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Full Length Research Paper

Growth of several indigenous species in the degraded forest in the northern Vietnam

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This study was conducted in the northern mountainous region of Vietnam. Research occurred at two main sites: the Hoa Binh province and the Phu Tho province. The objective of this study was to compare growth rate and the physiological characteristics of the indigenous tree species; with the ultimate goal of selecting a suitable species for the restoration of the degraded forest area. Except for an *Acacia* hybrid, this study indicated that *Pelthophorum tonlinensis, Lithocarpus ducampii* and *Cinamomum obtusifolium*, in the Hoa Binh Province, and *Pygeum arboretum, Cinamomum parthenoxylon* and *Endospermum sinensis*, in the Phu Tho Province, showed higher height growth. *Quercus poilanei, E. sinensis, Lithocarpus ducampii,* and *P. tonlinensisi* exhibited good physiological performances, and had potential for use in the restoration of degraded forest. The results of this study will improve the success of restoration programs, by selecting suitable species for planting on the degraded lands; according to their specific reforestation objectives.

Key words: Vietnam, degraded forest, growth, indigenous species, photosynthesis, water use efficiency.

INTRODUCTION

Forest cover in Vietnam has diminished rapidly for most of the latter half of the last century, declining from around 43% in the 1940s to 17% by the late 1970s (Nguyen, 2000). By 1995 the total area of land with grass or shrub cover was estimated at 9.7 million ha. Between 1976 and 1990, it is estimated that 185,000 ha of forest cover was being lost annually. Decades of deforestation and unsustainable land use have created large expanses of degraded land in northern Vietnam. There are a number of reasons for these losses, including logging and over-harvesting of forest products, wars, forest fires, slash and burn agriculture, and encroachment into forest regions by industrial agriculture (Lamb, 1998). There have been many studies on the restoration of degraded forests, by way of plantation or natural forest regrowth; however, reforestation of many of these degraded areas is difficult. Not only is it difficult to establish trees in fire-prone grasslands, but also many of the soils are infertile and very few native species are able to tolerate such conditions. The seedlings of some tropical tree species also appear to require some degree of initial shading in order to establish (Aide et al., 2000; Parrotta et al., 1997).

In Vietnam, there have been incentives for forest restoration, particularly in mixed species plantations. Most reforestation is carried out on farmers' lands and has required their participation, but they often have no or little experience in intensive tree plantation management, or little silvicultural knowledge about some of the commercially attractive timber species. Because of this, much early plantation development in Vietnam has focused on monoculture of fast-growing exotic species of *Eucalyptus*, *Acacia* and *Pinus*. However, many indigenous species have failed when taken from their original natural mixed stands to establish in pure plantations. The failed species such as *Erythphoelum fordii*, *Chukrasia tabularis*, and *Canarium album*, when planted in pure plantations as a monoculture, did not perform well. This is also the case with *Manglietia glauca* planted in the north; *Pahudia chochinchinensis*, *Michelia* spp., *Pterocarpus* spp., and

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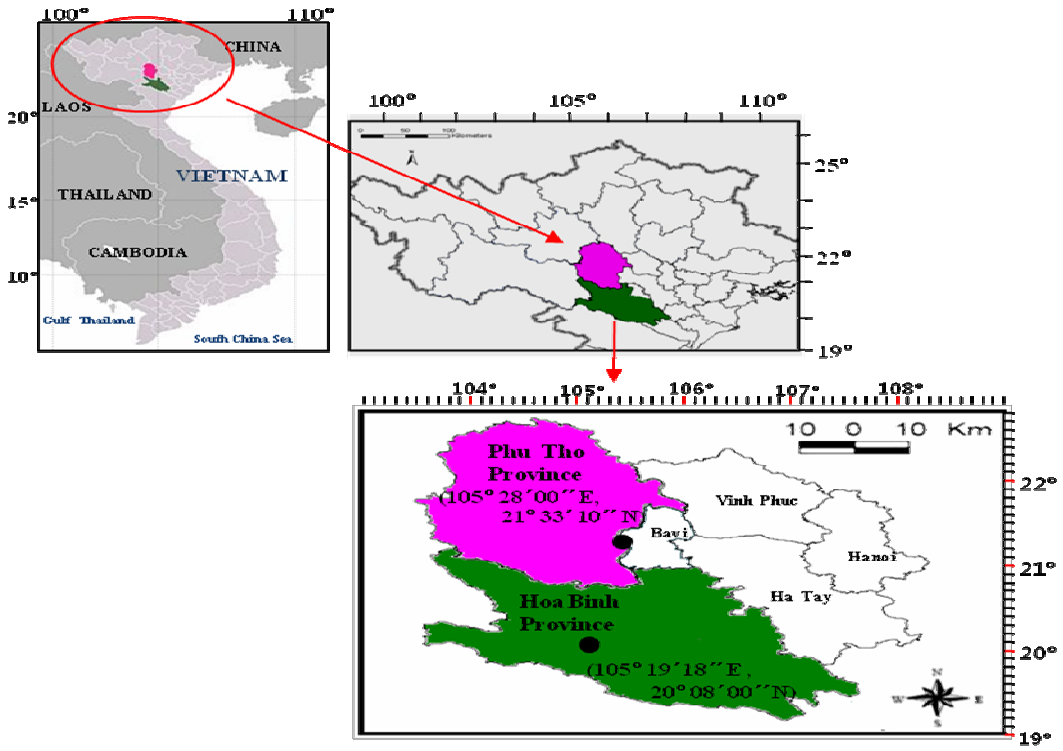

Figure 1. Map of the study sites in the mixed plantation and the secondary forest in Northern mountainous regions of Vietnam.

Toona spp. established in the central highland; and *Hopea* and *Dipterocarpus* spp. in southern Vietnam (Tran et al., 2005). When proposing appropriate silvicultural techniques for reforestation, it is necessary to understand the physiology of potential plants. In addition, it is necessary to provide an ecological information support system for the improved selection of species when rehabilitating degraded lands with indigenous tree species and sustainable forest management.

The objective of this study was to compare growth performance and the physiological characteristics of indigenous tree species, in order to select a suitable species for the restoration of degraded forest areas.

MATERIALS AND METHODS

Study site

There were two study sites in the northern mountainous region of Vietnam. One was established in the Thung Nai Commune (20° 33' 10'' N, 105° 19' 18''E), Hoa Binh Province, and the other was in the Chan Mong Commune (20° 8' N, 105° 28' E), Phu Tho Province. The sites were planted with indigenous species in 2003. In addition, the secondary forest area near the mixed indigenous plantation was regenerated naturally (Figure 1).

Site at Hoa Binh Province

Hoa Binh has an area of 4,797 km^2 with 757,637 inhabitants. The altitude of the site is between 100 to 300 m above sea-level (a.s.l.). The annual rainfall is between 1,600 to 1,900 mm. The average temperature is 29.9℃ (max. 36 ℃, min. 6℃). The maximum relative humidity is 98% and the minimum is 76%, with an average of 82%. The research site is hilly and lower mountainous, in the Da-river watershed area. The area was historically covered by evergreen broad-leaved forests, and has been degraded due to overexploitation and shifting cultivation; it has been under regeneration management since 1998 (Tran et al., 2005).

Selected trees at Hoa Binh

Six tree species were selected and their physiological traits were monitored: an *Acacia* hybrid, *Erythrophloeum fordii*, *Pelthophorum tonlinensis, Lithocarpus ducampii, Cinamomum obtusifolium* and *Hopea odorata.*

Site at Phu Tho Province

Phu Tho's covers 3,519 km^2 and contains 1,302,700 inhabitants. The altitude ranges between 60 to 100 m a.s.l. The average annual rainfall is 1,800 mm. The mean temperature ranges from 22.2 to 26.5℃, with an average of 22.9℃. The relative humidity ranges from 75 to 88%, with an average of 83%. Mainly, the area is covered by low hills, of which the slope varies from 10° to 35°. The original forest cover was an evergreen forest; composed of several typical species of the *Fagaceae* and *Fabaceae* families (such as *Quercus platycalyx, Lithocarpus fissus, Ormosia balancae* and *Machilus bonii*, among others), and plenty of bamboo, rattan, grass and shrub species. The site was degraded between 1976 to 1990 due to over exploitation and shifting cultivation. Effort at

Table 1. Height and diameter growth of six indigenous tree species in Hoa Binh Province.

No.	Species	Family	Root collar diameter (cm)	Height (m)
1	*Erythrophloeum fordii* Oliver	Euphorbiaceae	2.38±0.16b*	2.33±0.19c
2	*Acacia* hybrid	Leguminosae	4.77±0.22a	3.77±0.23a
3	*Pelthophorum tonlinensis* A. Chev	Fagaceae	2.57±0.09b	2.57±0.09b
4	*Lithocarpus ducampii* Camus	Caesalpinioideae	2.00±0.17c	2.73±0.29b
5	*Cinamomum obtusifolium* Nees	Lauraceae	2.47±0.24b	2.37±0.19c
6	*Hopea odorata* Roxb	Diterocarpaceae	2.57±0.19b	2.03±0.09d

*Values followed by the same letter are not significantly different among clones at $P < 0.05$ according to Duncan's multiple range tests. Numbers indicate mean ± standard error.

rehabilitation in this area started in the later 1990s (Do et al., 2004; Tran et al., 2005).

Generally, research sites for the study of natural forests are degraded forests based on natural forest classification system of Vietnam. Recorded growth in plantations has been very poor; species in plantations grew at half the rate of plants of the same species that had been planted in the fertile soils. The original vegetation at this study site is characterized as Tropical Rain Forest. The area was subjected to over-harvesting, illegal cutting, shifting cultivation and grazing, and removal of the top soil layer. Vegetative cover is mainly composed of some annual grass species mixed with some pioneer forest tree species, such as *Schima wallichii, Litsea cubeba, Ficus fulva* and *Macaranga denticulata* (Tran, 2001).

The site was selected because the plantations at this site have been relatively well-documented, and are representative of areas in need of rehabilitation in the Northern mountainous regions of Vietnam. Degraded forest in the research area has a potential for natural regeneration. However, there is a lack of regenerated seedlings in some places, due to the lack of parent trees needed for seed supply or due to unsuitable conditions for natural germination.

Selected tree species at Phu Tho

Six tree species were selected and their physiological traits were monitored: *Endospermum sinensis, Quercus poilanei, Quercus platicalyx, Erythrophloeum fordii, Cinamomum parthenoxylon* and *Pygeum arboreum.*

Physiological characteristics

Photosynthesis

Net photosynthesis (P_N) was measured on the forth fully expanded mature leaf, counted from the apex of each shoot, of every individual in the sites. Net photosynthesis was measured in a broad-leaf cuvette with a Licor-6400 Portable Photosynthesis System (Li-cor Inc., USA). The species light curve was developed, under 300 µmol CO_2, and the photosynthetic photon flux density (PPFD) ranged between 0 to 2,000 µmol m^{-2} s^{-1}. One fully expanded and healthy leaf per species was measured, in two replications; the average of the two replicates was recorded.

Water use efficiency

Water use efficiency (WUE) was calculated as a proportion of photosynthetic rate compared to the transpiration rate (P_N/E) (Ashraf et al., 2002). Each measurement of net photosynthesis and transpiration was taken at 1,200 µmol m^{-2} s^{-1} light intensity, with a Licor-6400 Portable Photosynthesis System (Li-cor Inc., USA).

$WUE = P_N/E$

Where: WUE is water use efficiency (µmol CO_2/mmol H_2O). P_N is photosynthetic rate (µmol CO_2 m^{-2} s^{-1}). E is transpiration rate (mmol H_2O m^{-2} s^{-1})

RESULTS

Growth performances and physiological characteristics of indigenous species in the Hoa Binh Province

Growth performance

During the first 48 months after planting, all species grew relatively slowly, except for the *Acacia* hybrid, which, as a nitrogen-fixing legume species, grew well and had the potential to improve soil fertility (Table 1). Except the *Acacia* hybrid, native species had different growth rates, in terms of both diameter and height. *Lithocarpus ducampii* had the highest growth, followed by *Pelthophorum tonlinensis, Cinamomum obtusifolium, Erythrophloeum fordii* and *Hopea odorata*. Their average heights at 48 months after planting were 2.73, 2.57, 2.37, 2.33 and 2.03 m, respectively (Table 1).

Physiological characteristics

The photosynthetic rate of *L. ducampii* was the highest among the five indigenous species, 9.64 µmol CO_2 m^{-2} s^{-1} at 2,000 µmol $m^{-2}s^{-1}$ PPFD. The four other species had lower rates at 2,000 µmol m^{-2} s^{-1}. The *Acacia* hybrid's photosynthetic rate, as a supporting species, was highest at 2,000 µmol m^{-2} s^{-1} (Figure 2). The results suggest that different species had different light requirements of the species; however, the differences were not significant. All species did not require high light intensities at the initial time of planting, which implies that these species should

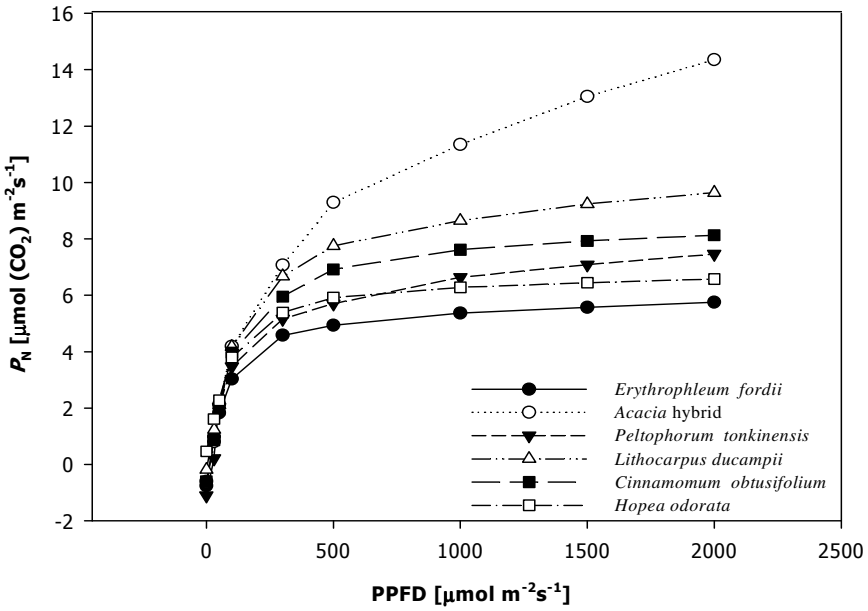

Figure 2. Net photosynthesis of six indigenous species in Hoa Binh Province.

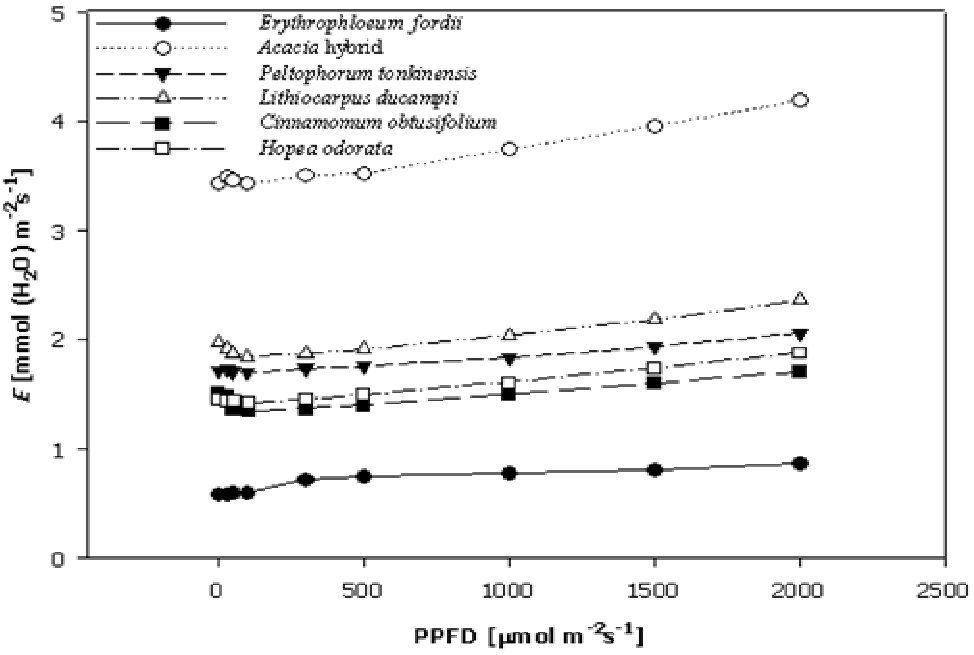

Figure 3. Transpiration of six indigenous species in Hoa Binh Province.

be planted under the shade, where the light intensities are lower.

The *Acacia* hybrid and *L. ducampii* had the highest transpiration rates at 2,000 µmol m^{-2} s^{-1}, 4.19 and 2.36 mmol H_2O m^{-2} s^{-1}, respectively. Most species exhibited decreased transpiration rates at 300 µmol m^{-2} s^{-1}. *E. fordii* had the lowest transpiration rates among the species examined (Figure 3). Species that had low transpiration rates exhibited reduced water loss under severe drought stress and high light intensities. These findings may help forest managers to properly allocate species into the site that best fits their growth requirements, in terms of light

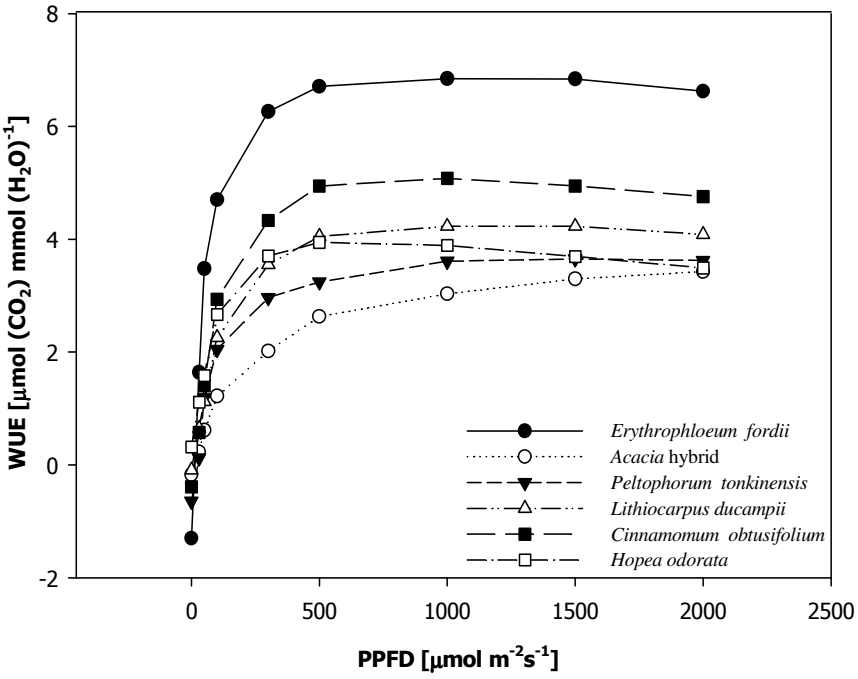

Figure 4. Water use efficiency of six indigenous species in Hoa Binh Province.

intensity and soil moisture levels. The water use efficiency (WUE) of plants is a good indicator of the plants' ability to photosynthesize while conserving water. The stomas are the same avenue by which carbon dioxide enters the plant for photosynthesis and water is lost through transpiration. Thus, the evaluation of WUE is an important ecophysiological characteristic of plants, as it combines both photosynthesis and transpiration.

The highest WUE value among the examined species was exhibited by *E. fordii* (6.85 µmol CO_2 mmol H_2O^{-1}, at 1,000 µmol m^{-2} s^{-1} PPFD). It was followed by *C. obtusifolium* (5.08 µmol CO_2 mmol H_2O^{-1}, at 1,000 µmol m^{-2} s^{-1} PPFD), *L. ducampii*, *H. odorata, P. tonlinensis* and the *Acacia* hybrid exhibited low WUE values, as they lost more water per mole of carbon dioxide than the other two species (Figure 4). This suggests that they should not be planted in areas where water is a limiting factor.

Growth performances and physiological characteristics of indigenous species in the Phu Tho Province

Growth performance

Significant differences and interactions among species were detected in the mean growth performance data. Maximum mean height and diameter were significantly different between *P. arboreum* and *C. parthenoxylon.* Over the four *P. arboreum* and *C. parthenoxylon*, had largest diameters, at the root collar, of 4.49 and 4.63 cm, and highest plants at 5.02 and 4.56 m, respectively. The minimum mean growth was exhibited by *E. fordii*, at 2.75 cm in diameter and 2.63 m in height (Table 2).

Physiological characteristics

The light curves of *C. parthenoxylon, P. arboreum,* and *E. sinensis* showed increasing photosynthetic rates over 300 µmol m^{-2} s^{-1}, and had the highest rate at 2,000 µmol m^{-2} s^{-1} PPFD; followed by *E. fordii, Q. poilanei,* and *Q. platicalyx.* In this study *C. parthenoxylon* and *P. arboreum* were considered to be the most photosynthetically efficient plants, because they had the high net photosynthetic rate at increased light intensities. *E. fordii* showed the lowest rate, at 3.53 µmol CO_2 m^{-2} s^{-1}, even at maximum PPFD of 2,000 µmol m^{-2} s^{-1}. The low photosynthetic rate of *E. fordii* has been adequately confirmed by its actual field performance (Figure 5).

Transpiration is a process by which water is lost from plants; it is both beneficial and detrimental. It is beneficial as a driving force, moving water and minerals from the soil into the roots and then into the various cells of the plant. In this study transpiration rate varied similarly to the rate of net photosynthesis. The transpiration values ranged between 0.288 to 2.67 mmol H_2O m^{-2} s^{-1}. *P. arboreum, E. sinensis,* and *Q. poilanei* had the highest transpiration rates (2.67, 2.285 and 1.95 mmol H_2O m^{-2} s^{-1}, respectively) at PPFD 2,000 µmol m^{-2} s^{-1} (Figure 6). The total transpiration rate per species was greater for *P.*

Table 2. Height and diameter growth of six indigenous tree species in Phu Tho Province.

No.	Species	Family	Root collar diameter (cm)	Height (m)
1	*Endospermum sinensis Benth*	Euphorbiaceae	3.62±0.28c*	3.90±0.27c
2	*Quercus poilanei* Hickel et. A.Camus	Fagaceae	4.23±0.18b	3.35±0.24d
3	*Quercus platicalyx* Hickel et al A.Camus	Fagaceae	3.06±0.23d	3.15±0.07e
4	*Erythrophloeum fordii* Oliver	Caesalpinioideae	2.75±0.32d	2.63±0.23f
5	*Cinamomum parthenoxylon* (Jack) Nees	Lauraceae	4.63±0.18a	4.56±0.09b
6	*Pygeum arboreum* Endl	Rosaceae	4.49±0.20a	5.02±0.26a

*Values followed by the same letter are not significantly different among clones at P < 0.05 according to Duncan's multiple range tests. Numbers indicate mean ± standard error.

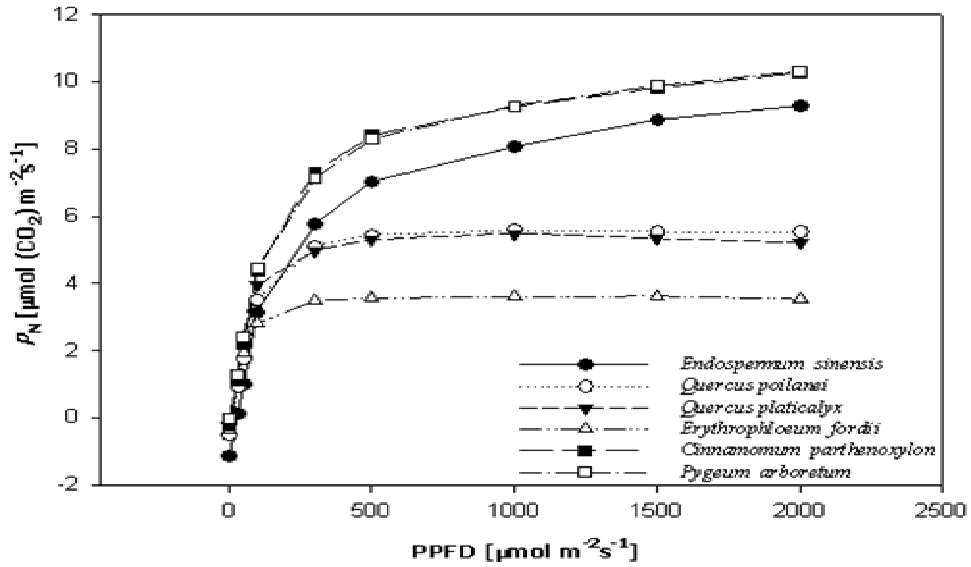

Figure 5. Net photosynthesis of six indigenous species in Phu Tho Province.

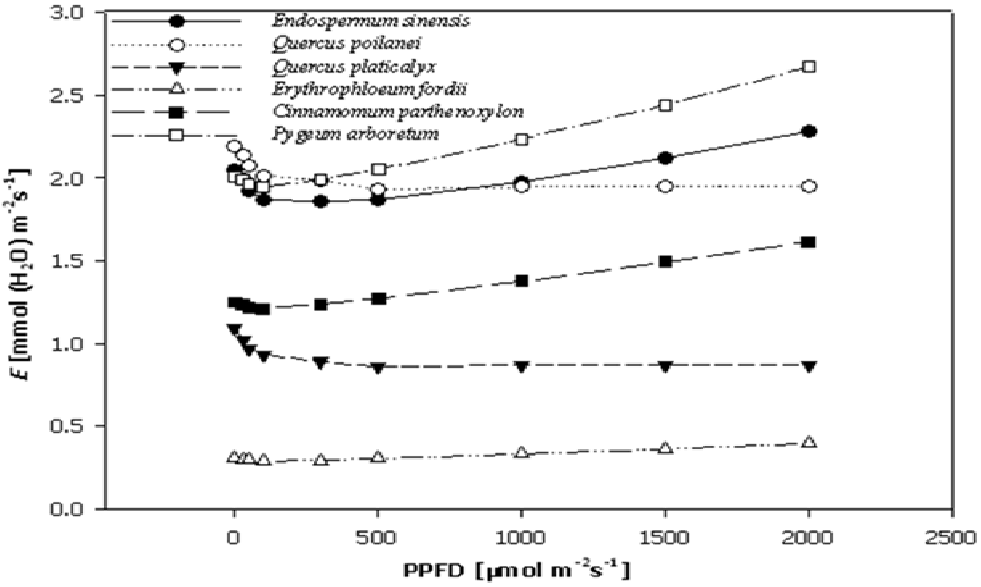

Figure 6. Transpiration of six indigenous species in Phu Tho Province.

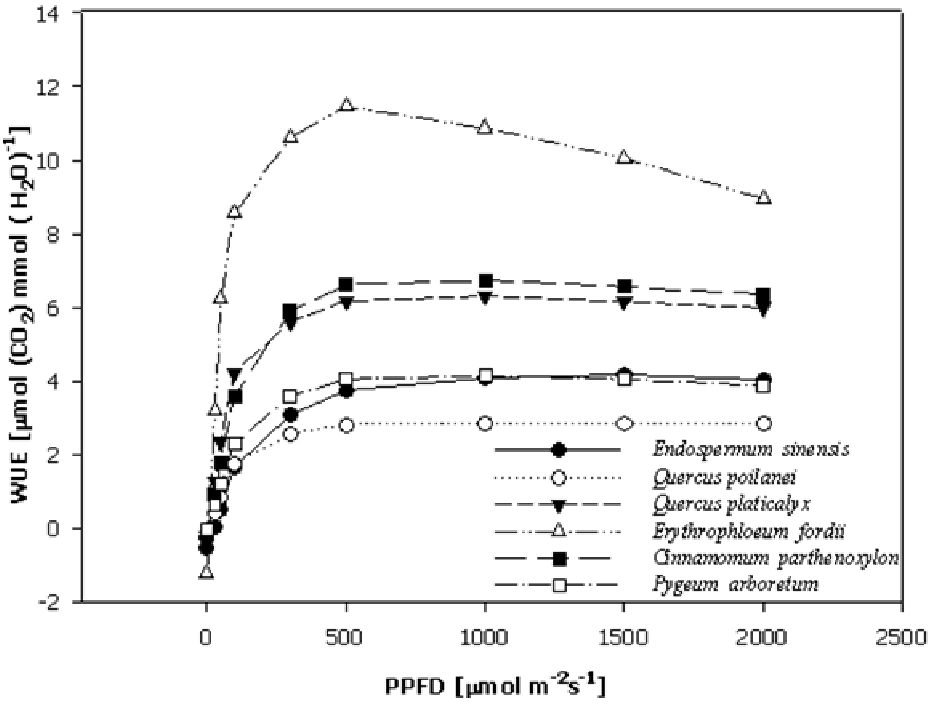

Figure 7. Water use efficiency of six indigenous species in Phu Tho Province.

arboreum, E. sinensis, and *Q. poilanei* than other species, because they had a greater total surface area of transpiration. *E. fordii, Q. platicalyx* and *C. parthenoxylon* transpired at rates of 0.394, 0.87 and 1.615 at PPFD 2,000 µmol m^{-2} s^{-1}, respectively (Figure 6).

The most water-use efficient species among the plants examined was *E. fordii*, with a WUE value of 11.925 µmol CO_2 mmol H_2O^{-1} at 300 µmol m^{-2} s^{-1} PPFD (Figure 7). It was followed by *C. parthenoxylon* (6.73 µmol CO_2 mmol H_2O^{-1} at 300 µmol $m^{-2}s^{-1}$ PPFD). *E. fordii* and *C. parthenoxylon* had high WUE values, which are indicative of an ability to survive under drought stress conditions, which are typical in degraded sites. The rest of the species examined will be comparatively disadvantaged, in terms of carbon gain, when planted in dry sites. *Q. platicalyx, E. sinensis, P. arboreum,* and *Q. poilanei* had lower WUE values (5.99, 4.05, 3.86 and 2.84 µmol CO_2 mmol H_2O^{-1} at 2,000 µmol m^{-2} s^{-1} PPFD, respectively) (Figure 7). These results could suggest that *E. fordii* and *C. parthenoxylon* tend to fix more carbon dioxide per unit of water loss, which means they could be planted in areas where water is limiting.

DISCUSSION

Evaluation of successful mixed-species plantations involving indigenous tree species must necessarily run for long periods before definite conclusions can be drawn. This is especially the case when inter-species competition is a key study issue. Four years is an early stage at which to assess the performance of species that could be expected to grow for several decades (Grant et al., 2006). However, the growth performance of several species in this study can be examined based on the rate at which height has increased. *C. parthenoxylon, P. arboreum, L. ducampii,* and *P. tonlinensisi* grew much more than the other species studied. It is commonly assumed that the early height growth rates of tropical trees reflect successional status (Whitmore, 1999). Height growth rates achieved, at these two experimental sites, for the indigenous species studied were not significantly higher than those of other species (Grant et al., 2006). However, other studies in the similar research areas showed the similar growing trends on the height and diameter at root collar (Lamb, 1998; Lamb and Nhan, 2006).

In the results, photosynthesis, transpiration and water use efficiency differed between indigenous tree species, on the study sites. The light curve for most species illustrated increasing photosynthetic rates beyond 300 µmol m^{-2} s^{-1} PPFD, but not for *E. fordii, Q. poilanei,* and *Q. platicalyx* in the Phu Tho province. The decrease in photosynthesis in these three species at PPFDs higher than 300 µmol m^{-2} s^{-1} PPFD is possibly due to photoinhibition, which is a common phenomenon in shade tolerant species exposed to high light intensity (Kozlowski et al., 1997). The photoinhibition level that an individual is subjected to can be modified by thinning of a stand, pruning, and by the spreading of branches (Kozlowski and Pallardy, 1997). This study has indicated that *P. tonlinensis, L. ducampii* and *C. obtusifolium*, in the

Hoa Binh Province, and *E. sinensis, C. parthenoxylon* and *P. arboretum*, in the Phu Tho Province, can tolerate higher light intensities compared with other species that growth under similar conditions. Transpiration rate for most species increased as light intensity increased above 500 µmol m^{-2} s^{-1} PPFD; but not for *Q. poilanei,* and *Q. platicalyx*, which both belong to the family *Fabaceae*, in the Phu Tho Province. The decrease in transpiration rates exhibited by these species was due to high light intensity and increasing water loss. *Q. poilanei, E. sinensis, L. ducampii* and *P. tonlinensis*, from both sites, exhibited their lowest WUE values at 2000 µmol m^{-2} s^{-1} PPFD. This result suggests that these species could grow well at the degraded sites.

In terms of physiological aspects, *Q. poilanei, E. sinensis, L. ducampii,* and *P. tonlinensisi* performed well and have potential for use in the restoration of degraded land. The results of this study will improve the success of restoration programs, by aiding in the selection of suitable species for plantation on degraded land, according to the specific reforestation objectives of the program.

ACKNOWLEDGEMENT

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