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Evaluation of Bent Trees in Juvenile Teak (*Tectona grandis* L.f.) Plantations in Costa Rica: Effects on Tree Morphology and Wood Properties

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Academic Editors: Phillip G. Comeau and Timothy A. Martin

Received: 26 November 2016; Accepted: 11 March 2017; Published: 14 March 2017

Abstract: Bent trees have been observed during the early years in juvenile plantations (less than 5 years-old) of *Tectona grandis* in Costa Rica. The relationship between bending and the morphological characteristics of the trees was explored. An evaluation of bent trees was conducted in six juvenile plantations (8, 17, 27, 28, 31, and 54 months old) of *Tectona grandis*. Site 1 with 8-month-old plantations did not display any relationship with any tree morphological variable (diameter, height, and crown weight of tree), whereas for the sites 2, 3, and 4 with 17-, 27-, and 28-month-old plantations, respectively, all the tree morphological variables were statistically correlated with the bent trees. A multiple regression analysis showed that the most influential variables were height to crown base, crown weight, diameter, and total height of the tree. An evaluation of the bending risk factor (RF) was correlated with the height to crown base, crown weight, and form factor. The modulus of elasticity and chemical compositions of bent trees differed from those of straight trees. The causes of tree bending are complex, involving, among other factors, the morphology of the trees, plantation conditions, and other factors specific to the xylem, such as the specific gravity, modulus of elasticity, and presence of calcium and magnesium in the wood.

Keywords: bent trees; tropical species; tree stability; wood; tropical wood

1. Introduction

Tectona grandis is widely used for reforestation in the tropical regions of America, Asia, and Africa [1]. The estimated planted area of this species is approximately 4.35 million hectares, and it is distributed in 52 different tropical countries [1]. Teak wood is well known in international markets for its natural resistance to fungal attack, excellent mechanical characteristics, and exceptional esthetical properties [2]. Teak, mahogany (*Swietenia* spp.), and red cedar (*Cedrela odorata*) are the tropical hardwoods with the greatest demand in the high-end market [3]. Currently, teakwood comes from fast-growing clonal plantations and is intensively managed with shorter rotations [1].

The teak silvicultural package has been undergoing important improvements in recent years in Latin America. Increasing initial spacing from 3 m × 3 m to 3 m × 4 m [4], together with the use of better genetic materials, results in a reduction in crop rotation to less than 30 years [5]. Tree development during the first years is affected by plantation stocking and influenced by the initial tree spacing [6], which determines site occupancy, and tree selection for final harvest [7]. A high initial density promotes a faster height growth [8], but restricts the diameter growth rate [7].

The height/diameter ratio is important in plantation management in order to maintain the verticality and stability of trees [9–11]. The susceptibility of trees to bending, crown breakage, or uprooting is one of the main problems associated with tree stability in teak and other species [12]. The presence of strong winds or storms can hinder the quality of plantation trees [12,13]. However, tree stability can also be related to the species, climate, topography, altitude, wind exposure, soil properties, stand structure, and tree morphology [14,15].

Tree bending, uprooting, or breaking in plantations can also be influenced by silvicultural management practices. For example, a high stand density results in smaller diameter growth, a higher diameter/height ratio, smaller crown size, higher tree mortality, and higher form factor [16]. It has also been reported [12,17] that tree morphology may affect resistance to uprooting (tree root system toppling).

Specific studies in bending trees were reported by Moore [18], who studied the resistive bending in *Pinus radiata* and found that bending was significantly and positively correlated with tree height, diameter, and stem volume. The study also found that trees with higher taper (lower ratio of tree height to diameter) exhibited a higher maximum resistive bending. In this species, bending trees show a larger production of resin bags in wood [19].

Bending can also affect some wood properties. Van Gelder et al. [20] found that the wood density of tropical trees was strongly positively related to wood strength and stiffness. The species safety factor for buckling has also been positively related to wood density and stiffness. In contrast, Anten and Schieving [21] found that trees with low wood density need to produce thicker stems, but at the same time, they need to invest less biomass per unit of stem length.

With the exception of eucalyptus species—which have been the focus of some studies—studies on tree bending, breaking, and uprooting in tropical species plantations remain scarce [6,22]. There are only two studies on *Tectona grandis* that report on tree bending under plantation conditions. Monteuuis et al. [23] and Chaix et al. [24] report that bending is 50% hereditary in plantations with seedlings between 49 and 106 months old. Although it was found that bending is not significant in clonal plantations less than 49 months old, it is significant at ages between 49 and 106 months old. However, although there are two reports on bending, studies in *T. grandis* are still scarce.

Tree bending and stem breaking have been observed in juvenile teak plantations in Costa Rica, with its consequent negative impact on growth and the returns of investors [25]. Tree shape and development during its first years are probably influenced by climatic conditions in Costa Rica [26]. The initial height growth rate in teak follows a faster pattern than diameter, which can cause the trees to bend as expected. In addition, this growth dynamic can affect other intrinsic wood properties in trees, such as the specific gravity and mechanical properties.

Given the described situation, the aim of this study was to investigate the incidence of bending and the height at which the damage begins in six different sites for juvenile plantations of *Tectona grandis* (8 to 54 months old) in Costa Rica. Additionally, the relationship between bending and tree characteristics (diameter, height, and crown weight) was analyzed. Destructive sampling was performed in Site 6 with a 54-month-old plantation to determine the influence of mechanical and wood density properties and to examine the nutrient content in the trunks of the bent trees. Based on this information, aspects that influence tree bending, such as tree characteristics, wood properties, or nutrient content, were identified, with the aim of contributing towards the understanding of how to handle bending in juvenile plantations of *T. grandis*.

2. Materials and Methods

2.1. Studied Plantations

Six juvenile *T. grandis* plantations planted in six different sites in the Southern Pacific region of Costa Rica were studied. All six plantations exhibited important evidence and a high percentage of bending trees (Figure 1a). Ages ranged between 8 and 54 months (0.67 to 4.15 years old), located in four sectors: plantations in Site 2 and 6 (17- and 54-month-old) are in separate sectors; the plantations in Site 1 and 3 (8- and 27-month-old) are both in the same sector and are close to the plantation in

Site 2, and plantations in Site 5 and 6 (28- and 31-month-old) are in a same area or site (Figure 1a). The six juvenile *T. grandis* plantations were established with seedlings. The plantations belong to the BARCA S.A. forestry company. Climatic, topographic, and wind conditions are detailed in Table 1.

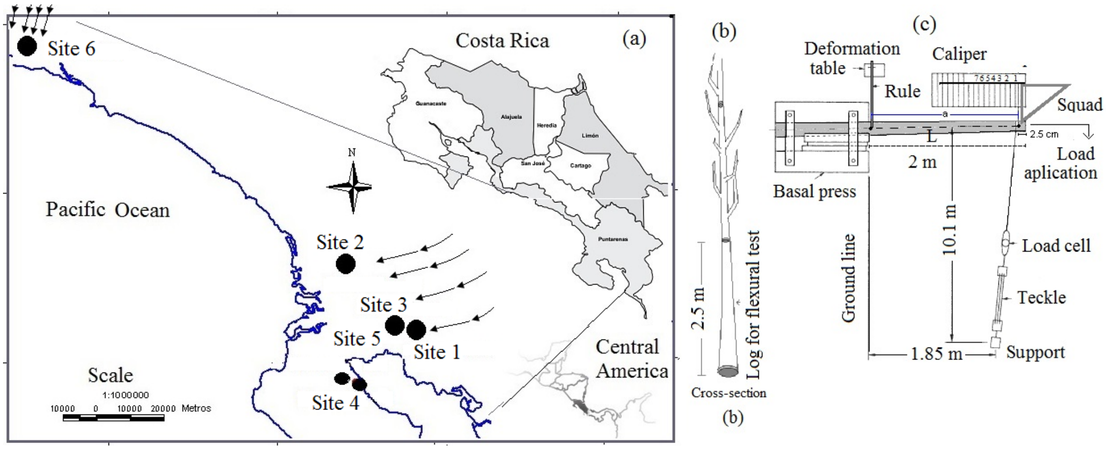

Figure 1. Geographic localization of sampled plantations with tree bending problems in southern Costa Rica indicating the wind direction in the site where the plantation was sampled. (**a**) Log extracted from sample tree for modulus of elasticity (MOE) determination; (**b**) Diagram of the static bending tests of poles; (**c**) the Cantilever Test Method was employed to measure the MOE.

Table 1. Site description and climatic conditions of the sampled plantations in the study of tree bending in *Tectona grandis* in the Southern Pacific region of Costa Rica.

Site and Tree Age	Soil Description	Elevation and Life Zone	Description of Topography and Climate
Site 6, 54-month-old	Soils are characterized by having little development of horizons.	100 meters above sea level and tropical moist forest with transition to per-humid	The topography is flat. Average precipitation varies from 3000 to 3200 mm per year. The rainiest months are September and October.
Site 1 and 3, 8- and 27- month-old	Soils are characterized by having little development of horizons.	100 meters above sea level and basal tropical wet forest.	The topography is flat. Annual rainfall is 4852 mm. Most rainfall occurs in September and October.
Site 2, 17-month-old	Soils are characterized by clay presence, with less than 35% base saturation, generally deep and well drained with relatively low fertility.	200 meters above sea level and basal tropical wet forest.	The topography is rugged in some sectors and in others is flat. The annual average rainfall is 4000 mm, with an average of three dry months from January to March.
Site 4 and 6, 28- and 31- month-old	Soil is younger, with a second horizon.	0 meters above sea level and basal tropical wet forest.	The topography is flat. The annual average rainfall is 4000 mm. The rainfall is concentrated from May to November.

2.2. Sampling Procedures

The sampled plantations ranged from 7.3 to 113.2 hectares (Table 2), and the incidence of tree bending was assessed in the whole plantation. For this study population, sample percentage varied from 15.2% to 19.1% per plantation. Table 2 shows the sample intensity in detail. Systematic sampling was used, and rectangular plots that were 10 m wide × 50 m long and continuously distributed along transects were established. The location of the first transect was randomly selected to avoid subjectivity. From this starting point, the remaining sampling transects or strips were placed systematically every 50 m.

Table 2. General information and sampling intensity used for the tree bending study in juvenile *Tectona grandis* plantations in southern Pacific of Costa Rica.

Site	Age and Plantation	Total Area (ha)	Plantation Density ($n \cdot ha^{-1}$)	Sampled Area (ha)	Number of Plots (n)	Sampling Intensity %
1	8-month-old	35.8	932	6.8	115	19.1
2	17-month-old	113.2	939	19.1	31	16.9
3	27-month-old	24.5	897	4.7	94	19.2
4	28-month-old	7.3	935	1.1	34	15.2
5	31-month-old	35.5	944	6.2	26	17.6
6	54-month-old	32.4	432	5.8	22	17.8

Note: Sampling intensity corresponds to the total area of sampling plots (with 10 m by 50 m in each) related to the total planted area.

2.3. Information Collected

The following variables were measured for each tree within the sampling plots: diameter at 1.3 m above the ground (*d*) with a diameter band meter, total height (*Ht*), height at crown base (*Hcb*), and bending height (*Hb*). These heights were measured using a telescoping height meter. This last variable corresponds to the distance from the ground up to the point at which the tree loses its verticality and starts to bend. It was measured using a meter stick or a telescopic pole. For bent trees, the cardinal bending orientation was recorded. Bent trees were classified into three different types, and one class was added, which corresponded to broken trees:

- Class 1: no bending observed (Figure 2a).
- Class 2: partial damage; estimated bending was less than or equal to 30° (Figure 2b).
- Class 3: severe damage; estimated bending was above 30° (Figure 2c).
- Class 4: the tree is broken and has lost its crown (Figure 2d).

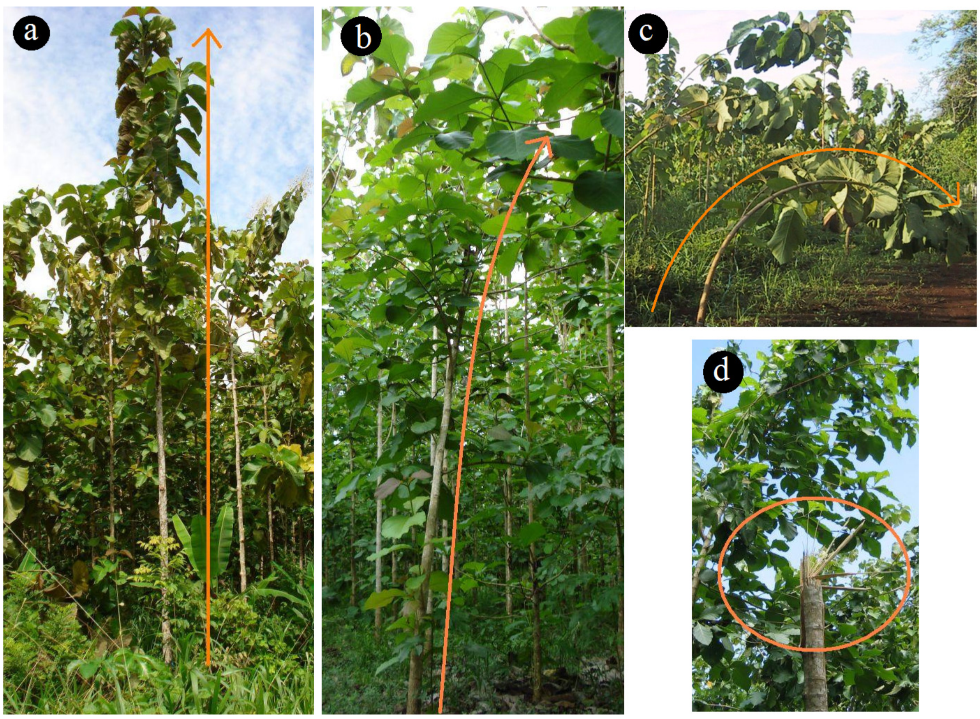

Figure 2. Bent tree classification according to bending damage for *Tectona grandis* plantations in Costa Rica: (**a**) straight trees; (**b**) partial bending; (**c**) severe bending; and (**d**) broken trees.

2.4. Analysis of Field Data

Several ratios were determined from field data: (i) the diameter/total height ratio (*d/Ht*); (ii) the height at crown base/total height ratio (*Hcb/Ht*); and (iii) the bending height/total height ratio (*Hb/Ht*). A Pearson correlation matrix was developed, where the bending heights of classes 2 and 3 from each sampled plantation were correlated against *d*, *Ht*, *Hcb*, *d/Ht* ratio, and *Hcb/Ht* ratio using a significance level of $\alpha = 0.05$. Forward stepwise multiple regression analysis was applied to determine which variables are significantly related to bending. In addition, an analysis of variance (ANOVA) was applied to determine likely differences among the morphological variables evaluated for classes 2, 3, and 4, and Tukey's multiple comparison test was used to estimate differences among plantations and bent class. The SAS 8.1 statistics program for Windows (SAS Institute Inc., Cary, NC, USA) was used to carry out the analyses.

2.5. Destructive Study in Site 6 (54-Month-Old Plantation)

Sampling: Site 6 was selected for more detailed analysis of the conditions that may explain causes of tree bending in juvenile plantations. In this plantation, 10 trees were randomly selected for each bending class (Classes 1, 2, and 3) from the total number of trees in the sampling plots (i.e., 30 trees were sampled for felling and their properties were measured). Class 4 was not considered in this analysis because the trees were broken.

Variables measured: After felling, the following variables were measured for each tree selected: the diameter at 1.3 m above the ground (*d*), total height (*Ht*), height at crown base (*Hcb*), and bending height (*Hb*). Then, each tree was cut at the lowest branch insertion point on the trunk (i.e., at the height at which the first branch at the base of the crown appears). The crown, trunk, branches, and leaves were weighed. These fresh weights were used to determine the live-crown weight (*Wc*), which included the crown, branches, and leaves. The trunk weight (*Wt*) free of branches was also determined. The tree information was used to determine the risk factor (RF) proposed by Jaquen et al. [27], which was then computed using Equations (1)–(3). RF measures the risk of stem bending (i.e., situations where buckling risk is a major ecological constraint, with a transition from self-supporting to liana habit for natural trees). Higher values indicate greater risk [27].

$$\text{Tree bending risk factor} = \frac{\text{Total tree height}}{\text{Critical buckling height}} \tag{1}$$

$$\text{Critical buckling height} = 0.792\left(\sqrt[3]{\frac{\text{Modulus of elasticity}}{\text{Total weight/Volume)}}}\right)^{\frac{1}{3}} \times \sqrt[3]{\text{Basal diameter}^2} \tag{2}$$

$$\text{Volume} = \pi \times \left(\frac{\text{Form factor}}{2}\right)^2 \times \text{Total tree heigt} \tag{3}$$

$$\text{Form factor} = \frac{d}{\text{Total tree heigth} - 1.3} \tag{4}$$

where total tree height is in m, the critical buckling height is in m, and the modulus of elasticity is in MPa. The coefficient of determination is indicated above, and the total weight is in kg, the volume is in m^3, and d is the diameter at 1.3 m above the ground in cm.

Wood properties: The specific gravity, modulus of elasticity, and inorganic composition of the trunk were determined for the 30 trees selected. Three 2.5-cm-thick cross-sections were cut from each tree trunk. The first cross-section was cut at the base of the trunk, the second at a height of 2.5 m, and the third at the upper part of the tree where the trunk diameter narrows to 2.5 cm. The first 2.5 m log cut from the base of the tree was utilized for the analysis of the modulus of elasticity (Figure 1b).

The discs were cut in half to remove the remains of the pith (in some cases, the parenchyma tissue residues are present in teak trees, which can alter the volume of the cross-section when it is measured by water immersion); then, the basic specific gravity was determined. The bark was removed on both sides of the discs. Then, they were polished to prevent bubble formation when measuring the volume by displacing water. Later, the samples were dried at 103 °C for 24 h to measure their dry weight. The moisture content was also determined for the discs from the three different heights by using the ASTM D-4442-92 standard [28]. The discs were previously fresh weighed and then kiln dried at 103 °C for 24 h.

To calculate the modulus of elasticity (MOE), the methodology proposed by the ASTM D-1036-99 [29] standard "Static bending tests of poles, Cantilever Test Method" was employed, as described in Figure 1c. This method was used because it measures the bending capacity of the trunk and it approaches the bending conditions of standing trees.

To determine deformation, loads ranging from 0 kg to 100 kg, at intervals of 10 kg, were applied to each log. The deformation of the table was measured for each calibration. Load vs. deformation values were plotted to establish the limit of proportionality (the wood stops being elastic to become plastic), and the values of load and deformation at that point were recorded. Based on this information, the *MOE* at the limit of proportionality was calculated using Equation (5).

$$MOE = \frac{661.467 \ * \ P\prime * a^3}{\delta_{PAC} * C_1^3 * C_2} \quad (5)$$

where *MOE* is the modulus of elasticity at the flexural point (kg/cm^2), P' is the applied load (kg), a is the span (m), δ_{PAC} is the deflection (mm), C_1 is the circumference of the log at the ground line (cm), and C_2 is the circumference at the point of load application (cm)

The inorganic composition of trunks was analyzed using the method described by Sparks [30]. Concentrations of nitrogen (N), phosphorus (P), calcium (Ca), magnesium (Mg), potassium (K), and sulfur (S), whose concentrations were reported as percentages, were determined. In addition, iron (Fe), manganese (Mn), cupper (Cu), zinc (Zn), and boron (B), whose concentrations were reported as milligrams of inorganic element per ash gram, were determined. For this analysis, only 9 of the 30 sampled trees were used, three per bending class, and only the trunk tissue was used. A section of the trunk (approximately 5 cm in each sampled tree) was milled. Then, all of the material from each class was mixed, and three samples were used to determine the inorganic composition.

The information obtained in this plantation was analyzed by an ANOVA for each wood property, morphological characteristic of the tree, or inorganic composition. The response variable was the bending class (1, 2, and 3), and the independent variables were the properties of wood, morphological characteristics of the tree, or inorganic compositions. Tukey's multiple range was used to estimate the differences between the averages of each class when the ANOVA test was significant.

3. Results

Although there are many uncontrolled factors during plantation development, such as soil fertility, wind intensity, and growth rate, a comparative study was carried out between the different sites to establish which factors affected the development of bending trees.

3.1. Morphological Characteristics of the Trees and Stand Density in Sampled Plantations

The morphological characteristics of *d*, *Ht*, and *Hcb*, showed significant increments for 17-, 27-, 31-, and 54-month-old plantations, Site 1, 2, 3, 4, 5, and 6, respectively. However, the 27- and 28-month-old plantations (Site 3 and 4) in all properties (Figure 3a–c) and plantations in Site 5 and 6 (31- and 54-month-old) in height to crown base were not significantly different (Figure 3c).

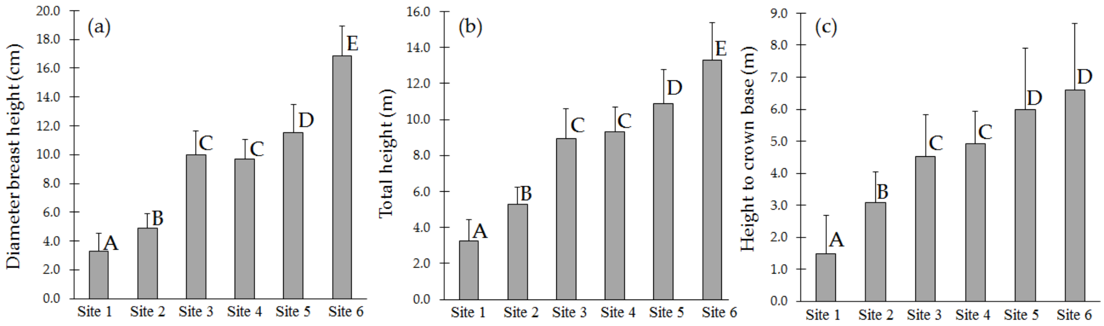

Figure 3. Variation of diameter (**a**); total height (**b**); and height to crown base (**c**) in trees growing in fast-growth plantations of *Tectona grandis* in Costa Rica. Note: the standard deviation and the average bar are presented. The letters next to these values indicate that the values are significantly different at a confidence level of 95% for morphological properties.

3.2. Incidence of Bent Trees and Bending Height

The evaluation of bent trees showed that the percentage of bent trees (Classes 2 and 3) increases with the age of the plantation, whereas the quantity of straight trees (Class 1) diminishes from 97.8% in the youngest plantation to 78% in the oldest plantations (Table 3). Although bending increases with age, no consistency was found regarding the increment of the classes of damage. Concerning Class 2, a reduction in the percentage of this type of damage in plantations in Site 4 and 5 occurred due to the increase in the percentage of Class 4 (trees with broken crowns). For Class 3 (severely damaged trees), the percentage decreased from 10.6% to 4.5% as the age of the plantation increased from Site 5 to Site 6 (Table 3).

Table 3. Percentage of trees per damage class in juvenile plantations of *Tectona grandis* in Costa Rica.

Plantation	Tree			
	Class 1	**Class 2**	**Class 3**	**Class 4**
Site 1	97.8 (±0.029)	0.6 (±0.015)	0.3 (±0.010)	1.3 (±0.022)
Site 2	93.2 (±0.054)	2.9 (±0.033)	1.8 (±0.026)	1.9 (±0.027)
Site 3	71.7 (±0.096)	11.9 (±0.069)	10.9 (±0.066)	3.7 (±0.040)
Site 4	77.3 (±0.082)	5.5 (±0.045)	9.4 (±0.057)	4.9 (±0.042)
Site 5	74.2 (±0.086)	5.8 (±0.046)	10.6 (±0.060)	7.7 (±0.053)
Site 6	78.0 (±0.088)	13.4 (±0.073)	4.5 (±0.044)	1.6 (±0.026)

Note: the standard deviation is presented in brackets. The plot measurements are provided in detail in Table 2.

The height to the start of bending increased with the age of the plantation for Classes 2, 3, and 4 (Figure 4a–c). For Class 2, the height varied from 0.8 to 6.5 m (Figure 4a), whereas for Class 3, the bending heights were lower, ranging from 0.3 to 5.7 m (Figure 4b). Class 4 trees (broken crown) (Figure 4c) presented a height of breaking point that was higher than the bending height of trees of Class 3 (Figure 4b). The relative height of bending trees shows that the different classes (2, 3, and 4) varied with Site (Figure 4d). Class 3 presents the lowest height percentages relative to the other damage classes (Figure 4d). For Classes 2 and 4, in plantation in Site 1, 2, 4, 5, and 6, the percentage ranges between 40% and 50% of the tree's total height.

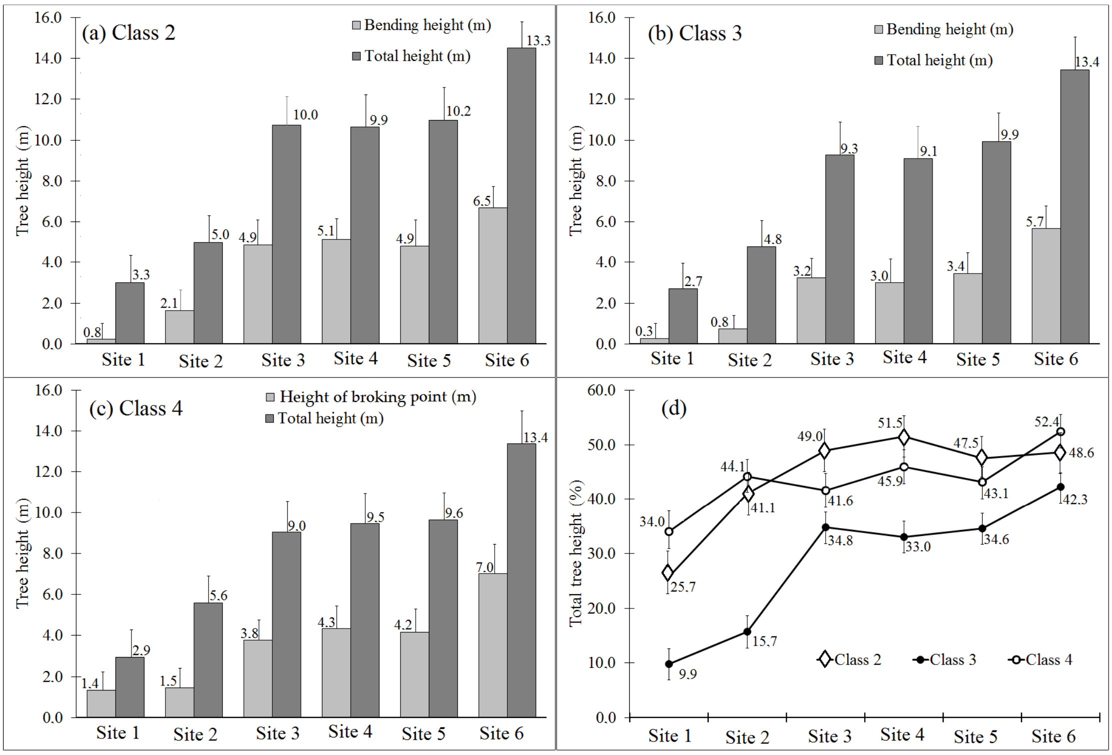

Figure 4. Total height and bending height for class 2 (**a**); class 3 (**b**); and height of breaking point in class 4 (**c**) of bending damage and percentage of the total tree height at which bending occurs (**d**) for plantations of *Tectona grandis* in Costa Rica. Note: the standard deviation and average bar are presented.

3.3. Relationship between the Morphological Characteristics and Bending Height

Relative to the morphological characteristics (*d*, *Ht*, *Hcb*, *d/Ht* ratio, and *Hcb/Ht* ratio) no relationship was found with the bending height (*Hb*) for the youngest plantation in Site 1; then, *Hb* did not increase or decrease for these morphological parameters. In contrast, all of the morphological variables were statistically correlated with *Hb* for the plantations in site 2, 3, and 4. Except for the *d/Ht* ratio, the variables were all positively correlated (Table 4), which means that *Hb* increases with an increase in the *d/Ht* ratio. The forward stepwise analysis showed that for these sites (2, 3, and 4), the height to crown base (*Hcb*) is the variable that influences bending the most. The final model explained from 29% to 49% of the variation of *Hb* (Table 5). The second most important variable in the variation of *Hb* for plantation in Site 3 and 4 is *Ht*, and it is the *Hcb/Ht* ratio for plantation in Site 3. Only *Hcb* influences the plantation in Site 2, and explains 47% of variation of *Hb* (Table 5).

Table 4. Pearson correlation matrix between the bending height (*Hb*) and the morphological variables of *Tectona grandis* in plantations of different ages.

Morphological Variable	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
n	11	74	750	154	212	446
d	0.38 ^{NS}	0.26 *	0.42 **	0.23 **	0.50 **	0.13 ^{NS}
Ht	0.41 ^{NS}	0.45 **	0.54 **	0.50 **	0.44 **	0.03 ^{NS}
Hcb	0.43 ^{NS}	0.66 **	0.54 **	0.63 **	0.62 **	0.37 **
d/Ht ratio	0.18 ^{NS}	−0.25 *	−0.20 **	−0.33 **	0.01 ^{NS}	0.09 ^{NS}
Hcb/Ht ratio	0.24 ^{NS}	0.46 **	0.28 **	0.52 **	0.53 **	0.31 **

Note: * coefficient of correlation significant at $p < 0.05$; **coefficient of correlation significant at $p < 0.01$; *n*: number of observation or number of pairs of scores; *d*: diameter at 1.3 m from the ground; *Ht:* total height; *Hcb*: height to crown base; *Hb*: bending height.

Table 5. Forward stepwise multiple regression analysis of the effect of the morphological variables (*d*, *Ht*, *Hcb*, *Hb*) on the bending height (*Hb*) for Classes 2 and 3 in *Tectona grandis* in plantations of different ages.

Morphological Variable	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
R^2 multiple	0.28	0.47	0.47	0.48	0.47	0.15
1st parameter	*Hcb* R^2 = 0.18 NS	*Hcb* R^2 = 0.43 **	*Hcb* R^2 = 0.29 **	*Hcb* R^2 = 0.39 **	*Hcb* R^2 = 0.39 **	*Hcb* R^2 = 0.13 **
2nd parameter	*Ht* R^2 = 0.10 NS	*Hcb/ht* ratio R^2 = 04 NS	*Ht* R^2 = 0.16 **	*Ht* R^2 = 0.08 **	*d* R^2 = 0.07 **	*d* R^2 = 0.01 NS
3rd parameter			*Hcb/ht* ratio R^2 = 0.02 **	D R^2 = 0.10 NS	*Hcb/ht* ratio R^2 = 0.01 NS	

Note: ** coefficient of correlation significant at $p < 0.01$; *n*: number of observation or number of pairs of scores; *d*: diameter at 1.3 m from the ground; *Ht:* total height; *Hcb*: height to crown base; *Hb*: bending height.

For the plantation in Site 5, according to the forward stepwise regression analysis, the most influential variables are *Hcb* and *d* (Table 5), explaining 39% and 7% of the variation of *Hb*, respectively. The variables correlated with *Hb* in the oldest plantation (Site 6 or 54 months old) were *Hcb* and the *Hcb*/*Ht* ratio (Table 4); in this plantation *Hb* increases with increases in *Hcb* and the *Hcb*/*Ht* ratio. *Hcb* accounted for 13% of the influence on the variation of *Hb* (Table 5).

3.4. Destructive Study in the Plantation Site 6 (54-Month-Old Plantation)

The evaluation of the tree bending risk factor (RF) showed no statistical correlation with *d* ($r = 0.19$; $p = 0.31$), *Ht* ($r = 0.15$; $p = 0.78$), *Wt* ($r = 0.09$; $p = 0.61$), Specify gravity *(SG)* ($r = 0.13$; $p = 0.11$), and *MOE* ($r = 0.02$; $p = 0.50$). However, RF positively correlated with *Hcb* and *Wc* (Figure 5b,c) and negatively correlated with *Hb* and form factor (Figure 5a,d).

The evaluation of the different morphological variables in the bending class (Figure 2) demonstrated that the bending class is negatively correlated with the *Hcb* ($r = -0.60$; $p < 0.0001$), positively correlated with *Wc* ($r = 0.47$; $p = 0.0067$), and positively correlated with *Hb* ($r = 0.57$; $p < 0.0001$), but *d* ($r = 0.19$; $p = 0.13$), Ht ($r = -0.15$; $p = 0.15$), and Wt ($r = 0.09$; $p = 0.67$) presented no effect on the bending class. Considering the significant variables (*Hcb*, *Wc*, and *Hb*) in the forward stepwise multiple regression analysis (Table 5), it was demonstrated that *Hcb* is again the most influential variable, accounting for 36% of the variation of the bending class, followed by *Wc* and *Ht*, explaining 7% and 9%, respectively.

The analysis of the different morphological characteristics, SG, MOE, and trunk chemistry showed that some of these properties vary between bending classes. The morphological variables *d* and *Ht* were not related to bending class (Table 6). However, *Hcb* decreased with the increase in the bending class, as opposed to *Wc*, which increases with greater damage class (Table 6) and is approximately 20% higher for *Hcb* and 20% lower for *Wc* in bent trees. Concerning the properties of the wood, specific gravity did not differ between the bending classes (Figure 6a), whereas MOE was 8% lower for bent trees (Classes 2 and 3) than for straight trees (Class 1) (Figure 6b). In relation to the nutrient contents in the trunk, the contents of Ca and Mg were significantly different in the different types of damage (Table 6). The Ca and Mg contents were approximately 30% higher in the bent trees (Classes 2 and 3) than in the straight trees (Class 1).

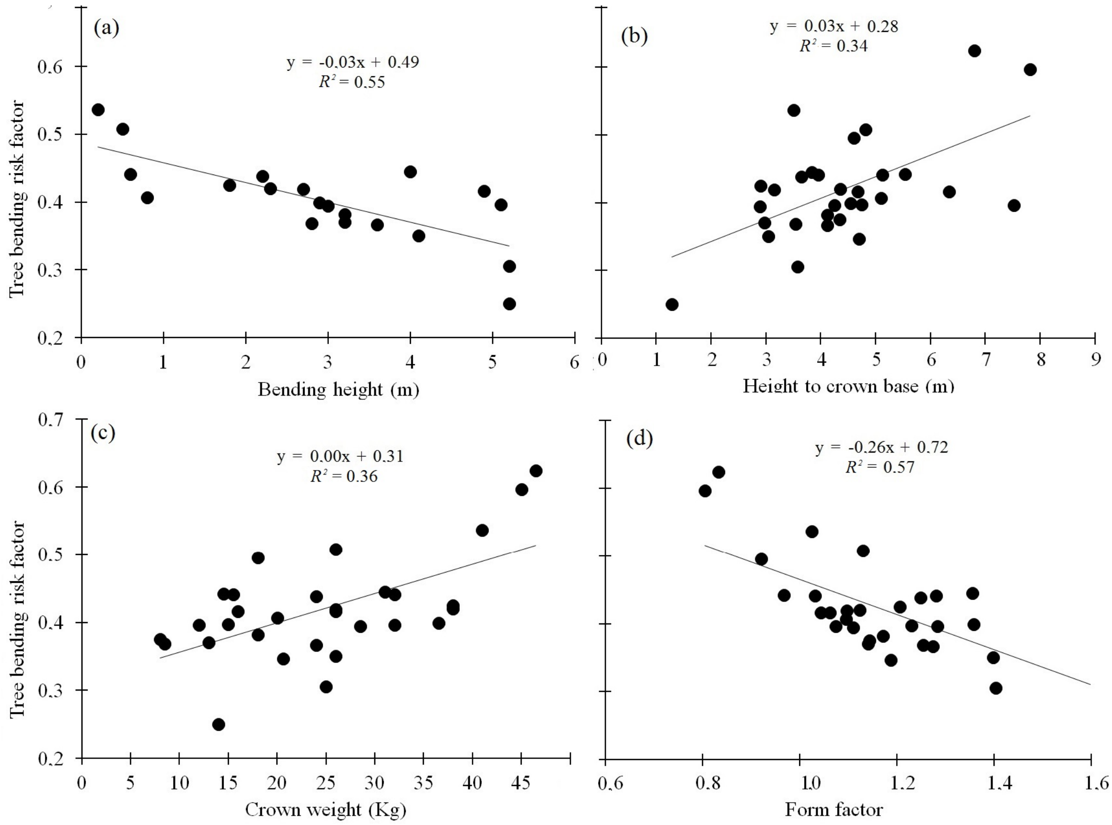

Figure 5. Correlation between tree bending risk factor and bending height (a), height to crown base (b), crown weight (c) and form factor (d) in Site 6, a 54-month-old plantation of *Tectona grandis* in Costa Rica.

Table 6. Average of the morphological characteristics and nutrient content in the trunk of bent trees in Site 6, a 54-month-old plantation of *Tectona grandis* in Costa Rica.

Variable	**Average**		
	Class 1	**Class 2**	**Class 3**
d (cm)	8.38 A	9.69 A	9.41 A
Ht (m)	9.26 A	9.91 A	9.16 A
Hcb (m)	5.59 A	4.02 B	3.58 C
Wc (kg)	15.10 A	23.25 B	27.85 C
N (%)	2.26 A	2.59 A	2.56 A
P (%)	0.16 A	0.23 A	0.22 A
Ca (%)	1.21 A	1.65 B	1.61 B
Mg (%)	0.09 A	0.22 B	0.15 B
K (%)	1.28 A	1.16 A	1.19 A
S (%)	0.15 A	0.16 A	0.16 A
Fe (mg/kg)	56.00 A	63.00 A	59.67 A
Cu (mg/kg)	13.33 A	16.00 A	14.00 A
Zn (mg/kg)	28.33 A	31.00 A	29.67 A
Mn (mg/kg)	23.00 A	33.67 A	35.00 A
B (mg/kg)	8.33 A	11.67 A	16.67 A

Legend: the letters next to these values indicate that the values are statistically different at a confidence level of 95% for different class bend. *d*: diameter at breast height (at 1.3 m height); *Ht:* total height; *Hcb:* height to crown base; *SF*: safety factor, *Hb*: bending height, and *Wc*: crown weight.

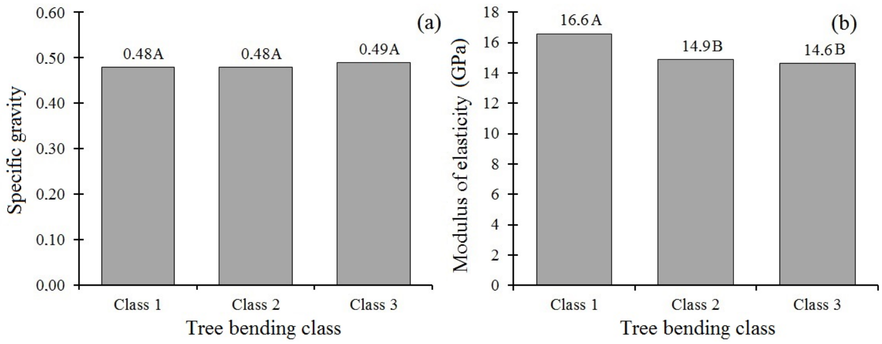

Figure 6. Specific gravity (a) and modulus of elasticity (b) for trees in Class 1, Class 2, and Class 3 bending damage in Site 6, a 54-month-old plantation of *Tectona grandis* in Costa Rica.

4. Discussion

DBH, height, height, and height to crown base ((Figure 3) increased as the age of the plantation increased [31]. Only the plantations that were between 27 and 28 months of age (plantations in Site 3 and 4) did not present differences, probably due to their similar ages. Growth values of the plantations sampled (Figure 3) are consistent with growth reported for *T. grandis* in Costa Rica [7,31,32]. Additionally, the low density of the 54-month-old plantation (the plantation in Site 6) is attributed to a 50% thinning conducted in the plantation 6 months before the bending analysis was carried out. However, care must be taken in considering the results, because there are many uncontrolled factors during plantation development, such as soil fertility, wind intensity, and growth rate. Then a comparative study was carried out between the different sites to establish which factors affected the development of bending trees.

The increase in the percentage of bent trees in Classes 2 and 3 with age of the plantation (Table 3) is the result of the decreasing number of straight trees (Class 1). As trees grow, the biomass added in the upper parts of the tree develops greater self-loading due to increased weight. Then, the biomass in the crown of trees and the presence of wind create flexural moments, generally at the base of the tree, which result in the bending of tree [33].

During the first years, the low branches [34] and low diameter growth in relation to the tree's height [7] prevent teak from having the morphological structure required to support the moments created by the wind against the biomass accumulated in the upper parts of the tree, which bends the stem without causing uprooting, as normally occurs with this species.

Thinning, which affects stand density, can reduce the incidence of bent trees because some bent trees are removed, resulting in a lower stand density [19]. However, it was not possible to confirm this situation in the teak plantations. The plantation in Site 6 (54-month-old) was thinned and therefore had a low density, but the incidence of tree bending was the highest (Figure 4a–c). This result indicated that the thinning was applied in the juvenile stage to reduce the stand density and that neither condition helped decrease the incidence of bent trees. The trees of this age probably have not yet developed a diameter that is able to withstand bending [35].

The forward stepwise regression analysis confirmed this because for all sites, *Hcb* has an impact on the *Hb* of the tree (Table 5) and on the bending class. Likewise, the study conducted in the plantation in Site 6 also confirms the effect of biomass accumulation on bent trees due to *Wc* (Table 5). In addition, as expected, important morphological characteristics (*Hcb*, *Wc*, and *Hb*) exert an influence on bending. Regarding the mechanical stability of the tree, increases in trunk bending with plantation age can be explained by the fact that the highest concentration of biomass and the distance of support of the tree (tree base embedded in the ground) produce a high moment value during wind events, creating an area of weakness in the trunk [35] where the tree bends.

From the perspective of stem quality for the future utilization of the logs, Class 3 is more critical compared to Class 2 because a greater bending of the log produces a lower lumber recovery factor (lumber volume production relative to the total log volume) [36,37]. Therefore, a higher percentage of Class 3 trees in plantations in Site 3, 4, and 5 (Table 3) means lower quality logs. It was observed, nevertheless, that the percentage of Class 3 trees decreased to 4.5% in plantations in which thinning had been applied, with a slight increase in both straight and bent trees in Class 2 (Table 3).

By comparing the results obtained regarding the number of straight trees with other studies, it becomes evident that they are within the range reported by Monteuuis et al. [23], who reports a wide range of percentages of straight trees (from 15% to 95%) for 42 provenances of 106-month-old teak in Sabah. However, according to these authors, the remaining bifurcated and bent trees were classified jointly; therefore, the percentage of bent trees was not established. Chaix et al. [24], in contrast, report a much lower range of percentages of bent trees for different provenances of teak in Sabah than the percentages found in the plantations analyzed in the present work.

As for the initial bending height, there is a positive correlation with increasing *Ht* (Figure 4). Moreover, consistent with the correlation analysis (Table 3) and the forward stepwise multiple regression (Table 4) of all of the plantations, the increasing *Hb* in most ages is related to increases in *Hcb*, followed by *Ht* in the plantations in Site 3 and 4 and *d* in the case of plantations in Site 5 and 6, with a slight influence from the ratio *Hcb*/*Ht* in the plantations in Site 3 and 4 (Table 4). Likewise, the specific analysis of the plantation in Site 6 confirms that *Hb* is linked both to the mentioned variables and to the *Wc* (Table 5).

The results found in teak trees agree with studies carried out by Moore [18] in *Pinus radiata*. He found that resistive bending was significantly and positively correlated with tree height, d, and stem volume, at a similar significance level to that found in teak in Costa Rica.

Mechanically explained, tree stability depends on the canopy as a lumped mass on a column [38] and the trunk as a weightless elastic column [39], modeling the stability of the tree as a series of *n* logs with lumped masses representing branch whorls along the trunk [40,41]. The strength of the wind impairs tree stability [13]. As the tree ages, *Hcb* and *Ht* increase [7,32], and the canopy weight and distance of support of the tree are also augmented, leading to tree bending as a result of the push of external factors, such as winds in the region.

An important aspect to highlight relative to the morphology of the tree that is not addressed in the present work on *T. grandis* is the resistance to bending or the mechanical stability of the tree [38]. Marked taper is considered an adaptive characteristic of the tree to resist the wind [38]; however, this characteristic is hardly noticeable during the first years of growth of *T. grandis* [32]. Therefore, tree bending due to a lack of mechanical resistance required to withstand the winds of southern Costa Rica is common.

The specific study in the plantation in Site 6 showed the importance of the tree's morphological variables to the tree bending risk factor (RF). This parameter measures the capacity of the tree to coexist under competent conditions without bending [27]. Although this parameter has been applied to tree stability and tree interactions in natural forests [42], it can also be applied to trees growing in forest plantations. In the case of plantations, the RF increases in value with increasing *Hcb* and *Wc* (Figure 5b), probably as a consequence of greater weight concentration in higher parts of the tree. However, the RF decreases as the tree's form factor increases (Figure 5d). Such behavior is explained by Mattheck [43], who indicated that for the same amount of material, a cone can be built higher than a cylinder. Indeed, a cone has both a lower load in its distal part where the lever arm is the largest and a higher bending inertia in the basal part that is subjected to the highest bending moment.

An important aspect to highlight is the relationship between the *RF* and *Hb*, which are negatively correlated (Figure 5a), indicating that trees with low values of *RF* are prone to bend at lower heights, whereas low values of this factor indicate that the tree will tend to bend at greater heights.

The specific study conducted in the 54-month-old plantation also suggests that other wood properties influence the tendency of teak trees to bend, in addition to the influence of *Wc* and *Hcb* on bending (Figure 5c,d). This behavior is consistent with the study by Skatter and Kucera [44] in Scots pine, which investigated the influence of the crown on flaws and stem bending. It is important to mention that *Ht* and total weight are included in the RF (Equations (1) and (2)), but these variables did not influence the RF. This means that there are other morphological characteristics that have a greater influence on the RF. The results found in teak trees agree with studies carried out by Moore [18] in *Pinus radiata*, where trees with higher taper (lower ratio of tree height to d) had higher maximum resistive bending times than trees with low taper.

Although researchers have investigated the influence of various wood properties on the flexural properties of the trunk of the tree [13,45], several studies indicate that MOE is most commonly and strongly related to bending, which is consistent with the results found in this study (Figure 6b). However, changes in the SG (Figure 6a) and in calcium (Ca) and magnesium (Mg) contents were also related to the bending of young teak (Table 6). Other studies have found similar effects on wood properties; for example, Van Gelder et al. [20] found that the wood density of tropical trees was positively related to wood strength and stiffness, and the species safety factor for buckling was positively related to wood density and stiffness. Another important parameter that affects stiffness is the microfibril angle [45], but it was not considered in this study.

Some elements are directly related to tree resistance. Calcium (Ca) is an essential element for teak meristematic development because it is one of the major structural components that forms the cell wall [46]. This nutrient provides rigidity and resistance to the roots [47]. In contrast, potassium (K) maintains the turgidity of tissues, prevents drought effects, increases resistance to diseases, reduces uprooting, and aids nitrogen fixation. It was found that fertilization with K in species such as pine positively influences the cell wall thickness of the early stem and the modulus of elasticity of the wood [46].

Finally, according to the results obtained, bent trees account for 78% to 98% (780 to 980 trees ha^{-1}) of the trees in the plantations (Table 3). This percentage will be reduced by future thinning applied as the plantation ages because the target stand density of the plantation is approximately 250–280 trees ha^{-1} [7]. Then, although the sites where teak trees are planted present characteristics that make trees susceptible to bending, plantation conditions should be sought to achieve at least the aforementioned density at the age when the plantation is to be felled.

5. Conclusions

Tree bending, analysed by the height where bending occurred (bending height) is influenced by the following morphological characteristics of Tectona grandis: positively correlation with height to crown base in the first place, crown weight, the diameter and total height of the tree, when the bending height is studied in a juvenile plantation (from 8 to 54 month old). The evaluation of bent trees showed that the percentage of bent trees (Classes 2 and 3) increases with the age of the plantation, while the quantity of straight trees (Class 1) diminishes from 97.8% in the youngest plantation to 78% in the oldest plantations. Nevertheless, the specific study conducted in the 54-month-old plantation suggests that, in addition to morphological characteristics of the tree, there are factors specific to the xylem (wood) that also have an effect on tree bending, such as modulus of elasticity and the presence of calcium and magnesium in the wood. Besides, teak tree bending increases as the tree ages and varies from 0.8 to 6.5 meters in height, which means a ratio between 10 and 50% of the total height. The results indicate that bending of teak trees in young plantations occurs in approximately 30% of the trees present, and occurs mainly between 27 and 54 months of age of the tree in conditions of total height above 10 meters, height to crown base above 5 meters and diameter above 10 cm.

Acknowledgments: This project was supported by the Vicerrectoría de Investigación y Extensión del Instituto Tecnológico de Costa Rica (ITCR), to whom we are grateful for their support throughout all the phases of this study. Special thanks to all teak reforestation companies that collaborated in this study: Brinkman & Asociados Reforestadores de Centroamérica, BARCA; and also to Gaëlle Jaouen, Ingénieure de Recherche, PhD.—AgroParisTech, UMR Ecologie des Forêts de Guyane for your scientific contribution to the paper.

Author Contributions: Nancy Guzmán contributed with tree sampling, determining wood properties, running the data analysis, and coordinating the research project. Róger Moya contributed with designing the experiment, tree sampling, determining wood properties, running the data analysis, and coordinating the research project. Olmán Murillo contributed with designing the experiment, writing the paper, and running the data analysis.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kollert, W.; Cherubini, L. Teak Resources and Market Assessment 2010. FAO Planted Forests and Trees Working Paper FP/47/E, Rome. 2012. Available online: http://www.fao.org/forestry/plantedforests/67508@170537/en/ (accessed on 22 November 2016).
2. Moya, R.; Bond, B.; Quesada-Pineda, H. A review of heartwood properties of *Tectona grandis* trees from fast-growth plantations. *Wood Sci. Technol.* **2014**, *48*, 411–433. [CrossRef]
3. Keogh, R. The Future of Teak and the High-Grade Tropical Hardwood Sector: Planted Forests and Trees Working Paper FP/44E. 2009. Available online: http://www.fao.org/forestry/site/10368/en/ (accessed on 24 November 2016).
4. Kumar, B.M.; Long, J.N.; Kumar, P. A density management diagram for teak plantations of Kerala in peninsular India. *For. Ecol. Manag.* **1995**, *74*, 125–131. [CrossRef]
5. Bhat, K.M.; Priya, P.B.; Rugmini, P. Characterisation of juvenile wood in teak. *Wood Sci. Technol.* **2001**, *34*, 517–532. [CrossRef]
6. Cassidy, M.; Palmer, G.; Smith, R.G.B. The effect of wide initial spacing on wood properties in plantation grown *Eucalyptus pilularis*. *New For.* **2013**, *44*, 919–936. [CrossRef]
7. Pérez, D.; Kanninen, M. Stand growth scenarios for *Tectona grandis* plantations in Costa Rica. *For. Ecol. Manag.* **2005**, *210*, 425–441. [CrossRef]
8. Tewari, V.P.; Álvarez-González, J.G.; García, O. Developing a dynamic growth model for teak plantations in India. *For. Ecosyst.* **2014**, *1*, 1–9. [CrossRef]
9. Bošе, M.; Konôpka, B.; Šebeň, V.; Vladovič, J.; Tobin, B. Modelling height to diameter ratio—An opportunity to increase Norway spruce stand stability in the Western Carpathians. *For. J.* **2014**, *60*, 71–80. [CrossRef]
10. Nunes, L.; Gower, S.T.; Monteiro, M.L.; Lopes, D.; Rego, F.C. Growth dynamics and productivity of pure and mixed *Castanea sativa* Mill. and *Pseudotsuga menziesii* (Mirb.) Franco plantations in northern Portugal. *iFor. Biogeosci. For.* **2014**, *7*, 93–107.
11. Opio, C.; Jacob, N.; Coopersmith, D. Height to diameter ratio as a competition index for young conifer plantations in northern British Columbia, Canada. *For. Ecol. Manag.* **2000**, *137*, 245–252. [CrossRef]
12. Shibuya, M.; Koizumi, A.; Torita, H. Tree shape and resistance to uprooting: A simple model analysis. *Eurasian J. For. Res.* **2014**, *17*, 11–17.
13. James, K.R.; Haritos, N.; Ades, P.K. Mechanical stability of trees under dynamic loads. *Am. J. Bot.* **2006**, *93*, 1522–1530. [CrossRef] [PubMed]
14. Cucchi, V.; Meredieu, C.; Stokes, A.; Berthier, S.; Bert, D.; Najar, M.; Denis, A.; Lastennet, R. Root anchorage of inner and edge trees in stands of Maritime pine (*Pinus pinaster* Ait.) growing in different podzolic soil conditions. *Trees* **2004**, *18*, 460–466. [CrossRef]
15. Mitchell, S.J. Wind as a natural disturbance agent in forests: A synthesis. *Forestry* **2013**, *86*, 147–157. [CrossRef]
16. Kilpatrick, D.J.; Sanderson, J.M.; Savill, P.S. The influence of five early respacing treatments on the growth of Sitka spruce. *Forestry* **1981**, *54*, 17–29. [CrossRef]
17. Cremer, K.W.; Borough, C.J.; McKinnel, F.H.; Carter, P.R. Effects of stocking and thinning on wind damage in plantations. *N. Z. J. For. Sci.* **1982**, *12*, 244–268.
18. Moore, J.R. Differences in maximum resistive bending moments of *Pinus radiata* trees grown on a range of soil types. *For. Ecol. Manag.* **2000**, *135*, 63–71. [CrossRef]
19. Jones, T.G.; Downes, G.M.; Watt, M.S.; Kimberley, M.O.; Culvenor, D.S.; Ottenschlaeger, M.; Xue, J. Effect of stem bending and soil moisture on the incidence of resin pockets in radiata pine. *N. Zeal. J. For. Sci.* **2013**, *43*, 10.
20. Van Gelder, H.A.; Poorter, L.; Sterck, F.J. Wood mechanics, allometry, and life-history variation in a tropical rain forest tree community. *New Phytol.* **2006**, *171*, 367–378. [CrossRef] [PubMed]
21. Anten, N.P.; Schieving, F. The role of wood mass density and mechanical constraints in the economy of tree architecture. *Am. Nat.* **2009**, *175*, 250–260. [CrossRef] [PubMed]

22. Braz, R.L.; da Silva Oliveira, J.T.; Rosado, A.M.; Vidaurre, G.B.; Paes, J.B. Parâmetros dendrométricos e resistência mecânica das arvores de clones de Eucalyptus em áreas sujeitas a ação dos ventos. *Ciência Florestal* **2014**, *24*, 945–956. [CrossRef]
23. Monteuuis, O.; Goh, D.K.; Garcia, C.; Alloysius, D.; Gidiman, J.; Bacilieri, R.; Chaix, G. Genetic variation of growth and tree quality traits among 42 diverse genetic origins of *Tectona grandis* planted under humid tropical conditions in Sabah, East Malaysia. *Tree Genet. Gen.* **2011**, *7*, 1263–1275. [CrossRef]
24. Chaix, G.; Monteuuis, O.; Garcia, C.; Alloysius, D.; Gidiman, J.; Bacilieri, R.; Goh, D.K. Genetic variation in major phenotypic traits among diverse genetic origins of teak (*Tectona grandis* L.f.) planted in Taliwas, Sabah, East Malaysia. *Ann. For. Sci.* **2011**, *68*, 1015–1026. [CrossRef]
25. Ladrach, W. Alternativas para el raleo de plantaciones de teca (*Tectona grandis* L.). *Rev. For. Mesoam.* **2012**, *6*, 6–15.
26. Frankie, G.W.; Baker, H.G.; Opler, P.A. Comparative phenological studies of trees in tropical wet and dry forests in the lowlands of Costa Rica. *J. Ecol.* **1974**, *62*, 881–919. [CrossRef]
27. Jaouen, G.; Alméras, T. How to determine sapling buckling risk with only a few measurements. *Am. J. Bot.* **2007**, *94*, 1583–1593. [CrossRef] [PubMed]
28. American Society for Testing and Materials (ASTM). *ASTM D-4442–92 (Reproved 2003), Standard Test Methods for Direct Moisture Content Measurements of Wood and Wood-Base Materials*; ASTM: West Conshohocken, PA, USA, 2003.
29. American Society for Testing and Materials (ASTM). *ASTM D-1036–99 (Reproved 2003), Standard Test Methods of Static Tests of Wood Poles*; ASTM: West Conshohocken, PA, USA, 2003.
30. Sparks, D.L. *Methods of Soil Analysis. Part 3, Chemical Methods*; Soil Science Society of America: Madison, WI, USA, 1996; p. 356.
31. Pérez, D. Growth and volume equations developed from stem analysis for *Tectona grandis* in Costa Rica. *J. Trop. For. Sci.* **2008**, *20*, 66–75.
32. Víquez, E.; Pérez, D. Effect of pruning on tree growth, yield, and wood properties of *Tectona grandis* plantations in Costa Rica. *Silva Fenn.* **2005**, *39*, 381–390. [CrossRef]
33. James, K.R.; Hallam, C.; Spencer, C. Measuring tilt of tree structural root zones under static and wind loading. *Agric. For. Met.* **2013**, *168*, 160–167. [CrossRef]
34. Toky, O.P.; Bisht, R.P. Observations on the rooting patterns of some agroforestry trees in an arid region of north-western India. *Agrofor. Syst.* **1992**, *18*, 245–263. [CrossRef]
35. James, K.R.; Hallam, C.; Spencer, C. Tree stability in winds: Measurements of root plate tilt. *Biosyst. Eng.* **2013**, *115*, 324–331. [CrossRef]
36. Thulasidas, P.K.; Bhat, K.M. Log characteristics and sawn timber recovery of home-garden teak from wet and dry localities of Kerala, India. *Small Scale For.* **2008**, *8*, 15–24. [CrossRef]
37. Malik, J.; Hopewell, G.P. Sawing Recovery of several sawmill in Jepara. *J. Penelit. Has. Hutan* **2011**, *29*, 331–342. [CrossRef]
38. Saunderson, S.E.; England, A.H.; Baker, C.J. A dynamic model of the behaviour of Sitka spruce in high winds. *J. Theor. Biol.* **1999**, *200*, 249–259. [CrossRef]
39. Baker, C.J. The development of a theoretical model for the wind throw of plants. *J. Theor. Biol.* **1995**, *175*, 355–372. [CrossRef]
40. Guitard, G.E.; Castera, P. Experimental analysis and mechanical modelling of wind-induced tree sways. In *Wind and Trees*; Coutts, M.P., Grace, J., Eds.; Cambridge University Press: Cambridge, UK, 1995; pp. 182–194.
41. Telewski, F.W. Wind induced physiological and developmental responses in trees. In *Wind and Trees*; Coutts, M.P., Grace, J., Eds.; Cambridge University Press: Cambridge, UK, 1995; pp. 237–263.
42. Alméras, T.; Costes, E.; Salles, J.C. Identification of biomechanical factors involved in stem shape variability between apricot tree varieties. *Ann. Bot.* **2004**, *93*, 455–468. [CrossRef]
43. Mattheck, C. Why they grow, how they grow: The mechanics of trees. *Arboricult. J.* **1990**, *14*, 1–17. [CrossRef]
44. Skatter, S.; Kucera, B. Tree breakage from torsional wind loading due to crown asymmetry. *For. Ecol. Manag.* **2000**, *135*, 97–103. [CrossRef]
45. Lasserre, J.P.; Mason, E.G.; Watt, M.S. Influence of the main and interactive effects of site, stand stocking and clone on *Pinus radiata* D. Don corewood modulus of elasticity. *For. Ecol. Manag.* **2008**, *255*, 3455–3459. [CrossRef]

46. Grey, R.; Kyanka, G. Potassium fertilization effects on the static bending properties of red pine wood. *For. Prod. J.* **1974**, *24*, 92–96.
47. Kjaer, E.; Kajornsrichon, S.; Lauridsen, E. Heartwood, calcium and silica content in five provenances of teak (*Tectona grandis* L.f.). *Silvae Genet.* **1998**, *48*, 1–3.

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