring widths and higher ring densities may be observed in mahogany trees in the experimental region. These findings were consistent with the idea that mechanical stresses can stimulate the formation of reaction wood in some tree species (Mattheck & Breloer 2003), which can lead to changes in wood properties.

In general, natural forest trees grow more slowly than those in artificial forests due to higher density and competition in natural forests compared to the growth conditions of artificial forests. The wood density of mahogany trees in artificial forests was found to be significantly lower than that of trees in natural forests, making wood density an ecological indicator (Langbour et al. 2011). Observations of natural mahogany forests indicate that forest management can reduce tree growth rate to improve wood quality for the forestry industry (Mayhew & Newton 1998). The growth and wood quality of mahogany trees in artificial forests are affected by their location and climate, thus requiring an understanding of different growing conditions to explain variations in tree growth rate and wood performance. Tropical tree species planted at the forest edge are affected by edge effects, mainly because wood shifts to produce more axial parenchyma cells (Silva da Costa et al. 2020). However, further analysis is needed to explain variations in cell tissue growth and size, length, woodiness and quality caused by increased wood growth in trees growing at the forest edge.

Variations in radial patterns in trees are due to the presence of juvenile wood and its relative proportion to mature wood (Zobel & Sprague 1998). Juvenile wood undergoes rapid changes, while mature wood is relatively constant in its growth, and its properties reflect the growth of the tree. The transition between mature and juvenile wood creates a distinct two-stage variation pattern in radial width, with an undefined wood region in between, known as the transition zone, resulting in a distinct three-stage variation pattern. Various standards and methods exist for determining the juvenile period, such as a radial width that decreases from the pith outward for a specific number of years and then remains mostly constant (Haygreen & Bowyer 1982, Zobel & Sprague 1998). Typically, researchers consider the first 5–20 growth rings to be dominated by juvenile wood (Haygreen & Bowyer 1982).

The boundary between juvenile and mature wood in the stem of mahogany tree was reported by Cho and Chang (2014) to be at the 20^{th} growth ring from the pith, where the elongation rate of fibre cell length change decreased to 1%. In this study, the boundary was visually determined by interpreting the graphic radial change in radial width to be approximately the 8^{th} to 20^{th} ring region from the pith (Figure 2), consistent with the general understanding that the first 5–20 growth rings are dominated by juvenile wood (Haygreen & Bowyer 1982). Furthermore, the radial width decreased from the pith to the bark, which was in agreement with previous research findings (Lin et al. 2012).

In this study, the radial pattern of tree ring density showed a gradual increase from the center (pith) towards the outer layer (bark). The wood with higher tree ring densities was typically found towards the bark side, which is associated with mature wood. On the other hand, the wood closer to the pith area had lower densities and is usually considered as juvenile wood. For many diffuse porous hardwoods, there is only a moderate relationship between tree age and wood density, but generally, the middle to high wood density diffuse porous hardwoods follow a pattern of low wood density near the pith area, followed by a gradual increase, and then a leveling off toward the bark side (Zobel & van Buijtenen 1989, Mayhew & Newton 1998, Zobel & Sprague 1998, Montes et al. 2007, Anoop et al. 2014). Tree growth is accompanied by an increase in structural demands, which can be met by producing denser wood each year (Montes et al. 2007). Trees respond to continuous growth by producing secondary xylem and reaction wood with higher wood density in order to enhance their structural integrity, and it is normal for wood density to increase radially (de Castro et al. 1993).

Initial assumptions suggested that faster tree growth may lead to lower wood density.

However, this study revealed a weak negative correlation between radial growth and wood density, indicating that the growth rate of mahogany plantation trees at Xinhua Forest Farm is unlikely to significantly affect wood density. Previous studies have found a positive correlation between growth rate and wood density in mahogany trees, but no specific relationship between tree dimension and wood density was found (Zobel & van Buijtenen 1989). For diffuse porous hardwoods, the correlation between growth rate and wood density can vary depending on multiple factors such as species, site conditions, management practices, tree age and height (Zobel & van Buijtenen 1989, Zobel & Jett 1995, Saranpaa 2003). It is important to note that trees can exhibit complex results influenced by multiple factors, and further research is necessary to explore the underlying reasons and mechanisms.

Both *Pinus taeda* and *Liriodendron tulipifera* showed significant growth rate increases within 5 meters of the forest edge, but edges accounted for a smaller proportion of the variability in growth rates compared to soil texture, nutrients and topographic factors (McDonald & Urban 2004). In forests, trees compete for sunlight, water and nutrients. This competition leads to various strategies for survival, including growing taller and straighter or developing specialised roots. At the forest edge, competition for resources is reduced, allowing trees to grow more freely. However, they may also be exposed to environmental stressors such as wind, frost and drought.

CONCLUSIONS

In general, trees growing on the forest edge exhibited greater growth rates and ring densities than those growing within the interior of the forest. In the radial direction, the ring width components showed a decreasing trend from the pith to the 7th ring (Ring A), followed by a gradual decrease until the 20th ring (Ring B). Thereafter, the components remained almost constant towards the outer layer (Ring C). Conversely, the ring density components demonstrated an increasing trend from the pith towards the bark in the radial direction. The observed patterns of the various components differed along the radial direction of the tree. Trees at the forest's edge exhibited greater growth in Rings B and C compared to those in the forest interior, while there was no significant difference in Ring A. There was no significant difference in ring density between Rings A and C specimens of trees at the forest's edge and those in the forest interior, but Ring B tree specimens of trees at the forest's edge had higher density than those in the forest interior. The correlation between RW and RD was weak, suggesting that the growth rates of mahogany trees may not have a significant effect on wood density.

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REFERENCES

Alteyrac J, Cloutier A, Ung CH & Zhang SY. 2006. Mechanical properties in relation to selected wood characteristics of black spruce. *Wood and Fiber Science* 38: 229–237.

Anoop EV, Jijeesh CM, Sindhumathi CR & Jayasree CE. 2014. Wood physical, anatomical and mechanical properties of big leaf mahogany (*Swietenia macrophylla* Roxb) a potential exotic for South India. *Research Journal of Agriculture and Forestry Sciences* 2: 7–13.

Cienciala E, Mellander PE, JiÍí Kucera J, Opluštilová M, Ottosson-Löfvenius M & Bishopet K. 2002. The effect of a north-facing forest edge on tree water use in a boreal Scots pine stand. *Canada Journal Forest Research* 32: 693–702. https://dx.doi.org/10.1139/x02-013.

Cho CL & Chang CY .2014. Variations of growth ring characteristics and wood fiber length of 30-year-old domestic plantation big-leaf mahogany. *Forest Products Industries* 33: 71–78. (in Chinese) https://dx.doi.org/10.6561/FPI.2014.33(2).2.

Dignan P & Bren L. 2003. Modeling light penetration edge effects for stream buffer design in mountain ash forest in southeastern Australia. *Forest Ecology and Management* 179: 95–106. https://dx.doi.org/10.1016/S0378-1127(02)00491-7.

de Castro F, Williamson GB & de Jesus RM. 1993. Radial variation in the wood specific gravity of Joannesia princeps: The roles of age and diameter. *Biotropica* 25: 176–182. https://dx.doi.org/10.2307/2389181.

Dünisch O, MontÓia VR & Bauch J. 2003. Dendroecological investigations on *Swietenia macrophylla* King and Cedrela odorata L. (Meiaceae) in the central Amazon. *Trees* 17: 244–250. https://dx.doi.org/10.1007/s00468-002-0230-2.

Francis JK. 2003. Wood densities of mahoganies in Puerto Rican plantation. *Big-Leaf Mahogany: Genetics, Ecology, and Management* 159: 358–361. https://dx.doi.org/10.1007/0-387-21778-9_18.

Gilbero DM, Abasolo WP, Matsuo-Ueda M & Yamamoto H. 2019. Surface growth stress and wood properties of 8-year-old planted Big-leaf mahogany *(Swietenia macrophylla* King) from different landrace provenances and trial sites in the Philippines. *Journal of Wood Science* 65: 35. https://dx.doi.org/10.1186/s10086-019-1814-4.

Grogan J, Landis MR, Ashton MS & GalvÃo J. 2005. Growth response by big-leaf mahogany (*Swietenia macrophylla*) advance seedling regeneration to overhead canopy release in southeast Pará, Brazil. *Forest Ecology and Management* 204: 399–412. https://dx.doi.org/10.1016/j.foreco.2004.09.013.

Haygreen JG & Bowyer JL. 1982. *Forest Products and Wood Science : An Introduction*. The Iowa State University Press, Iowa.

Langbour P, GÉrard J, Roda JM, Fauzi PA & Guibal D. 2011. Comparison of wood properties of planted big-leaf mahogany (*Swietenia macrophylla*) in Martinique island with naturally grown mahogany from Brazil, Mexico and Peru. *Journal of Tropical Forest Science* 23: 252–259.

Lin CJ, Chung CH & Lin ST. 2011. Ring characteristics and withdrawal resistance of naturally regenerated *Chamaecyparis obtuse* var. *formosana* trees. *Journal of Wood Science* 57: 352–362. https://dx.doi.org/10.1007/s10086-011-1184-z.

Lin CJ, Lin ST & Chung CH. 2010. Tree ring and wood quality of naturally regenerated *Chamaecyparis obtuse* var. *formosana* stand in Chi Lan-Shan. *Quarterly Journal of Chinese Forestry* 43: 131–141 (in Chinese). https://dx.doi.org/10.30064/QJCF.201003.0009.

Lin CJ, Chung CH, Cho CL & Yang TH. 2012. Tree ring characteristics of 30-year-old *Swietenia macrophylla* plantation trees. *Wood and Fiber Science* 44: 202–213.

Mattheck C & Breloer H. 2003. *The Body Language of Trees: A Handbook For Failure Analysis.* HMSO Publications, London.

Mayhew JE & Newton AC .1998. *The Silviculture of Mahogany* (*Swietenia macrophylla*). CAB International, Wallingford.

McDonald RI & Urban DL. 2004. Forest edges and tree growth rates in the North Carolina piedmont. *Ecology* 85: 2258–2266. https://dx.doi.org/10.1890/03-0313.

Montes CS, HernÁndez RE & Beaulieu J. 2007. Radial variation in wood density and correlations with growth of *Calycophyllum spruceanum* at an early age in the Peruvian Amazon. *Wood and Fiber Science* 39: 377–387.

Moya R & Munˇoz F. 2010. Physical and mechanical properties of eight fast-growing plantation species in Costa Rica. *Journal of Tropical Forest Science* 22: 317–328.

QMS (Quintek Measurement Systems). 1999. *QMS Tree Ring Analyzer Users Guide Model QTRS-01X.* Quintek Measurement Systems, Knoxville, TN.

SaranpÄÄ P. 2003. Wood density and growth. Pp 87–117 in Barnett JR and Jeronimidis G (eds) *Wood Quality and Its Biological Basis.* Blackwell Publishing Ltd., CRC Press, London.

Silva da Costa W, Da Cunha M, José F. Pena Rodrigues P, de Andrade Iguatemy M, Valladares F & Franca Barros C. 2020. Intraspecific variation in functional wood anatomy of tropical trees caused by effects of forest edge. *Forest Ecology and Management* 473: 118305. https://dx.doi.org/10.1016/j.foreco.2020.118305.

Verissimo A, Barreo P, Tarifa R & Uhl C. 1995. Extraction of a high-value natural rsource from Amazon: the case of mahogany. *Forest Ecology and Management* 72: 39–60. https://dx.doi.org/10.1016/0378-1127(94)03432-V.

Zobel BJ & Jett JB. 1995. *Genetics of Wood Production.* Springer-Verlag Berlin and Heidelberg, Berlin.

Zobel BJ & Sprague JR. 1998. *Juvenile Wood in Forest Trees.* Springer-Verlag Berlin and Heidelberg, Berlin.

Zobel BJ & van Buijtenen JP. 1989. *Wood Variation: Its Causes and Control.* Springer-Verlag Berlin and Heidelberg, Berlin.

