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Effects of Enrichment Planting with Five Native Species and Different Plantation Treatments on Seedling Growth Characteristics at Logged-over Forest in Lao PDR

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라오스 개벌림에서 다섯가지 자생수종과 각기 다른 조림처리의 Enrichment Planting이 묘목의 생장특성에 미치는 효과

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ABSTRACT

Enrichment planting is commonly used for increasing the density of tree species in secondary forests and one of forest rehabilitation programs in Lao PDR. This study aimed to determine the performance of five native species in enrichment planting using different canopy opening treatments, and to examine the suitable species and silviculture techniques applicable to a logged-over forest in Lao PDR. Results of the study showed that only crown height had significant difference among species and planting treatments. The survival rate and crown diameter were significantly different by species, but not by planting treatments. However, root collar diameter (RCD) and height of seedlings showed significant differences among planting treatments. Among the study species, *Hopea odorata* and *Dalbergia cochinchinensis* showed significantly higher survival rate and height growth, indicating their suitability in enrichment planting for rehabilitation of forest in Lao PDR. The results also suggested that 2 m width line planting stimulated RCD growth, but wider line planting, such as gap planting, promoted height growth of seedlings.

***Key words*: Line and gap planting, Logged-over forest, Rehabilitation, Seedling growth, Survival rate**

I. INTRODUCTION

Secondary forest constituted 63% of the total forest cover in Southeast Asia in 2005 (Kettle, 2010). Enrichment planting has been commonly used for restoring previously logged- over forests and increasing timber volume and economic value of secondary forests (Lamprecht, 1989; Kartawinata, 1994; Adjers *et al.*,

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1995; Paquette *et al*., 2006; Kettle, 2010). The general principle of enrichment planting is to improve the light environment condition around the planted seedlings by removing overtopping trees as canopy openings are critical for regeneration of many canopy tree species, and to reduce competition from surrounding undergrowth (Augspurger, 1984; Hartshorn, 1989; Appanah and Weinland, 1993; Denslow, 1995; Pena-Claros *et al*., 2002).

Enrichment planting by line and gap plantings are also practiced in tropical America, Africa and Asia Pacific on degraded early-sucessional and old fallow secondary forest (Appanah and Nair, 1999; Kobayshi *et al*., 1999; Oliveira, 2000; Pariona *et al*., 2003; Lamb *et al*., 2005; Park *et al*., 2005; Paquette *et al*., 2006; Inman *et al*., 2007). Enrichment planting can also be used in attempts to supplement natural regeneration, where it is judged to be insufficient (Appanah and Weinland, 1993). The method involves planting nursery-raised seedlings in cleared lines or in gaps that have either been created artificially or naturally (Wyatt-Smith, 1963). Line planting is now an established method (Lamb, 1969; Montagnini *et al*., 1997; Peña-Claros, 2002), but gap planting techniques in which clusters of seedlings are under-planted in artificially created gaps (Otsamo, 2000) or pre-existing gaps (Oliviera, 2000) are still at an experimental stage. The gap cluster planting approach is similar to "group-planting" as described by Anderson (1953) and or "nest-planting" (Anderson, 1951), in which seedlings of different species are planted together in a cluster.

In contrast to planting in regularly spaced lines, gap cluster planting has some resemblance to natural gap dynamics (Denslow, 1987; Kuuluvainen, 2002), which could be considered advantageous in restoration programs. Practical examples of enrichment plantation in tropical rainforests have been reported in many literature (Ådjers *et al*., 1995; Tuomela *et al*., 1996; Marod *et al*., 2004; Evans and Turnbull, 2007; Romell *et al*., 2008). However, drawing general conclusions regarding the effects of various treatments and the optimal conditions for enrichment planting is not straightforward due to the variability and dynamic nature of enrichment planting sites and the lack of knowledge regarding post planting site requirements in many species of the nursery-reared seedlings.

The factors considered important for the survival and early growth of under-planted non-pioneer seedlings in tropical secondary forests are canopy openness (Denslow, 1987; Tuomela *et al*., 1996; Jennings *et al*., 1999; Peña-Claros, 2002) and the quality of light close to the forest floor (Chazdon and Pearcy, 1991; Rijkers *et al*., 2000; Leakey *et al*., 2003). In addition, Ramos and del Amo (1992) claimed that the intensity of gap creation has to be matched with species-specific light requirements to achieve sufficient survival and growth rates.

However, the accumulated knowledge about enrichment planting in secondary tropical forests and the per-

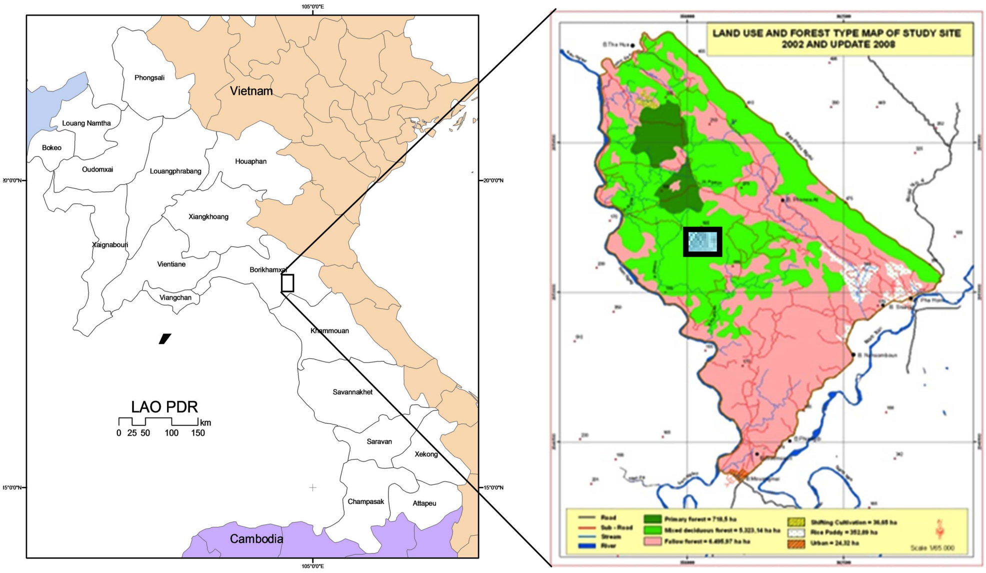

Fig. 1. Location of the study site in Borikhamxay Province, Lao PDR.

formance of planted species is still limited (Ramos and del Amo, 1992; Ådjers *et al*., 1995; Kammesheidt, 2002). Therefore, the objectives of this study were to investigate the performance of five native species in enricnhment planting using different canopy opening treatments and to determine the optimal species and silviculture techniques applicable to a logged-over forest in Lao PDR.

II. MATERIALS AND METHODS

2.1. Site description

The study was conducted in a logged-over lowland mixed deciduous forest in Bolikhan District, Borikhamxay Province, Lao PDR. The area lies between 18° 34' 35" N to 103° 41' 09" E (Fig. 1) and has an average elevation of 164 m above sea level, with a slope of two to five degrees. The annual rainfall ranged from 2,000 mm to 2,700 mm while the temperature ranged from 21.4°C to 31.2°C for the site. The relative humidity was estimated between 56 and 90% with average sunlight of 184 hours year^{-1} (Paksan, Borikhamxay Station, 2000~2008).

The study site was originally a lowland mixed deciduous forest. The height was estimated at 26 to 28 m with 55 to 60% canopy cover based on the vegetation map from a nationwide reconnaissance survey in 1982. The forest was covered by dominant commercial species such as *Pterocarpus macrocarpus* Kurz, *Afzelia xylocarpa* Craib, *Dipterocarpus alatus* Roxb. & G.Don, *Anisoptera costata* Korth., *Vatica cinerea* King, *Hopea odorata* Roxb., *Dalbergia cochinchinensis* Pierre, *D. cultrata* T.S.Ralph, *Schima wallichii* Choisy, *Cratoxylon* spp., and *Sindora cochinchinensis* Baill.

2.2. Planting materials

Five native species, namely *Afzelia xylocarpa*, *Anisoptera costata*, *Dalbergia cochinchinensis*, *Dipterocarpus alatus* and *Hopea odorata,* were selected for enrichment planting within the study site. Seedlings were six-months-old at the time of planting (June 1, 2002) with an average height of about 50 cm (AKECOP, 2006).

2.3. Experimental design

Enrichment planting by line and gap plantings was conducted using Randomized Complete Block Design with seven replicates. The layout was from East to West and North to South. All trees with diameter at breast height (DBH) of < 5 cm as saplings and seedlings were cut. The line planting treatments at 2 m and 3 m width were used, each with seven lines amounting to a total of 14 lines. The distance between plants was 3 m, and the distance between lines was 20 m for both treatments. Eleven seedlings for each species were randomly planted in a line. There were a total of 55 seedlings per line and 770 seedlings in total. In the case of gap planting, a size of 14 m × 14 m was considered with 3 m distance between plants. Thirty five gaps, with 25 seedlings per plot, were randomly distributed in the experimental area. Overall, 1,645 seedlings were planted occupying a land area of 8.16 ha.

2.4 Data collection and analysis

The effects of different canopy openings on survival rate, root collar diameter (RCD), tree height (hereafter described as height), crown height and crown diameter of all seedlings were determined for six years between June 2002 and June 2008. The survival rate was calculated based on the average number of trees per line and gap. RCD, height, crown height and crown diameter growth data were log-transformed prior to analysis.

Mean annual RCD and height increments were also estimated based on existing age of the seedling for each treatment. Means that exhibited significant differences were compared using Duncan's Multiple Range Test (DMRT) at 5% level of significance. Two way analysis of variance (ANOVA) was performed on the survival

Table 1. Summary of ANOVA for effects of planting treatments (Trt) and species (Sp) on survival rate, root collar diameter (RCD), height, crown height and crown diameter at six years after planting in a logged-over lowland mixed deciduous forest

Sources of variation	df	Survival		RCD		Height		Crown height		Crown diameter	
		F	P	F	P	F	P	F	P	F	P
Model	14	4.94	0.0001	1.89	0.0444	3.30	0.0005	5.65	0.0001	2.78	0.0028
Trt	2	1.16	0.3198	7.16	0.0015	13.17	0.0001	11.14	0.0001	1.52	0.2276
Sp	4	15.97	0.0001	1.93	0.1152	3.11	0.0209	10.39	0.0001	7.87	0.0001
Trt × Sp	8	0.38	0.9289	0.54	0.8195	0.93	0.4969	1.91	0.0728	0.55	0.8111
Error	65										

Table 2. Mean survival rates of five species at six years after planting in lines and gaps in a logged-over mixed deciduous forest

Species	Planting treatments			
	Line 2 m width	Line 3 m width	Gap	Overall mean
Hopea odorata	59.09 (9.66)c	81.82 (9.96)a	73.71 (5.37)b	71.65 (8.33)
Dalbergia cochinchinensis	62.11 (8.81)a	60.60 (8.32)a	61.14 (8.36)a	61.28 (8.49)
Dipterocarpus alatus	25.00 (9.87)b	33.33 (10.50)a	30.86 (8.67)ab	29.71 (9.68)
Afzelia xylocarpa	18.18 (3.44)b	30.30 (8.65)ab	33.71 (9.52)a	29.34 (7.20)
Anisoptera costata	29.09 (5.65)a	18.18 (3.44)b	28.00 (6.35)a	25.34 (5.15)

Note: Numbers in parentheses indicate standard error; values in a row followed by different letters indicate significant difference at 5% level of probability using Duncan's Multiple Range Test

rate, RCD, height, crown height and crown diameter in response to treatments and species. All statistical analyses were performed using SAS 9.1.3 (SAS Institute Inc., USA).

III. RESULTS AND DISCUSSION

3.1. Survival rate

In Lao PDR, the approved standard survival rate for plantation was 70% of the total planted seedlings (Department of Forestry, 1986). The means of survival rate of planted seedlings showed significant difference among study species ($F = 15.97$, $p = 0.0001$) at six years after planting (Table 1).

Table 2 shows the survival rates of all five species during assessment of the enrichment planting. *Hopea odorata* and *Dalbergia cochinchinensis* had higher survival rates among the five species, but the others showed significantly lower rates of below 30%. Survival rates of *Dalbergia cochinchinensis* showed insignificant differences among the planting treatments and is thus suitable to be planted either through line planting or gap. *Hopea odorata*, having the highest overall mean survival, showed a significant preference ($p < 0.05$) for 3 m width line planting in terms of survival rate followed by gap planting. A similar trend was also observed for *Dipterocarpus alatus*. On the contrary, survival of *Anisoptera costata* was the poorest ($p < 0.05$) in the 3 m width planting treatment. Meanwhile, the survival of *Afzelia xylocarpa* increased with improved light condition as shown in gap planting.

The suvival of seedlings is much affected by direct results of drought or non-drought stressors, such as herbivores, pathogens and competition exacerbated by drought. During the inventory, we noted that the planting lines were heavily over-shadowed by the crown of surrounding big trees and rampantly growing bamboos compared to gap plantings. The steady closure of canopy from the starting of the second year, due to rapid growth of bamboos and the intermediate canopy trees, had reduced the level of irradiance in both gap and line plantings.

The success of line planting almost depends on light penetration. Insufficient light may cause high survival for shade-tolerant species (Chai and Uderbe, 1977) and light condition is related with line width and stand height as well (Tang and Wadley, 1976). However, there could be other factors influencing the survival of seedlings. According to Adjers *et al.* (1995), Pena-Claros *et al.* (1995) and Ramos and Amo (1992), line

Table 3. Means of root collar diameter of five species at six years after planting in lines and gaps in a logged-over mixed deciduous forest

Species	Planting treatments			
	Line 2 m width	Line 3 m width	Gap	Overall mean
Hopea odorata	15.83 (0.26)a	9.00 (0.06)b	14.81 (0.20)ab	13.30 (0.17)
Dalbergia cochinchinensis	13.61 (0.34)a	6.35 (0.07)b	12.18 (0.11)a	10.79 (0.17)
Dipterocarpus alatus	14.90 (0.40)a	8.97 (0.13)b	14.35 (0.28)a	13.36 (0.27)
Afzelia xylocarpa	13.27 (0.17)a	13.43 (0.13)a	10.95 (0.21)b	12.06 (0.17)
Anisoptera costata	20.74 (0.54)a	6.50 (0.08)b	19.14 (0.29)ab	17.15 (0.30)

Note: Numbers in parentheses indicate standard error; values in a row followed by different letters indicate significant difference at 5% level of probability using Duncan's Multiple Range Test direction and width do not affect the survival rate of seedlings. Based on the results of their studies, they suggested that a 6 m width for line planting is most suitable for a trees growth. Canopy gap between 25 and 54% is best for height growth while not affecting crown trait and survival. Moura-Costa *et al.* (1994) and Okimori *et al.* (2006) confirmed that the main factor affecting survival rate is low annual rainfall.

3.2. Root collar diameter

The overall means of RCD were significantly different among treatments ($F = 7.16$, $p = 0.0015$) and species ($F = 1.93$, $p = 0.1152$) as shown in Table 1. All study species showed higher RCD at 2 m width line planting than the other treatments (Table 3). *Anisoptera costata* showed the highest overall RCD mean among the study species with the biggest value at 20.74 mm in 2 m width line planting followed by gap planting, but with the smallest value in the line planting 3 m width. *Dalbergia cochinchinensis* showed the smallest overall RCD with the lowest value in 2 m width line planting. In addition, *Hopea odorata* and *Dipterocarpus alatus* also showed lower RCD in the 2 m width line planting. Thus, the results of this study disagree with Adjers *et al.* (*1995*) who reported that line width and line direction did not affect the survival and growth of seedlings, but rather horizontal maintenance affected survival and growth of seedlings. Paquettte *et al.* (*2006*) suggested that overstorey retention gradient, protection, understorey competition, survival and growth were strongly affected with optimal level of sites (line/strip, gap).

3.3. Height growth

Table 1 shows that the overall height means of seedlings were significantlly different among the treatments ($F = 13.17$, $p = 0.001$) and species ($F = 3.11$, $p = 0.0209$). Compared to other species (Table 4), *Hopea odorata* showed the best height growth followed by *Dalbergia cochinchinensis*.

All study species showed higher height growth in gap planting than in line planting treatments. This indicated that all seedlings of each species prefer higher light intensity for height growth. However, in line planting treatments, strong damage to the shoot of *Afzelia xylocarpa, Anisoptera costata* and *Dipterocarpus alatus* occurred due to limited light intensity. The dipterocarp species in our study also showed differences in height growth in relation to level of light. *Hopea odorata* appeared to be less shade-tolerant than *A. costata* and *D. alatus*. In gap planting, optimal gap size of 500 m^2 or above has been suggested for better height growth of dipterocarp species (Tuomela *et al.*, 1996). However,

Table 4. Mean of height of five species at six years after planting in lines and gaps in a logged-over mixed deciduous forest

Species	Planting treatments			
	Line 2 m width	Line 3 m width	Gap	Overall mean
Hopea odorata	110.33 (16.94)ab	96.53 (12.09)b	139.11 (15.00)a	116.58 (14.67)
Dalbergia cochinchinensis	80.86 (8.84)b	101.64 (10.92)ab	144.02 (12.72)a	110.69 (10.83)
Dipterocarpus alatus	47.32 (4.36)c	62.22 (3.03)b	107.31 (19.19)a	80.51 (8.86)
Afzelia xylocarpa	63.50 (8.74)c	77.44 (16.33)b	110.76 (11.76)a	92.16 (12.28)
Anisoptera costata	68.23 (8.50)b	62.89 (4.60)c	111.05 (19.57)a	87.15 (10.89)

Note: Numbers in parentheses indicate standard error; values in a row followed by different letters indicate significant difference at 5% level of probability using Duncan's Multiple Range Test

Table 5. Crown height (Mean ± standard error) of five species after six years of planting in lines and gaps in logged-over mixed deciduous forest

Species	Planting treatments			
	Line 2 m width	Line 3 m width	Gap	Overall mean
Hopea odorata	54.62 (5.35)b	49.73 (8.65)bc	83.02 (8.24)a	63.54 (7.41)
Dalbergia cochinchinensis	41.59 (4.41)b	39.68 (5.28)b	87.40 (8.32)a	58.88 (6.00)
Dipterocarpus alatus	37.18 (8.15)ab	26.25 (3.12)c	42.41 (10.60)a	36.12 (7.29)
Anisoptera costata	25.50 (6.70)bc	29.74 (3.08)b	42.91 (9.10)a	34.17 (6.29)
Afzelia xylocarpa	32.93 (9.32)a	25.46 (10.54)b	26.99 (5.81)b	28.14 (8.56)

Note: Numbers in parentheses indicate standard error; values in a row followed by different letters indicate significant difference at 5% level of probability using Duncan's Multiple Range Test

Table 6. Means of crown diameter of five species at six years after planting in lines and gaps in a logged-over mixed deciduous forest

Species	Planting treatments			
	Line 2 m width	Line 3 m width	Gap	Overall mean
Hopea odorata	59.35 (5.83)a	60.08 (11.76)a	51.29 (3.65)b	56.62 (8.33)
Dalbergia cochinchinensis	54.73 (6.49)a	43.45 (6.77)b	41.44 (5.68)b	45.94 (8.49)
Dipterocarpus alatus	48.75 (4.86)a	39.68 (6.81)b	48.97 (7.51)a	46.02 (9.68)
Anisoptera costata	34.88 (8.04)ab	34.28 (4.32)ab	36.26 (4.70)a	35.33 (5.15)
Afzelia xylocarpa	32.28 (2.56)a	27.19 (10.32)b	6.91 (1.39)c	20.10 (7.20)

Note: Numbers in parentheses indicate standard error; values in a row followed by different letters indicate significant difference at 5% level of probability using Duncan's Multiple Range Test

for line planting, Pena-Claros *et al.* (1995), Ramos and Amo (1992), and Adjers *et al.* (1995) suggested that a 6 to 10 m width is most suitable for growth.

3.4. Crown height and diameter

The overall crown height was significantly different in planting treatments ($F = 11.14$, $p = 0.0001$) and species ($F = 10.39$, $p = 0.0001$) as well. *Hopea odorata* and *Dalbergia cochinchinensis* showed higher crown height among the study species. Most species showed higher values in gap planting except *Afzelia xylocarpa* (Table 5). This implicated that each study species had different adaptations to light conditions, and better light conditions such as the gap is more favorable than other plantation treatments (Tuomela *et al*., 1996; Pinard *et al*., 1998).

The overall crown diameter was significantly different among five species (F = 7.87, p = 0.0001). The overall means of crown diameter showed a decreasing order of *Hopea odorata* > *Dipterocarpus alatus* > *Dalbergia cochinchinensis* > *Anisoptera costata* > *Afzelia xylocarpa* (Table 6). The limited growth of crown height and diameter in three planting methods in logged-over forest are strongly affected by light intensity compared to the seedlings planted at open canopy cover areas during the same period (Phengdouang *et al*., 1994; Phongoudome *et al*., 2010). A better understanding of ecological traits such as light or shade tolerance for the target species could improve techniques for enrichment planting in secondary forests (Appanah and Weinland, 1993; Kenzo *et al*., 2008). It is therefore necessary to consider specific species favorable to be planted in light conditions when conducting effective enrichment planting in degraded secondary forests.

IV. CONCLUSION

The overall highest survival rates were exhibited by *Hopea odorata* and *Dalbergia cochinchinensis* among the five study species in this study. These two species also performed better in terms of height growth and thus, can be used as optimal species for rehabilitation of logged-over and fallow forests in Lao PDR. This study also showed that planting treatments significantly affected seedling growth, regardless of species. Therefore, this implicated that not only the selection of optimal species, but also the selection of planting methods should be thoroughly considered in order to achieve fruitful results in enrichment planting. In addition, constant assessment is recommended in order to verify species suitability and optimum line width or gaps of canopy opening for enrichment planting activities in restoring secondary forest in Lao PDR and other tropical regions.

적 요

Enrichment planting은 라오스에서 산림복원 프로그램의 일환으로, 이차림에서 수종의 밀도를 증가시키는데 흔히 쓰인다. 본 연구는 다섯 종의 자생수종을 대상으로 임관층을 다양한 방법으로 소개하고 Enrichment planting을 실시하여 라오스에서 개벌 이후 적용할 수 있는 조림방법과 적합한 수종을 조사하였다. 본 연구 결과, 수관층의 높이만 조사수종간 그리고 식재처리간 모두에서 통계적으로 유의한 차이가 나타났다. 묘목의 생존율과 수관층의 직경은 조사수종간에서는 유의한 차이가 나타났으나, 식재처리간에는 차이가 없었다. 반면 묘목의 근원경과 묘고는 식재처리간에서만 유의한 차이가 나타났다. 조사수종 중에는 *Hopea odorata* 와 *Dalbergia cochinchinensis* 가 다른 수종들에 비해 생존율과 수고생장 모두 양호한것으로 나타났는데, 이는 이들 수종들이 향후 라오스 산림복원을 위한 Enrichment planting에 적용하기 적합할 것으로 판단된다. 또한

2m간격의 line planting은 묘목의 근원경 생장을 촉진시킬 수 있을 것으로 제안되지만 gap planting과 같이 넓은 간격의 line planting은 묘고생장을 촉진시킨 것으로 나타났다.

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