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GROWTH PERFORMANCE OF DIPTEROCARP SPECIES PLANTED ON ABANDONED MINING AREA IN SOUTHERN THAILAND**

JETSADA WONGPROM*

Faculty of Forestry, Kasetsart University, Bangkok 10900, Thailand

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ABSTRACT

Dominant Dipterocarp trees hold a significant importance in the ecology and economics of the declining tropical forests of Asia. Of equal importance is the restoration of these Dipterocarp forest using the technique of matching species with silvicultural practices. The study aimed to investigate the effect of the *Acacia mangium* nurse trees on the survival and growth of six Dipterocarp species planted on abandoned mining areas in the Phangnga Forestry Research Station, Thailand, namely; *Dipterocarpus alatus* Roxb., *Dipterocarpus gracilis* Blume, *Hopea odorata* Roxb., *Shorea gratissima* (Wall. ex Kurz) Dyer, *Shorea roxburghii* G. Don, and *Parashorea stellata* Kurz. The approximately 1.5-year-old Dipterocarp seedlings were planted at a 6-year-old *A. mangium* plantation cover and at open plots. The survival rate, diameter at root collar (D_0), total height (H) and the relative growth rate (RGR) of D_0 and H of the seedlings were compared. Soil samples at the open and the *A. mangium* plots were collected and its physical and chemical properties were analyzed. The results indicated that the survival rates of the Dipterocarps planted at the *A. mangium* plot were higher than those at the open plots. The survival rates (75-100%) of the 1 to 3-year-old *D. alatus*, *H. odorata*, *S. gratissima*, *S. roxburghii*, and *P. stellata* were relatively high at the *A. mangium* plot, but not for *D. gracilis*. The D_0 of *S. roxburghii*, *D. alatus*, *H. odorata*, and *P. stellata* were higher at the *A. mangium* plot. However, the D_0 and H of *S. roxburghii*, *D. alatus*, and *H. odorata* at the open plot were high and similar to that of the *A. mangium* plot. RGR_{D0} and RGR_H of *S. roxburghii*, *D. alatus*, and *H. odorata* were high both at the *A. mangium* and the open plots. Generally, the Dipterocarp seedlings were growing better under the *A. mangium* nurse trees, thus suggesting the possibility of their improved survival and growth in mined out areas. Moreover, the findings also suggest that *S. roxburghii*, *D. alatus*, and *H. odorata* can be planted at open areas with poor soil conditions and extreme environments. Lastly, thinning interventions are also needed to improve the growth of Dipterocarp trees.

Keywords: Dipterocarp species, growth performance, mining area, Phangnga Forestry Research Station

INTRODUCTION

Dipterocarp trees mostly dominate the Asian tropical rain forests (Ghazoul 2016). These species are widely planted for forest ecosystem maintenance and for the restoration of degraded lands (Kettle 2010; Yeong *et al*. 2016; Budiharta *et al*. 2018). With the diminishing non-timber forest products, these Dipterocarp trees have become an important component of the rural livelihoods.

Illegal logging and conversion of forests to agricultural lands, mainly for oil palm and rubber, plantations has dramatically resulted in deforestation and forest loss (Appanah *et al*. 2016; Ghazoul 2016). Hence, forest restoration has become one the options left throughout the region of Southeast Asia (Appanah *et al*. 2016). Dipterocarp trees have been widely planted for commercial, conservation, and agroforestry purposes as well as forest restoration (Sakai *et al*. 2014; Appanah *et al*. 2016; Ghazoul 2016). However, those trees planted on open and degraded lands has low survival and growth rates (Hattori *et al*. 2013). Forest rehabilitation with Dipterocarp trees generally plant nurse

*Corresponding author, e-mail: fforcrw@ku.ac.th

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trees using the line, strip, and gap methods (Norisada *et al.* 2005; Hattori *et al.* 2013; Sakai *et al.* 2014; Budiharta *et al.* 2014). Providing nurse trees for Dipterocarp trees significantly influenced the growth and survival of Dipterocarp seedlings (Norisada *et al.* 2005; Sakai *et al.* 2014). Moreover, environmental factors such as light, air temperature and soil properties also improved and thereby, enhanced the growth performance of Dipterocarp trees (Norisada *et al.* 2005; Sakai *et al.* 2014). Forest restoration using native tree species with appropriate silvicultural practices significantly contribute in the recovery of forest structure, diversity, and ecological services by improving tree growths and enhancing natural regeneration.

A. mangium is a fast-growing, nitrogen fixing tree commonly planted in commercial plantations and used for rehabilitation of degraded lands in Southeast Asia, including Thailand (Norisada *et al.* 2005; Sakai *et al.* 2011). Compared with other fast-growing and native tree species, its survival and growth rates on abandoned mining area are relatively higher (Martpalakorn 1990). Forest plantations do not only provide wood, but also simultaneously improve the ecosystems. Soil properties, nutrient cycling and biodiversity have been reportedly improved and restored after plantation establishment (Parrotta 1999; Lanuza *et al.* 2018), particularly under *A. mangium* plantation. Soil nutrients and organic matter contents were remarkably increased (Kongchum *et al.* 2016).

Globally, mining operations have severely impacted the environment, particularly, the soil properties, resulting to very low soil nutrient levels with strong acidic soil pH. The soil structure becomes unsuitable for planting tree species (Oktavia *et al.* 2015). In addition, mining also destroys the existing vegetation. Hence, the restoration of previously mined areas has been undertaken on many sites using the plantation approach (Bohre & Chaubey 2014; Kongchum *et al.* 2016). However, the forest structure and diversity levels are usually low. As such, plantation using mixed species are then recommended for restoration of degraded lands, including at post-mining sites (Lamb 2014), but the survival and growth rate of seedlings depend much on the tree species, environmental factors (Norisada *et al.* 2005; Sakai *et al.* 2014; Lestari *et al.* 2019), and silvicultural practices (Sakai *et al.* 2011; Sakai *et al.* 2014). To recover the forest structure, diversity and functions, the restoration of mined out areas using indigenous tree species has been going on for a long time. Moreover, tree selection for such degraded lands and appropriate management intervention for nurse trees, such as thinning, are such important steps needed to promote the growth of native trees (Sakai *et al.* 2014). Understanding the influence of silvicultural practices on the growth performance of Dipterocarp trees is very critical in any restoration program. Thus, the objectives of this study were to (1) investigate and compare the survival and growth performance of Dipterocarp seedlings planted at a 6-year-old *A. mangium* plantation and at open plots in a mined out area and, (2) to investigate the influence of thinning the *A. mangium* stand on the growth of Dipterocarp seedlings growing on mined out areas.

MATERIALS AND METHODS

Study Site and Experimental Plot

The experimental plot was located in an abandoned tin mine at the Phangnga Forestry Research Station, Thakuapa District, Phangnga Province, Thailand. The Province experiences the rainy season during April-November and the dry season during December-March. Its mean annual rainfall is 3,649.4 mm per year and the relative humidity is around 83.7% (Wongprom *et al.* 2013). The post mined area has a high bulk density and very low soil nutrient levels (Kongchum *et al.* 2016).

Species

Using completely randomized design with three replications, six species of approximately 1.5-year-old nursery-raised Dipterocarp seedlings were planted both at the open and *A. mangium* plots (Fig. 1). The species chosen were *Dipterocarpus alatus* Roxb. ex. G. Don, *D. gracilis* Blume, *Hopea odorata* Roxb., *Shorea gratissima* (Wall. ex Kurz) Dyer, *S.roxburghii* G. Don, and *Parashorea stellata* Kurz. Thirty Dipterocarp seedlings were planted in a 15 x 15 m plot with a spacing of 3 x 3 m at the open plot, and thirty Dipterocarp seedlings at the *A. mangium* plot were planted with a spacing of 3 x 3 m between the rows of 6-year-old *A. mangium*. The original spacing of the *A. mangium* plot was 3 x 3 m. Weeding and liana cutting were practiced two times a year. Growth performances of 1 to 3-year-old Dipterocarp seedlings after planting, including the survival rate, diameter at root collar (D_0), and total height (H), were measured.

At the *A. mangium* plot, the number of 7-year-old *A. mangium* trees was reduced to 50% using the row thinning method. The crown cover at the *A. mangium* plot was evaluated before and after thinning by using hemispherical photographs taken at 5 points by a digital camera (Nikon Coolpix 4500 with a fisheye lens) set on a tripod at 1.2 m above the ground. The cover was analyzed using Hemiview 2.1 (Delta-T Device Ltd.). Moreover, diameter at breast height (DBH), height, density and crown cover of the 6 to 8-year-old *A. mangium* trees were also measured (Table 1).

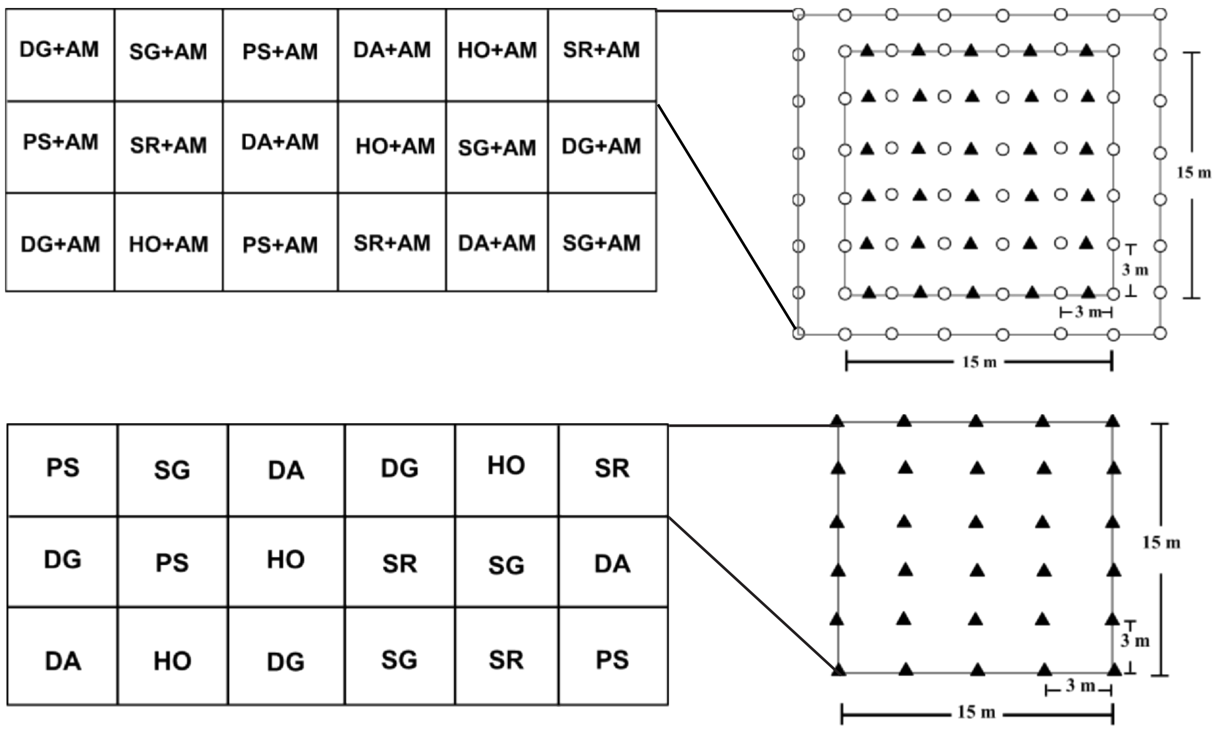

Figure 1 Layout of Dipterocarp seedling planted at the open and at the *A. mangium* plots
Notes: AM = *Acacia mangium*, DG = *Diptertocarpus gracilis*, DA = *Dipterocarpus alatus*, SR = *Shorea roxburgii*, SG = *Shorea gratissima*, HO = *Hopea odorata*, PS = *Parashorea stellata*); filled triangle (▲) = Dipterocarp seedlings and the open circle (●) = *A. mangium*.

Table 1 Density, diameter at breast height (DBH), height (H), and crown cover of the 6 to 8-year-old *A. mangium* plot growing on the mined out area in Phangnga Forestry Research Station

Age (year)	Density (tree/ha)	Mean DBH (cm)	Mean H (m)	Crown cover (%)	Remark
6	943.75	14.14	13.89	71.16	-
7	471.87	15.60	14.46	23.92	thinned *A. mangium*
8	425.00	16.86	15.76	-	-

Soil Properties

Soil samples were taken from two soil depths, i.e., topsoil (0-10 cm) and subsoil (20-30 cm), using a split tube sampler at three random locations from both the open and *A. mangium* plots. Soil physical properties including soil particle and soil texture, as well as soil chemical properties were measured. Organic matter content (OM) was analyzed using the Walkley and Black's rapid titration method. The available phosphorus (P) was extracted using the Bray II method (Bray & Kurtz 1945) and was analyzed using a spectrometer. Exchangeable potassium (K), calcium (Ca) and magnesium (Mg) were extracted using 1 N pH 7.0 ammonium acetate (NH_4OAc) and analyzed using an atomic absorption spectrometer (Estefan *et al.* 2013). Soil moisture of the topsoil and subsoil, both at the open and *A. mangium* plots, were measured monthly for 1 year after planting of the Dipterocarp trees. The collected soils were oven-dried at 80 °C for 48 hours to constant weight.

Data Analyses

Relative growth rate (RGR) of D_0 (RGR_{D0}) and H (RGR_H) was calculated using the formula:

$RGR_{D0} = (\ln D_0 2 - \ln D_0 1) / (t2 - t1)$

$RGR_H = (\ln H2 - \ln H1) / (t2 - t1)$

where $D_0 1$ and $D_0 2$ are diameter at root collar and H1 and H2 are height at times t1 and t2.

The survival rate, D_0, H, RGR_{D0}, and RGR_H of the six Dipterocarp seedlings, both at the open and *A. mangium* plots, were compared and tested using the one way analysis of variance (ANOVA) with the Duncan's Multiple Range Test (DMRT).

RESULTS AND DISCUSSION

Soil Properties

Most of the soil particles at the experimental plots were more than 80% sand particles. Soil texture at both the open and *A. mangium* plots were of a loamy and sandy types for the topsoil and subsoil, respectively, while the soil pH was strongly acidic. The soil nutrient levels in the topsoil layer, including the exchangeable K (21.92 ppm), Ca (109.52 ppm), Mg (18.38 ppm), and available P (2.33 ppm), were very low (Table 2), except OM content (2.50%), which was at a moderate level (USDA 1967). These low levels of soil nutrients in such areas are a result of intense mining. However, the levels of exchangeable K, Ca, Mg, P and OM content at the *A. mangium* plot were higher than those in a abandoned mining area (Kongchum *et al.* 2016). Nitrogen fixing trees, like *A. mangium*, help improved the soil properties of degraded lands, particularly in increasing the soil organic matter and nutrient content (Kongchum *et al.* 2016).

Survival Rate

Survival rates of the Dipterocarp seedlings significantly differed among the species, both at the open and *A. mangium* plots. One year after planting, most of the Dipterocarp seedlings at the open and *A. mangium* plots survived, ranging from 75 to 100% indicating a high survival rate. However, survival rate of the 2 and 3-year-old Dipterocarp seedlings at the open plot decreased (Fig. 2). Three year old *S. roxburghii* had the highest survival rate (62.22%) followed by *H. odorata* (44.44%) and *D. alatus* (33.33%), while *P. stellata*, *S. gratissima* and *D. gracilis* did not survive at all (100% mortality)

Table 2 Physical and chemical properties of soil at the open and *A. mangium* plots at Phangnga Forestry Research Station, southern Thailand

Plot	Soil depth	Soil particle (%)			Soil	pH	Exchangeable (ppm)			Available P	OM
	(cm)	Sand	Silt	Clay	texture		K	Ca	Mg	(ppm)	(%)
A. mangium	0-10	86	7	7	LS	4.4	21.92	109.52	18.38	2.33	2.50
	20-30	91	2	7	S	5.5	6.34	43.58	7.36	1.73	0.57
Open	0-10	82	10	8	LS	5.1	37.74	339.40	18.94	2.04	2.41
	20-30	90	3	7	S	5.2	11.48	94.46	14.76	0.87	0.16

Notes: LS = Loamy sand, S = Sandy.

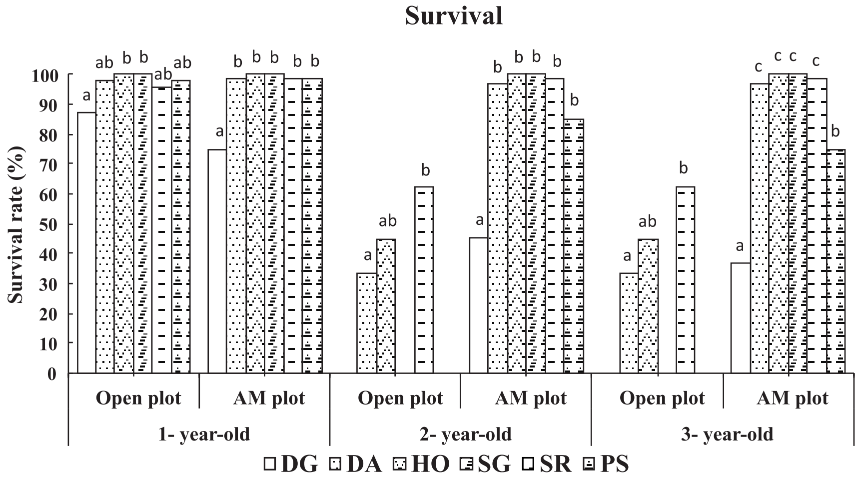

Figure 2 Survival rates of Dipterocarp trees planted at the open and at *A. mangium* (AM) plots
Notes: DG = *Diptertocarpus gracilis*, DA = *Dipterocarpus alatus*, SR = *Shorea roxburgii*, SG = *Shorea gratissima*, HO = *Hopea odorata*, PS = *Parashorea stellate*;
Different letters above bars indicate significant differences at $p < 0.05$ among species by DMRT.

However, the Dipterocarp seedlings in the *A. mangium* plot had higher survival rates, between 75% and 100%, except for *D. gracilis* (Fig. 2). Thinning of the *A. mangium* stand resulted in the mean crown cover being reduced from 71.16 to 23.92%. The thinning may have negatively influenced the survival rate of *P. stellata* and *D. gracilis* seedlings. Stronger light intensity in the open areas negatively affected the survival as well as the growth of many Dipterocarp seedlings (Hattori *et al.* 2009). The subsequent reduction in the sunlight intensity due to the canopy of the *A. mangium* resulted in the high survival rate of the Dipterocarp seedlings (Kenzo *et al.* 2011). Although *S. roxburghii*, *H. odorata* and *D. alatus* had moderate survival rates in the open plot, these can still be planted in open areas with poor soil conditions. A study in southern Thailand, showed that these Dipterocarp species are drought and stress tolerant and can be planted on degraded sandy soil in open areas Moreover, their high survival rates, especially *S. roxburgii*, ranged between 78% and 97%, when planted in an open area in a disturbed dry evergreen forest in northeastern Thailand (Niamrat & Marod 2005). When *S. roxburgii* was planted in a grassland interspersed with bushes, its survival rate was also reportedly high (93%) (Ang *et al.* 2003). Hence, rehabilitation of degraded lands using Dipterocarp seedlings is better done alongside nurse trees as these can create a microclimate suitable for the survival and growth of the seedlings.

After *A. mangium* was thinned by 50%, the survival rate of *D. gracilis* and *P. stellata* decreased gradually from 75 to 36.67% and 98.33 to 75%, respectively, after 3 years. The higher mortality of *D. gracilis* and *P. stellata* may have been caused by stronger light intensity. Light intensity distinctively affected the survival rates of Dipterocarp seedlings planted on degraded lands (Norisada *et al.* 2005; Sakai *et al.* 2014). High soil temperature and water stress, result in higher mortality, especially in drought conditions (Norisada *et al.* 2005). The sandy soil type in the study area expectedly held a very low water storage in dry season (Fig. 3), despite the fact that soil moisture significantly influences the establishment of a seedling (Hattori *et al.* 2013). In this study, soil moisture at *A. mangium* plot was higher than that in the open plot, indicating that *A. mangium* can reduce water transpiration from the soil. The crown cover and high amounts of litterfall from *A. mangium* create a microclimate preferable for the establishment of Dipterocarp seedlings under a mixed plantation. As the light requirements of Dipterocarps depend on the species (Sakai *et al.* 2014; Hattori *et al.* 2009), *D. gracilis* and *P. stellata* behavior showed that these may thrive well in darker conditions. Thus, to enhance the Dipterocarp seedlings survival, thinning of *A. mangium* may be delayed for mixed plot of *D. gracilis* and *P. stellata*. Lastly, thinning intensity is equally important in the enrichment planting of Dipterocarp seedling (Sakai *et al.* 2014).

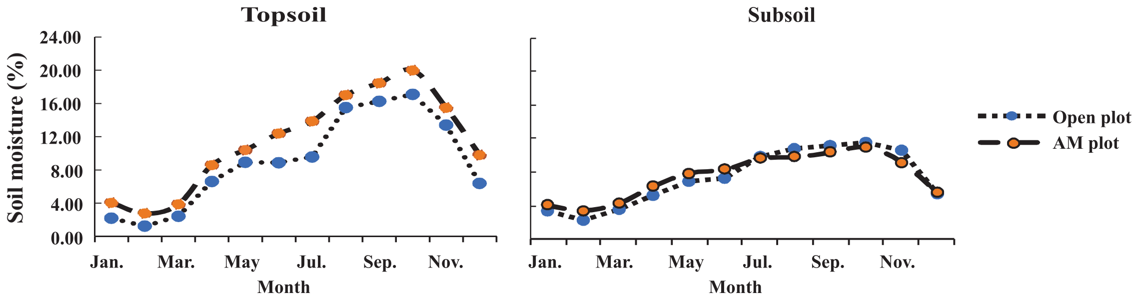

Figure 3 Soil moisture in the topsoil and subsoil levels at the open and *A. mangium* (AM) plots during a one-year period after planting of the Dipterocarp seedlings

Diameter at Root Collar (D_0) and Height (H) of the Dipterocarp Seedlings

Diameter at root collar (D_0) and height (H) of the six Dipterocarp seedlings, for the years 1 to 3, significantly differed among the species in the open plot. D_0 and H of *D. alatus* were the highest in the open plot after the first year of planting. Moreover, D_0 of *D. alatus* (6.04 cm) was significantly higher than that of *S. roxburghii* (4.07 cm) and *H. odorata* (2.95 cm), but their heights (H) did not differ at ages 2 and 3 years. The *D. alatus* seedling experienced a good growth in the open area and its stem diameter (7.20 cm), at 30 cm above the ground, was larger than those of the Dipterocarp seedlings reported by Sakai *et al.* (2014). However, D_0 and H of the 1 to 3-year-old *S. roxburghii* and *H. odorata* seedlings experienced a relatively higher growth at the open plot indicating their preference for brighter light conditions. *H. odorata* and *S. roxburghii* seedlings had good growths and were both tolerant to drought, suggesting that these can be planted in open areas.

At the *A. mangium* plot, the D_0 of 1-year-old *P. stellata* and *D. alatus* seedlings were significantly higher than those of other species. After *A. mangium* was thinned by 50%, the D_0 of *D. alatus* (2.38 cm) gradually increased and was the highest at 2 years after planting, but that of *D. gracilis* (1.21 cm) seedlings was the lowest. Reducing the *A. mangium* canopy positively influenced the D_0 of *D. alatus*, *S. roxburghii*, *H. odorata* and *P. stellata* seedlings, but not of *D. gracilis* and *S. gratissima* seedlings which exhibited a lower growth rate. Moreover, their mortality rate was 100% in the open plot, 2 years after planting. Species vary in their responses to different light conditions (Hattori *et al.* 2009). The D_0 and DBH of *D. alatus* and *H. odorata* in a 75% thinned *Leucaena leucocephala* plantation were higher than those in a 50% thinned *L. leucocephala* plantation, while D_0 and DBH of *Shorea henryana* in a 100% thinned *L. leucocephala* plantation were higher than in a 75% and 50% thinned plantation (Sakai *et al.* 2014).

Height growth of the six Dipterocarp seedlings was significantly different among the species at the *A. mangium* plot. The *P. stellata* seedling was the tallest at ages1 and 2 years. Among the 3-year-old seedlings at the thinned *A. mangium* plot, *S. roxburghii* (255.01 cm) was the tallest but not different from *P. stellata* (215.78 cm), while *D. gracilis* (138.87 cm) was the shortest. D_0, H, and survival rate of *D. gracilis* seedling were low, indicating its unsuitability for mined out areas with poor soil and bright light conditions.

The seedlings of *S. roxburghii* and *H. odorata* planted at the thinned *A. mangium* plot were taller than those planted in the open plot. Both species were the tallest when planted with nurse trees, an observation similar to that of Norisada *et al.* (2005). However, this result is contrary to that of Niamrat and Marod (2005), who indicated that the *H. odorata* seedlings planted in open areas were taller than those under a canopy of 4 and 20-year-old *Eucalyptus camaldulensis* stand. Similarly, the *H. odorata* seedling growth rate was higher in an open area compared to that in *A. auriculuformis* and *E. camaldulensis* plantations (Sakai *et al.* 2009). The good growth of *D. alatus* seedlings both in the open and *A. mangium* plots was also observed by Niamrat and Marod (2005). Soil properties of the post-mining area limited the tree growth and seedling establishment because of its low soil nutrients and high sand particle.

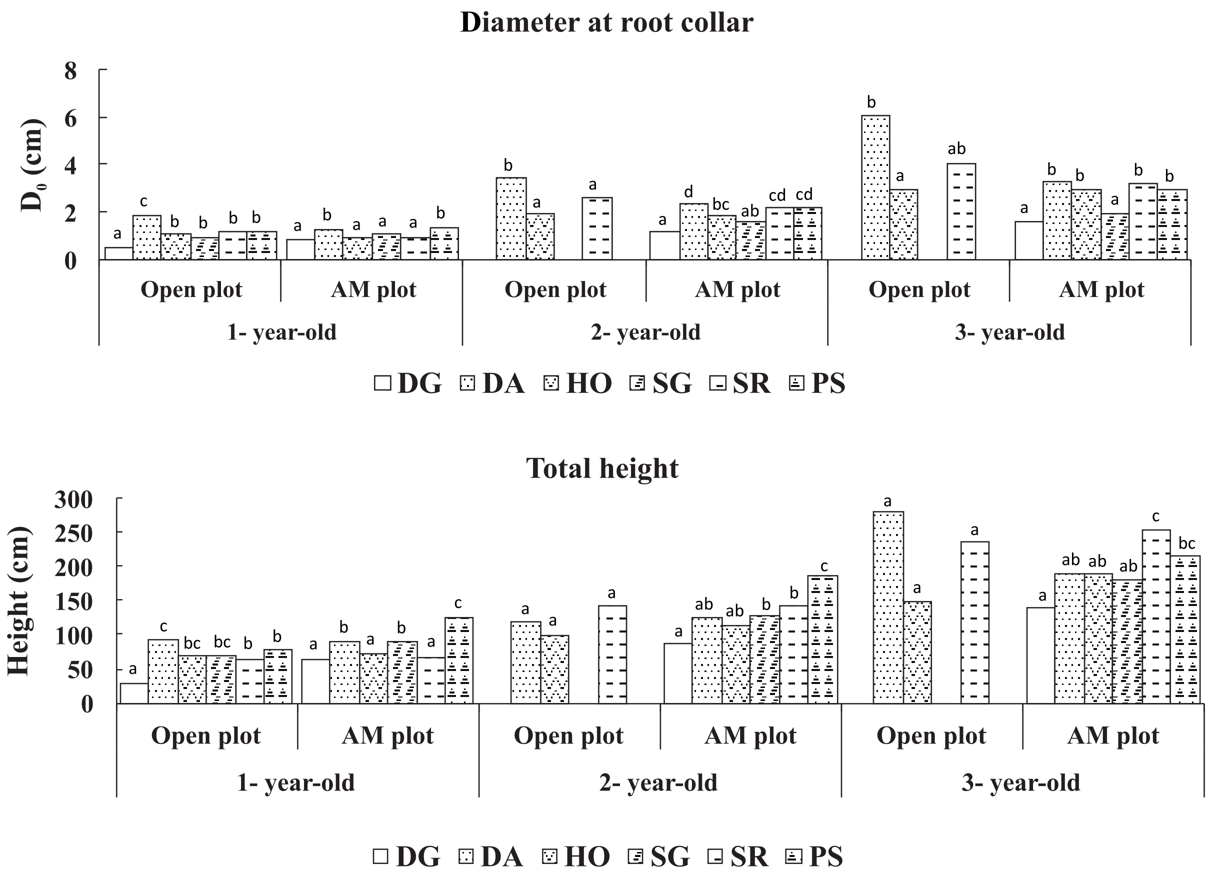

Figure 4 Diameter at root collar (D_0) and total height of Dipterocarp species at the open and *A. mangium* plots
Notes: Different letters above bars indicate significant differences ($p < 0.05$) among treatments by DMRT; DG = *Diptertocarpus gracilis*, DA = *Dipterocarpus alatus*, SR = *Shorea roxburgii*, SG = *Shorea gratissima*, HO = *Hopea odorata*, PS = *Parashorea stellata.*

The 3-year-old Dipterocarp seedlings, growing under the *A. mangium* canopy, showed a high survival rate and satisfactory stem and height growth. Hence, rehabilitation of mining areas using Dipterocarp species should include *A. mangium* nurse trees as has been recommended in degraded sites (Norisada *et al.* 2005). *A. mangium* not only enhanced the growth and survival rates of Dipterocarp trees, but also improved the soil properties (Kongchum *et al.* 2016), particularly nitrogen, a crucial nutrient for seedling growth in degraded areas.

Fast-growing trees also play an important role in reducing the demand for wood from the natural forests (West 2014). *A. mangium* grows well and are widely used for restoring degraded areas (Lamb 2011). Thinning of *A. mangium* stands can improve both the growth and quality of the wood of the remaining *A. mangium* trees (Wongprom *et al.* 2013).

Relative Growth Rate (RGR)

RGR of the base diameter (RGR_{D0}) in the open plot significantly differed among the 1-year-old species, but not among the 2 and 3-year-old (Table 4). RGR_{D0} of a 1-year-old *S. roxburghii* (0.67 cm/cm/yr) seedling was the highest followed by *D. alatus* (0.55 cm/cm/yr), *P. stellata* (0.49 cm/cm/yr), *S. gratissima* (0.45 cm/cm/yr), *H. odorata* (0.33) cm/cm/yr, and *D. gracilis* (0.12 cm/cm/yr). RGR of the height (RGR_H) of all the 1 to 3-year-old Dipterocarp seedlings in the open area did not significantly differ ($p > 0.05$), but was the highest for the *S. roxburghii* seedling (0.58 cm/cm/yr). The *S. roxburghii* seedling growth both for RGR_{D0} and RGR_H in the open area were greater than those of *Dipterocarpus oblongifolius* and *Dryobalanops oblongifolia* (Ang *et al.* 2003).

The RGR_{D0} of the 1-year-old Dipterocarp seedlings planted at the *A. mangium* plot was not significantly different among species, but for

RGR_H, *S. roxburghii* (0.71 cm/cm/yr) and *P. stellata* (0.70 cm/cm/yr) seedlings had significantly higher RGR_H than *D. alatus* (0.31 cm/cm/yr), *D. gracilis* (0.16 cm/cm/yr), *H. odorata* (0.38 cm/cm/yr) and *S. gratissima* (0.38 cm/cm/yr). After the *A. mangium* plantation was thinned by 50%, the RGR_{D0} and RGR_H values of 2-year-old *S. roxburghii* seedling were 0.91 and 0.75 cm/cm/yr, respectively and were the highest. However, both RGR_{D0} and RGR_H for *D. gracilis* seedlings (0.36 and 0.28 cm/cm/yr, respectively) were the lowest.

After the removal of the *A. mangium* crown cover *D. alatus* and *H. odorata* seedlings attained a much taller height. The intensity of light reaching the seedlings had increased, leading to enhanced growth rates of the Dipterocarp (Hattori *et al.* 2009; Sakai *et al.* 2011) as well as non-Dipterocarp seedlings growing under the canopy (Sakai *et al.* 2011). The relative growth rates of the Dipterocarp seedlings also depend on the thinning intensity of the nurse trees, species type and methods of planting, line, gap or strip (Hattori *et al.* 2009; Sakai *et al.* 2009; Sakai *et al.* 2014). The RGR_{D0} and RGR_H of *P. stellata* seedlings drastically decreased after the thinning of *A. mangium*, indicating its shade tolerant ability. Among the 3-year-old Dipterocarp seedlings planted at the *A. mangium* plot, *S. roxburghii* had the highest RGR_{D0} and RGR_H. However, RGR_{D0} and RGR_H of *S. roxburghii* was relatively higher in the *A. mangium* stand. Similarly, RGR_{D0} and RGR_H of *D. alatus* and *H. odorata* seedlings in the open was greater than that in the *A. mangium* stand, suggesting that *S. roxburghii*, *D. alatus,* and *H. odorata* can be planted in open areas, even under severe environmental stresses in post-mining sites.

Table 4 Relative growth rate (cm/cm/yr) of diameter at root collar (D_0) and height (H) of Dipterocarp seedlings at the open and the *A. mangium* plots

Age (year)	Species	Open plot		*A. mangium* plot	
		RGR_{D0}	RGR_H	RGR_{D0}	RGR_H
1	*Dipterocarpus gracilis*	0.12^{a}	0.26	0.35	0.16^{a}
	Dipterocarpus alatus	0.55^{bc}	0.42	0.66	0.31^{a}
	Hopea odorata	0.33^{ab}	0.33	0.56	0.38^{a}
	Shorea gratissima	0.45^{bc}	0.38	0.51	0.38^{a}
	Shorea roxburghii	0.67^{c}	0.44	0.73	0.71^{b}
	Parashorea stellata	0.49^{bc}	0.34	0.70	0.70^{b}
	F-value	3.602^{*}	0.742^{ns}	2.002^{ns}	5.776^{*}
2	*Dipterocarpus gracilis*	-	-	0.36^{a}	0.28^{a}
	Dipterocarpus alatus	0.64	0.44	0.62^{bc}	0.33^{a}
	Hopea odorata	0.57	0.33	0.73^{cd}	0.47^{a}
	Shorea gratissima	-	-	0.40^{ab}	0.36^{a}
	Shorea roxburghii	0.80	0.59	0.91^{d}	0.75^{b}
	Parashorea stellata	-	-	0.49^{ab}	0.39^{a}
	F-value	1.755^{ns}	1.361^{ns}	9.335^{**}	6.843^{**}
3	*Dipterocarpus gracilis*	-	-	0.29^{ab}	0.33^{b}
	Dipterocarpus alatus	0.56	0.64	0.31^{ab}	0.49^{bc}
	Hopea odorata	0.43	0.39	0.45^{b}	0.50^{bc}
	Shorea gratissima	-	-	0.21^{a}	0.35^{b}
	Shorea roxburghii	0.44	0.67	0.41^{b}	0.58^{c}
	Parashorea stellata	-	-	0.30^{ab}	0.16^{a}
	F-value	1.424^{ns}	2.705^{ns}	2.752^{*}	9.548^{**}

Notes: * = Significantly different at $p < 0.05$; ** = Significantly different at $p < 0.01$; ns = non-significant difference at $p > 0.05$; different letters in the same column indicate significant difference by DMRT.

CONCLUSION

Dipterocarp seedlings planted in the abandoned mining area in southern Thailand performed better with *A. mangium* as the nurse trees. Their survival rates in the *A. mangium* stand clearly improved and exceeded 75%. In contrast, the Dipterocarp seedlings planted in the open plot had lower survival rates, except for *S. roxburghii*, which was moderate. The stem diameter at the root collar and the height of *S. roxburghii*, *D. alatus*, *P. stellata*, and *H. odorata* seedlings were higher in the *A. mangium* plot than that in the open plots indicating that these species can be used to rehabilitate degraded lands. The stem diameter at root collar, height and relative growth rate of *S. roxburghii* seedlings were relatively high, indicating its suitability for rehabilitating mined out areas with poor soil conditions, with or without the use of nurse trees. Moreover, thinning intervention should also be practiced to improve the growth of Dipterocarp seedlings. Mixed plantation of fast-growing trees and Dipterocarp species is therefore, recommended for rehabilitating degraded areas, for improving forest structure, diversity, soil properties and for promoting wood utilization of fast-growing trees.

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