EFFECTS OF PRUNING INTENSITY AND SEASON ON WOUND OCCLUSION AND STEM FORM OF TEAK (*TECTONA GRANDIS*) IN CHINA

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Pruning is an important and beneficial management practice for improving stem form in teak plantations and obtaining knot-free timber. However, the effects of pruning intensity and seasonal timing on pruning wound occlusion and stem form of teak are not well understood. In this study, a pruning trial with two factors of intensity and season was conducted in a four-year-old teak plantation in Nanning City, Guangxi Zhuang Autonomous Region, China. The wound occlusion rate and the proportion of complete occlusion were relatively higher when pruning intensity was 55% in the vigorous growth period. The number of sprouts around the wound increased gradually with pruning intensity, but the sprouting rate exhibited a decreased trend. Both of these values were minimum when pruning was conducted in the vigorous growth period. Pruning intensity strongly affected teak stem form. Ratios of height to diameter of stem and crown diameter to length also tended to increase with pruning intensity because of the distinct increase in tree height. Based on our results, pruning of teak should be conducted with 55% intensity in the vigorous growth period. In addition, epicormic shoots should be removed to enhance growth in height and to obtain defect-free straight bole.

Keywords: Occlusion proportion, sprouting rate, growth performance, teak plantation

INTRODUCTION

Knots in trees are a normal physiological phenomenon during the growth and development process of trees. They are generally considered a major defect affecting wood utilisation. The classification of timber grades is universally based on knot characteristics. Thus, knot defects become important indicators of timber quality (Xu 2011). Unlike natural pruning, many studies have shown that artificial pruning can shorten wound occlusion time and reduce knot size and discoloration length. Artificial pruning is also the most effective management measure to reduce dead knot-related defects (Hein & Spiecker 2007, Wang et al. 2016) and produce high quality, knot-free wood (Ferraz Filho et al. 2014). However, wounds resulting from artificial pruning may be infected easily by fungi, leading to longer occlusion time (Beadle et al. 2007), which is not beneficial to knot occlusion inside the trunk (Sandi et al. 2012). Thus, research on wound occlusion of pruned trees is important for production of high-quality timber.

Wound occlusion is a series of physiological processes from callus regeneration to new bark formation, which can effectively protect wood from insect and bacterial infestation (Stobbe et al. 2002, Delvaux et al. 2009). Liu et al. (2012) showed that initial wound size and pruning intensity affect occlusion rate in *Corymbia torelliana*. The wound occlusion rate of *Erythrophleum fordii* increased by 12.20–13.58% when one-third of the tree crown was removed (Hao 2017). Additionally, Guan et al. (2020) reported that *Fraxinus mandshurica* had fewer wounds and wound closure was fastest under 40% pruning intensity. However, during the period from wound creation to complete closure, many new sprouts may emerge at the site of pruning wounds or trunks (Waring & O'Hara 2005, Springmann et al. 2011). Although this may be a strategy by which trees increase their photosynthetic capacity (Alcorn et al. 2008b), the development and subsequent growth of these shoots most likely directly affect wound occlusion and increase knot numbers.

In addition to pruning intensity and secondary shoot emergence, wound occlusion capacity is also influenced by the season of wounding (Fini et al. 2013, Niemistö et al 2019).

The rates of wound occlusion and epicormic shoots vary with different pruning seasons (Gordon et al. 2006, Vasaitis et al. 2012). Pruning in summer may promote the growth of remaining branches (Zhang et al. 2021), expand the crown diameter and volume (Alvarez et al. 2013), and accelerate wound occlusion to improve timber quality. Therefore, it is obvious that appropriate pruning intensity and season are crucial for the cultivation of knot-free timber and enhancing its economic value.

Pruning off some live branches has a certain impact on tree growth that is induced by reduction in leaf quantity and crown area (Ma et al. 2021). Light pruning has generally little effect on tree growth (Chandrashekara 2007, Martín et al. 2015). Moderate pruning can significantly enhance height growth and stem volume (Wu et al. 2014), whereas heavy pruning has negative impact on growth in the short term (Pinkard 2002, Ferraz Filho et al. 2016). However, diameter growth of tree trunks has been reported to decrease to varying degrees under different pruning intensity treatments for *Ailanthus triphysa* (Chandrashekara 2007) and *Acacia nilotica* (Siddiqui et al. 2010), and gradually diminish with increasing pruning intensity in *Betula pendula* (Skovsgaard et al. 2021). The performance of the key processes, such as net photosynthetic rate (Liu et al. 2019), foliar nitrogen utilisation efficiency, and stomatal conductance (Maurin & DesRochers 2013) in remaining leaves after reasonable pruning improved to compensate for diminished growth caused by crown reduction. These physiological changes may further accelerate callus formation in the wound. Wound occlusion rate and stem diameter are likely to be positively correlated, and wounds in faster growth may thus occlude quicker (Montagu et al. 2003, Williams 2020). However, the rate also depends on tree species (Delvaux et al. 2010).

Teak (*Tectona grandis*) is a well-known durable timber species used worldwide. Due to its moderate density, high hardness, strong decay resistance and easy processing of heartwood, it is economically valuable and is widely used in the manufacture of flooring and furniture. Effects of pruning intensity on the diameter and height growth of teak have been reported in previous studies (Víquez & Pérez 2005, Roshetko et al. 2013, Budiadi et al. 2017). However, effects of pruning intensity and season on wound occlusion and sprouting in teak plantations have not yet been reported. In this study, the experiment of two pruning intensities was performed in three different seasons for a four-year-old teak plantation. The major objectives were: (1) to identify the influence of pruning intensity and season on wound occlusion and sprouts, (2) to explore the growth and stem form in response to pruning intensity and season, and (3) to clarify the relationships between wound occlusion and tree growth.

MATERIALS AND METHODS

Study area

The study was conducted in a four-year-old teak plantation located in Liuxu town, Qingxiu District, Nanning City, Guangxi Zhuang Autonomous Region, China (22 42′ N, 108 41′ E, altitude 100 m), with a subtropical monsoon climate and mean annual temperature of 21.6 °C. The maximum and minimum temperatures are 40.4 °C and -2.4 °C respectively. The mean annual rainfall and humidity are 1304 mm and 79% respectively. The soil type is Latosol and the soil layer is deep over 1 m. The plantations, with a total area of 30 ha, were established in 2014 and planted with seedlings of teak propagated through tissue culture using a superior clone. Plant spacing was at 2.5 m × 3 m.

Experimental design

The trial started in August 2018 and a split-plot design was adopted with three replicates. Pruning intensities applied in the main plot were H_1, H_2 and CK (no pruning), whereby all branches below 40 and 55% of tree height were removed in H_1 and H_2 respectively. The subplot consisted of three pruning seasons corresponding to the three stages of growth: G_1, early growth stage (April); G_2, vigorous growth stage (August); and G_3, late growth stage (December). There were 27 sample plots, and each consisted of 25 trees. The inner nine trees were used for the assessment. Before pruning, the height (H_0), diameter at breast height (DBH_0), height to crown base (HCB_0) and crown diameter (CW_0) of all trees in the experimental plot were measured (Table 1).

Table 1 Growth of different treatment plots before pruning in teak plantation

Pruning intensity	Pruning season	Tree height (m)	Diameter at breast height (cm)	Height to crown base (m)	Crown diameter (m)
H_1	G_1	10.54 ± 0.17	11.46 ± 0.26	2.55 ± 0.09	3.97 ± 0.12
	G_2	10.08 ± 0.14	11.03 ± 0.20	2.34 ± 0.09	3.64 ± 0.10
	G_3	10.33 ± 0.18	11.10 ± 0.19	2.44 ± 0.08	3.86 ± 0.11
H_2	G_1	10.39 ± 0.14	11.24 ± 0.23	2.60 ± 0.09	3.81 ± 0.08
	G_2	10.54 ± 0.15	11.57 ± 0.28	2.44 ± 0.13	z3.55 ± 0.13
	G_3	10.59 ± 0.16	10.91 ± 0.29	2.64 ± 0.07	3.83 ± 0.09
CK	G_1	10.62 ± 0.40	11.54 ± 0.63	2.62 ± 0.07	4.21 ± 0.21
	G_2	10.04 ± 0.38	10.66 ± 0.19	2.24 ± 0.15	3.64 ± 0.11
	G_3	10.12 ± 0.22	10.96 ± 0.44	2.36 ± 0.20	3.94 ± 0.10

Value indicates mean ± standard error; H_1 = pruning to 40% of tree height, H_2 = pruning to 55% of tree height, CK = control, G_1 = pruning at the early growth stage, G_2 = pruning at the vigorous growth stage, G_3 = pruning at the late growth stage

Wound occlusion rate

The initial number (n_0) of pruning wounds and wound horizontal width (w_0) were investigated after pruning. The number of wounds fully occluded (n_1), the current width of the wound (w_1), and the number of sprouts around the wound (N) were assessed in April 2021. According to the survey data, the sprouting rate (SR) was calculated as the ratio of sprout quantities (N) to the initial wound numbers (n_0). The wound occlusion rate (WOR, %) and complete occlusion proportion (COP, %) were calculated following the methods described by Liu et al. (2012).

$$\text{WOR} = \frac{(w_0 - w_1)}{w_0} \times 100$$

$$\text{COP} = \frac{n_1}{n_0} \times 100$$

Growth and stem form

The height (H, m), diameter at breast height (DBH, cm), height to crown base (HCB, m) and crown diameter (CW, m) were measured in April 2021. The crown length (CL) was the difference between H and HCB. The ratios of tree height to diameter at breast height (H/DBH), crown ratio (CL/H) and crown shape (CW/CL) were also calculated. Stem volume (V, dm^3) was based on the equation by Kuang (1996). The growth increment (Δ) indicated the difference between two measurements in 2021 and 2018.

Comprehensive evaluation of the pruning effects

Nine indices covering growth increment, stem form and wound occlusion were used. They were converted using the mathematical fuzzy subordinate function value method (Hong et al. 2021) as the following equations. Subsequently, the average subordinate function value was calculated for each index.

Positive indices: $Z_{ij} = (X_{ij} - X_{min})/(X_{max} - X_{min})$

Negative correlation indices:
$Z_{ij} = 1 - (X_{ij} - X_{min})/(X_{max} - X_{min})$

where, Z_{ij} is the subordinate function value of the i processing and j index, X_{ij} represents the determination value of i processing and j indicator. X_{min} and X_{max} respectively represent the minimum and maximum values of the corresponding index for each processing step.

Statistical analysis

The wound occlusion rate and complete occlusion proportion data were first subjected to logarithmic transformation and homogeneity tests. One-way and two-way analyses of variance (ANOVA) modules in SPSS 25.0 were used to analyse the differences in pruning treatments. Tukey's multiple comparison test (5%) was used to compare significant differences between the treatment means. Pearson correlation analysis was performed using Origin 2021 to identify the correlations between wound occlusion, stem form and tree growth.

RESULTS

Effects of pruning on wound occlusion and sprout quantities

The wound occlusion rate (WOR) varied from 84.88 to 95.31%. The effect of pruning season on WOR was more significant ($p < 0.05$) than that of the pruning intensity (Table 2). Trees exhibited greater rates of wound occlusion for H_1 intensity in the G_2 stage than in the G_1 and G_3 stages, and were higher by 6.99 and 6.74% respectively. While under H_2 intensity, the WOR in the G_2 stage was significantly higher (10.91%) than that in the G_1 stage.

The complete occlusion proportion (COP) ranged from 69.72 to 92.50%. In H_1 intensity, the COP in the G_2 stage was higher by 15.91 and 13.44% respectively compared with G_1 and G_3 stages. In H_2 intensity, the average COP values in G_2 and G_3 were 26.62 and 19.43% higher than that in the G_1 stage respectively. However, no clear differences in COP were observed between H_1 and H_2 intensities.

The average number of sprouts from pruning wounds increased with increasing pruning intensity, and the SR showed an opposite trend, although the differences were mostly not significant under different treatments (Table 2). Only the SR in H_2 intensity was affected by pruning season. The SR was lowest and highest in the H_2G_2 and H_1G_1 treatments respectively. The sprouting rate in H_2G_2 was reduced by 50.96% compared to that in H_1G_1.

Effects of pruning intensity on stem form parameters

The H/DBH ratio significantly increased with pruning intensity, but it was insignificant between the pruning seasons (Figure 1a). The mean ratio was highest in G_3 stage under H_2 intensity and was 12.36% higher than control. In general, crown ratios markedly reduced after tree pruning, particularly in H_2 intensity, and the mean values largely declined (Figure 1b). This ratio was lowest in the H_2G_1 treatment and was 25.32% lower than control. However, crown ratios of H_2 treatment and control were not statistically affected by pruning seasons.

Crown shape is represented by the ratio of the crown diameter and crown length (CW/CL). Higher CW/CL ratio indicated that the stem was more uniform (Figure 1c). The CW/CL ratio tended to increase with pruning intensity, and the highest value was in the H_2G_2 treatment, 23.08% higher than that of the control, but no difference was observed between pruning seasons.

Table 2 Occlusion rates of wounds and sprout quantity in different pruning treatments

Treatment		Wound occlusion rate (%)	Complete occlusion proportion (%)	Number of sprouts	Sprouting rate (%)
H_1	G_1	89.08 ± 0.02 Aa	79.80 ± 0.04 Ab	2.15 ± 0.37 Ba	25.65 ± 0.04 Aa
	G_2	95.31 ± 0.02 Aa	92.50 ± 0.02 Aa	2.04 ± 0.29 Aa	19.52 ± 0.03 Aa
	G_3	89.29 ± 0.02 Aa	81.54 ± 0.04 Ab	2.14 ± 0.35 Aa	24.16 ± 0.04 Aa
H_2	G_1	84.88 ± 0.03 Ab	69.72 ± 0.06 Ab	3.52 ± 0.51 Aa	21.99 ± 0.03 Aa
	G_2	94.14 ± 0.02 Aa	88.28 ± 0.03 Aa	2.25 ± 0.45 Aa	12.58 ± 0.02 Ab
	G_3	92.75 ± 0.02 Aab	83.27 ± 0.04 Aab	3.00 ± 0.31 Aa	21.35 ± 0.02 Aa

Value indicates mean ± standard error, different capital letters in the same column indicate significant differences between pruning intensity, different lowercase letters in the same column represent significant differences among the pruning seasons ($p < 0.05$); H_1 = pruning to 40% of tree height, H_2 = pruning to 55% of tree height, G_1 = pruning at the early growth stage, G_2 = pruning at the vigorous growth stage, G_3 = pruning at the late growth stage

Effects of pruning on tree growth

The growth indices of teak 2.5 years after pruning is presented in Table 3. For H, ΔH and HCB in G_2 and G_3 stages, there was a significant enhancement with increasing pruning intensity, and ΔV differed between pruning and control group ($p < 0.05$) only in the G_2 stage. However, significant differences were not shown between H_1 and H_2 pruning intensity treatments for the above indices. The changes of DBH, V, CW and ΔDBH were also not significant between pruning seasons or pruning intensities.

Correlations between wound occlusion, stem form indices and tree growth characters

Pearson's correlation coefficients revealed the relationships between wound occlusion (WOR, COP, N), stem form (H/DBH, CL/H and CW/CL) and tree growth characteristics (H, DBH, V, ΔH, ΔDBH and ΔV). WOR, COP and CL/H were significantly ($p < 0.01$) and positively correlated with ΔDBH and ΔV (Figure 2). CW/CL was positively correlated with HCB, and negatively correlated with H and ΔH. The CL/H of the stem

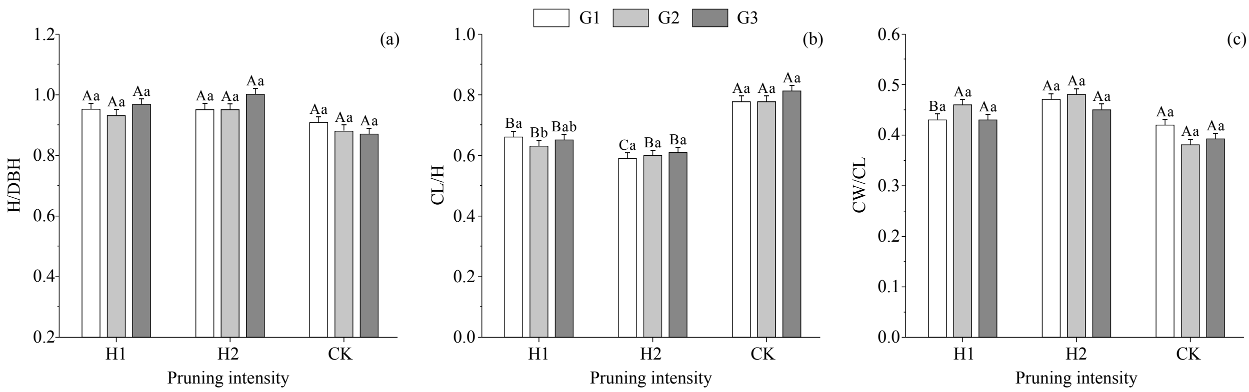

Figure 1 Stem form indices in different pruning treatments; different capital letters in the same column indicate significant differences between pruning intensity, different lowercase letters in the same column represent significant differences between pruning season treatments ($p < 0.05$); H_1 = pruning to 40% of tree height, H_2 = pruning to 55% of tree height, CK = control, G_1 = pruning at the early growth stage, G_2 = pruning at the vigorous growth stage, G_3 = pruning at the late growth stage; H/DBH = ratio of tree height to diameter at breast height, CL/H = crown ratio (ratio of crown length to tree height), CW/CL = crown shape (ratio of crown diameter to crown length)

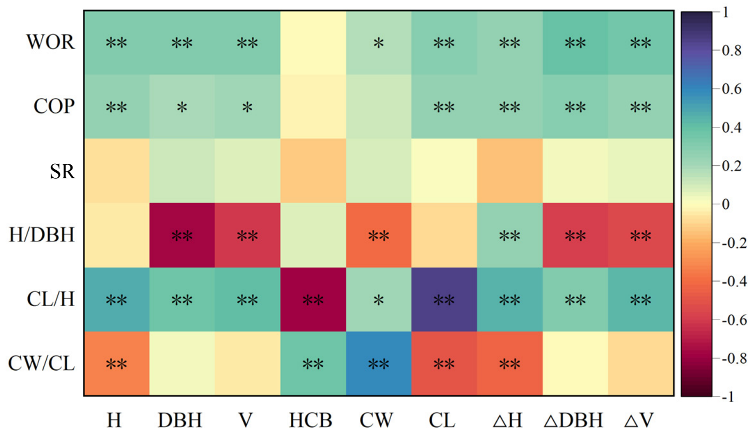

Figure 2 Pearson's correlation analysis between the wound occlusion, stem form and tree growth; H, DBH, V, HCB, CW, CL, H/DBH, CL/H, CW/CL, ΔV, ΔH, ΔDBH, SR, WOR and COP = tree height, diameter at breast height, volume, height to crown base, crown, crown length, the ratio of H to DBH, the ratio of crown length to H, the ratio of crown diameter to length, increment of individual volume, tree H and DBH, sprouting rate, wound occlusion rate and complete occlusion proportion; blue indicates a positive correlation between different variables and red indicates a negative correlation, * $p < 0.05$, ** $p < 0.01$

Table 3 Changes in teak growth in response to pruning treatment

Pruning intensity	Pruning season	H/m	DBH/cm	V/dm³	HCB/m	CW/m	ΔH/m	ΔDBH/cm	ΔV/m³
	G_1	13.64 ± 0.25 A	14.51 ± 0.43	0.144 ± 0.009	4.59 ± 0.09 B	3.86 ± 0.13	3.10 ± 0.16 A	3.04 ± 0.20	0.076 ± 0.006 A
H_1	G_2	12.94 ± 0.20 A	14.06 ± 0.30	0.125 ± 0.007	4.74 ± 0.09 B	3.70 ± 0.12	2.89 ± 0.16 A	3.03 ± 0.13	0.065 ± 0.004 A
	G_3	13.31 ± 0.25 A	13.86 ± 0.35	0.127 ± 0.008	4.60 ± 0.13 B	3.68 ± 0.12	2.97 ± 0.15 A	2.76 ± 0.19	0.065 ± 0.006 A
	G_1	13.27 ± 0.20 A	14.09 ± 0.33	0.130 ± 0.008	5.37 ± 0.08 A	3.68 ± 0.08	2.88 ± 0.15 A	2.84 ± 0.15	0.066 ± 0.005 A
H_2	G_2	13.74 ± 0.22 A	14.59 ± 0.42	0.145 ± 0.009	5.46 ± 0.11 A	3.92 ± 0.13	3.21 ± 0.15 A	3.02 ± 0.19	0.075 ± 0.006 A
	G_3	13.61 ± 0.20 A	13.82 ± 0.40	0.130 ± 0.009	5.25 ± 0.09 A	3.72 ± 0.10	3.02 ± 0.14 A	2.76 ± 0.16	0.067 ± 0.005 A
	G_1	12.96 ± 0.29 A	14.38 ± 0.74	0.130 ± 0.014	2.90 ± 0.26 C	4.12 ± 0.19	2.34 ± 0.22 A	2.84 ± 0.27	0.061 ± 0.008 A
CK	G_2	11.74 ± 0.48 B	13.42 ± 0.53	0.103 ± 0.010	2.62 ± 0.12 C	3.43 ± 0.17	1.70 ± 0.14 B	2.76 ± 0.34	0.048 ± 0.007 B
	G_3	11.98 ± 0.31 B	13.72 ± 0.40	0.109 ± 0.008	2.32 ± 0.18 C	3.73 ± 0.07	1.86 ± 0.25 B	2.76 ± 0.13	0.050 ± 0.003 A

Values indicate mean ± standard error; different capital letters in the same column indicate significant differences between pruning intensity; H_1 = pruning to 40% of tree height, H_2 = pruning to 55% of tree height, CK = control, G_1 = pruning at the early growth stage, G_2 = pruning at the vigorous growth stage, G_3 = pruning at the late growth stage; H, DBH, V, HCB, CW, ΔH, ΔDBH and ΔV = tree height, diameter at breast height, individual volume, height to crown base, crown, and increments of tree height, diameter at breast height and individual volume respectively was negatively correlated with HCB. There was negative correlation between N and CL. Similar negative associations were also found between H/DBH of the stem and ΔDBH, ΔV, and CW, but with no marked relationships between H/DBH and HCB, H/DBH and CL.

Comprehensive evaluation of pruning effects

To effectively evaluate the pruning effect, nine indices were used for the comprehensive evaluation of teak growth, stem form, and wound occlusion (Table 4). The comprehensive evaluation order of pruning effect after 2.5 years was listed as $H_2G_2 > H_2G_3 > H_1G_2 > H_1G_1 > H_1G_3 > H_2G_1$. The comprehensive evaluation value ranked first, indicating that 55% pruning intensity in the vigorous growth stage will be greatly beneficial for teak growth and formation of high-quality wood.

DISCUSSION

Rapid occlusion of the wounds caused by artificial pruning can decrease the number of knots emerging from the inner stem and the risk of wood decay, promoting the production of knot-free timber (Mäkinen et al. 2014, Vasaitis et al. 2012). The retention rate of tree crowns is higher when artificial pruning intensity is lower, and can provide adequate nutrient supply to fulfil wound occlusion, thereby accelerating the occlusion rate (Liu et al. 2012). In this study, the wound occlusion rate was not significantly different between the two pruning intensities, because there was almost no difference in tree growth (height and stem diameter, as well as their increments) (Table 3). This conclusion is also supported by the strong and positive relationships between wound occlusion rate and growth indices, as shown in Figure 2. Pruning season significantly affected the wound occlusion rate in the study. The wound occlusion rate and proportion of complete occlusion were higher in the vigorous growth stage than in the rest of the stages. There may be a relation between occlusion process of pruning wounds and the adequate supply of assimilatory substance (Alcorn et al. 2008a). The organic matter content produced by photosynthesis is much higher in the vigorous growth season than in the less active growth season (Maurin & DesRochers 2013). Moreover, the results by Niemistö et al (2019) further revealed that the meristematic activity of the cambium is vigorous during the growing season, which accelerates wound occlusion process. Tree growth after pruning also influences wound occlusion. This study showed that increments of H, DBH and V were positively correlated with occlusion speed and complete occlusion proportion. This is consistent with the result reported by Montagu et al.(2003), who suggested that a higher growth rate could facilitate a more rapid wound occlusion. In general, trees with softer wood and bark generally grow faster and exhibit more wound occlusion than trees with harder wood and bark (Williams 2020). Therefore, it can be deduced that the status of tree growth is a comprehensive indicator for determining the occlusion process of pruning wounds.

In the present study, the number of sprouts from pruning wounds decreased with decreasing pruning intensity, while the sprouting rates showed the opposite trend, particularly when pruning operation was done in the vigorous growth stage. DesRochers et al. (2015) also demonstrated that pruning in summer reduced the formation of epicormic shoots of hybrid poplars. Pruning in the late growth stage and dormancy period may produce adventitious buds and twigs in next year. Thus, the pruning season is found to be a crucial factor affecting branch development (Gordon et al. 2006), and the shoots are also regulated by phytohormones and the annual carbon distribution of trees (Meier et al. 2012).

H/DBH, CW/CL, and CL/H ratios were statistically different between pruned and non-pruned trees in this study. These results are inconsistent with the results obtained by Kerr and Morgan (2006) for *Fraxinus excelsior* and Wu et al. (2014) for *Paulownia fortunei*, stating that elevation pruning could improve stem form, but the effects were not markedly different. This could be related to the growing height of teak after pruning, which led to a reduction in stem taper and improvement in the stem form. However, long-term effects of pruning on teak stem form needed to be investigated in future.

Numerous studies have reported that the effects of pruning on diameter growth of trees are insignificant (Roshetko et al. 2013, Budiadi et al. 2017). On the other hand, increments of DBH and V declined with increasing pruning intensity,

Table 4 Comprehensive evaluation of pruning effects in teak plantation

Treatment		Subordinative function value									Comprehensive evaluation	Evaluation order
Pruning intensity	Pruning season	ΔH	ΔDBH	ΔV	H/DBH	CL/H	CW/CL	WOR	COP	SR		
	G_1	0.69	1.00	1.00	0.38	0.00	0.03	0.40	0.44	0.00	0.438	4
H_1	G_2	0.00	0.94	0.04	0.00	0.43	0.58	1.00	1.00	0.47	0.496	3
	G_3	0.33	0.00	0.00	0.56	0.13	0.00	0.42	0.52	0.11	0.230	6
	G_1	0.07	0.28	0.07	0.33	1.00	0.85	0.00	0.00	0.28	0.320	5
H_2	G_2	1.00	0.90	0.98	0.40	0.89	1.00	0.89	0.81	1.00	0.874	1
	G_3	0.45	0.54	0.26	1.00	0.71	0.46	0.75	0.59	0.33	0.566	2

H_1 = pruning to 40% of tree height, H_2 = pruning to 55% of tree height, CK = control, G_1 = pruning at the early growth stage, G_2 = pruning at the vigorous growth stage, G_3 = pruning at the late growth stage, ΔH, ΔDBH and ΔV = increments of tree height, diameter at breast height and individual volume respectively, H/DBH = the ratio of tree height to diameter of breast height, CL/H = the ratio of crown length to tree height, CW/CL = the ratio of crown diameter to length, WOR = wound occlusion rate, COP = complete occlusion proportion, SR = sprouting rate and the growth of tree height significantly decreased after pruning compared with non-pruned trees in teak (Víquez & Pérez 2005) and *Eucalyptus cloeziana* (Ren et al. 2017) plantations. This study demonstrated that height growth increased with pruning intensity. This could be because artificial pruning hampers longitudinal transportation for assimilating matter in the trunk, leading to the accumulation of organic matter in the upper crown layers, which in turn help enhance tree height growth (Wang et al. 1993). Presumably, the growth of tree height may have been achieved at the expense of diameter growth to maintain the dominant position of tree crown in the stand, while rebuilding photosynthetic capacity (Amateis & Burkhart 2011). Pruning intensity affected the increase of diameter growth and crown to a lesser extent in this study, which indicated that pruning intensity did not cause growth loss. This is consistent with a previous study by Budiadi et al. (2017), which reported that pruning had no direct effect on teak growth. A possible reason is that pruned trees adapt to the changes in the environment within a short time and improve negative influences of pruning by stimulating the downward translocation of solutes of photosynthesis to the remaining leaves (Maurin & DesRochers 2013, Li et al. 2020).

The pruning season had little effect on teak growth in this study. The growth of teak branches and leaves was active in the early stages of growth, which may compensate the impacts of canopy reduction caused by low-intensity pruning. During the vigorous growth stage, plants are more sensitive to external disturbances and responses seem to be more quickly. Nevertheless, in the later growth stage, teak growth is relatively slow with a lower occlusion speed because of nutrient deficiencies.

CONCLUSION

This study demonstrated that the pruning season significantly affected wound occlusion of teak. The wound occlusion rate and the proportion of complete occlusion after pruning were highest in the vigorous growth stage, and the number of new sprouts was minimum. Pruning can diminish the stem taper and crown ratio, and improve the stem form. Height growth increment enhanced with increasing pruning intensity, but the DBH, crown size and stem volume were less affected. Pruning season also had little influence on stem form and tree growth. In order to obtain knot-free or less knot timber of teak, it is suggested that pruning off all branches be conducted below 55% of tree height in the vigorous growth stage, and new sprouts emerging at the wound be removed. Physiological processes and wood structures after pruning should be studied in the future, which are also crucial for the management in making decisions for the establishment of high-quality stands.

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