Research paper

Silvicultural Growth Performances of Thirteen Endemic Broadleaf Trees of Taiwan

Han-Ming Yu,[1,4)]Fu-Ching Ma,[1)] Yen-Ray Hsu,[2)]
Nai-Hang Chang,[3)] Fu-Wen Horng[1)]

【Summary】

We investigated the growth potential of some endemic broadleaf species used in restorative reforestation. In March 1993, mix-plot planting of the 13 test species native to mid-elevation forests of Taiwan was carried out in a tract situated at 800 m elevation with a southwest facing slope at the Taimali Research Center Taiwan Forestry Research Institute, Taitung, southeastern Taiwan. Each species was planted with 3~5 plot repetitions, and in each plot, 50 trees of the same species were planted with a 2×2-m spacing. A survey of sapling growth was carried out periodically, and tree forms were also investigated in later years. Results showed that common elaeocarpus (*Elaeocarpus sylvestris*) and incense machilus (*Machilus zuihoensis* var. *zuihoensis*) saplings had better growth performances and survival rates, and the respective mean height growth had reached 750 and 730 cm 9 yr after out-planting. Their survival rates all reached 60%. With the exception of *Pasania kawakamii* and *Tricalysia dubia* which did not reach 5 m in height, the mean height growth of the other indigenous broadleaf trees including *Pasania ternaticupula*, *Schima superba*, *Schefflera octophylla*, *Lithocarpus castanopsisifolius*, and *Cinnamomum micranthum*, all exceeded 5 m, although their growth was not as fast as some general plantation species such as *Fraxinus formosana*, and their mean diameter at breast height (dbh) growth all reached 7 cm. The net height growth of the studied species in the first 3 yr, was 30~50 cm yr^{-1}, with the exception of *Zelkova serrata* which reached 80 cm yr^{-1}. However, all species had net height growth exceeding 80 cm yr^{-1} during 3~5 yr, with *E. sylvistris* reaching 140 cm yr^{-1}. The fast-growing period of the saplings among tree species lasted to 88 mo after out-planting. These results suggest that endemic broadleaf species have tremendous afforestation potential in mid- and low-elevation plantation forests of Taiwan. When coupled with good tending and management of the forests, even greater silvics potential can be realized.

Even in the early stage of growth, saplings often had forking tendencies with 2 m or more of crown width of planted trees, which may cause retardation of subsequent growth performance and may also influence the tree quality for timber utilization. In particular, as the average forking rate

1) Division of Silviculture, Taiwan Forestry Research Institute, 53 Nanhai Rd., Taipei 10066, Taiwan. 林業試驗所育林組，10066台北市南海路53號。

2) Chung-Pu Research Center, Taiwan Forestry Research Institute, 65 Wunhua Rd., Lane 432, Chiayi 60044, Taiwan. 林業試驗所中埔研究中心，60044嘉義市文化路432巷65號。

3) Liu-Kuei Research Center, Taiwan Forestry Research Institute, 198 Chun-Shine Village, LiuKuei, Kaohsiung 84443, Taiwan. 林業試驗所六龜研究中心，84443高雄縣六龜鄉中興村198號。

4) Corresponding author, e-mail:yhm@tfri.gov.tw 通訊作者。

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reached 40%, we deem that pruning and thinning of small-diameter logs should be scheduled to promote tree form quality. A correlated regression analysis of tree height growth and tree age indicated that 2-degree polynomial regression equations ($R^2 \geq 0.90$) by tree age of tree species can be used to predict the early growth performance of planted trees at the site.
Key words: endemic species, broadleaf, growth performance, silviculture.
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研究報告

13種原生闊葉樹造林生長表現

游漢明[1,4)] 馬復京[1)] 許原瑞[2)] 張乃航[3)] 洪富文[1)]

摘 要

為探討台灣原生闊葉樹種應用於復舊造林之生長潛力，1993年3月於台東太麻里研究中心，海拔800 m，坡向西南之林地進行原生闊葉樹塊狀混合造林。每一樹種栽植3~5區，每一小區栽植同一樹種50株，株行距2×2 m，共計13種樹種參試。定期調查與比較年度間造林木的樹高及胸徑生長差異，結果顯示杜英及香楠之生長及成活率均佳，在造林9年後，平均高生長分別達750及730 cm，平均造林成活率均維持在60%左右。其他的原生闊葉樹，除大葉杜樹高未達5 m外，包括鬼櫟、木荷、江某、三斗柯、牛樟等台灣中海拔闊葉樹種，其高生長雖稍遜於一般之闊葉樹種造林木如光臘樹，這些樹種平均高生長均達5 m以上，且平均胸徑達7 cm以上。各造林樹種在造林初期前三年之樹高淨生長表現，除台灣櫸可達約80 cm yr^{-1}之生長外，餘樹種之淨生長量皆在30~50 cm yr^{-1}之間，但至3~5年間，各樹種之樹高淨生長平均可達80 cm yr^{-1}，其中杜英更高達140 cm yr^{-1}，且此快速生長時期，可持續至第7.5年。顯示原生闊葉樹種應用於造林時，藉由良好的撫育管理下，在台灣中、低海拔林地極具造林潛力。

造林木初期生長均有分叉現象，且樹冠幅均達2 m以上，可能會影響造林木後續生長表現及木材形質利用，尤其造林木平均分叉率達40%，建議可提早造林木的修枝及疏伐小徑木，促進林分的健康生長。由樹高生長(應變數)與林齡(自變數)進行迴歸分析結果，迴歸係數(R^2)均在0.90以上，顯示此一元二次迴歸方程式可用於林木初期生長之預測。
關鍵詞：原生種、闊葉樹、生長表現、造林。
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INTRODUCTION

During 1965 to 1969, Taiwan undertook an effort to renovate the island's forest structures, replacing mixed hardwood forests of low stocking levels with trees of higher economic value. This endeavor created vast mid- to low-elevation pure stands of coniferous forests. Privately owned forestland, on the other hand, were largely converted to tea plantations, orchards, and even betelnut palm plantations. These changes caused the originally rather highly diverse plant and animal species in mixed hardwood forests to be replaced with monocultural plantation systems. According to ecological concepts, this monocultural system markedly reduced the existing biodiversity and may cause great risks and uncertainties in terms of species compositions, structures, and functions of the forest ecosystem (Chapin et al. 1992, Smith 1992, Smith et al. 1997). Hence from land protection and sustainable forest development perspectives with biological diversity, active promotion of multispecies mixed hardwood forests through either artificial or natural regeneration is one of the greatest challenges for silviculturists in Taiwan (Horng 1993).

The structure and composition of Taiwan's forests at elevations between 500 and 2100 are warm temperate forest, while mixed with conifers and hardwoods at high stocking levels. In addition to the highly valued timber species of *Chamaecyparis formosensis* and *C. obtusa* var. *formosana*, these are also the main distribution areas of important dominant hardwood trees of the Lauraceae and Fagaceae. These areas are not only rich in tree stocks, having numerous tree species and plentiful of life forms, but also produce many superior-quality hardwoods, such as *Zelkova formosana*, *Michelia compressa*, *Schefflera octophylla*, *Schima superba*, and *Elaeocarpus sylvestris*. *Cyclobalanopsis gilva*, and *Castanopsis carlesii* of the Fagaceae; and *Cinnamomum micranthum*, *Nothaphoebe konishii*, *Machilus zuihoensis*, and *M. kusanoi* of the Lauraceae. Even small understory trees of *Tricalysia dubia* and *Calamus margaritae* are superior for carving and making artifacts. There are also many producers of medicines and foodstuff such as *Phellodendron amurensis*, *Cinnamomum osmophloeum*, and *Ficus awkeotsang*, that provide innumerable services (Lu and Lin 1990). Less species diversity resulted from past silivicultural practice of planting pure artificial stands in Taiwan. In recent, reforestation efforts have attempted to establish man-made multistory forests composed of adaptive species as mentioned previously to achieve either diversified structures or complex composition of reforested land and thereby provide adequate habitats for various animals, insects, birds, microbes, etc. On the other hand, indigenous hardwood trees of long-rotation should be used to meet the goals of providing forest products to strike a balance with the conservation of ecological diversity (Butterfield 1995, Butterfield and Espinoza 1995, Haggar et al. 1998).

Furthermore, from the perspective of global silvicultural trends, it has become a rather common practice to plant exotic species and construct structurally simple and intensely managed plantations (Evans and Turnbull 2004). But in contrast, there is a scarcity of information concerning the use of indigenous species in domestic reforestation, particularly in countries of tropical and subtropical regions. Because of certain misconceptions regarding hardwood trees used for regeneration, they are often excluded from silvicultural plans. These misconceptions include (1) endemic hardwoods are hard to germinate; (2) hardwood saplings grow slowly; (3) endemic hardwoods often require a shadier site condition, and are not suited for plantation reforestation; (4) hardwood trees need fertile soils; and (5) plantation-grown hardwoods have inferior wood quality (Jagels 1990, Kanowski et al. 1992). As a consequence, plantation species in tropical countries are generally mostly confined to the genera of *Pinus*, *Eucalyptus*, and *Tectona* (Evans 1992). The potential of utilizing endemic trees in plantations is thus often overlooked (Butterfield and Fisher 1994). Plantations or man-made forests can be designed to provide both timber production and habitat restoration functions that also resolve the risk of forest soil erosion (Lugo 1997). In cut-over forests of the tropics, suitable endemic trees (most of which are hardwoods) can be used for plantation habitat rehabilitation, then because of the regeneration of understory plants, further development of the stand will be facilitated with successions of plants which in the end form a stable forest ecosystem (Parrotta et al. 1997).

The purpose of this study was to establish time-scale performance data of Taiwan's indigenous tree species through long-term plantation tree growth surveys. By understanding the growth, competition, and ability to endure environmental stresses of the individual tree species, we can provide basic knowledge for regenerative programs for mid- and low-elevation areas. This study is an extention of an earlier initiative of the project, "Establishment and utilization of a forest tree seed bank" implemented by the Tree Seed Lab of the Division of Silviculture, Taiwan Forestry Research Institute (TFRI), which conducted a series of practical and extensive collections, germination of tree seed studies, and its silvicultural research (Lin 1995, Lin and Chien 1995). The Silvicultural Technology Lab of the same division has followed suit by using the germinated seedling to construct mixed-block plots in plantations of endemic broadleaf trees since 1993 (Yu 1996, Hsui et al. 2001).

MATERIALS AND METHODS

Site description

Setup of the experimental site

The mixed hardwood plantation is located in the experimental forest of the Taimali Research Center of TFRI in Taitung, southeastern Taiwan. The site is at an elevation of 800 m with a southwest-facing slope. The forestland was natural broadleaf woods prior to being clearcut for timber harvesting in 1985. After the cut, a mixture of a conifer species of *Taiwania cryptomerioides* and a broadleaf species *Liquidambar formosana* was planted at the site. Although the average survival rates reached 88% in the first 3 yr, the frequent assault by typhoons resulted in bad growth performance of the planted trees in the succeeding years. Mix-plot planting of endemic broadleaf trees was implemented for restorative reforestation in March 1993. The site was prepared in a horizontal strip fashion, and the selected tree species were planted in a mixed-block fashion, with each block planted with 50 trees of the same species (5 rows of 10 trees each); and the blocks are randomized with each species comprising 3~5 blocks for a total of 57 blocks. The planting spacing was 2×2 m. The selected hardwood species and planting numbers are shown in Table 1.

Climate conditions at the experimental site

Upon establishing the permanent mixed-hardwood experimental site, a nearby weather station, the Maililu station of the Taimali Research Center provided year-round temperature and rainfall information which are shown in Table 2. The data show that the plantation site has an annual mean temperature of ca. 20℃ with a maximum daily temperature of 36℃. It has an annual rainfall of 3500 mm and a maximum monthly rainfall of 1000 mm. The annual number of rainy days can be as high as 160 or more. There are records of temperatures of < 10℃ during the period from November to March, and even in winter an average temperature of 15℃ was attained. Thus, the site has a relative high annual mean temperature plus rich precipitation that enhance plant growth year round. These factors also suggest that during the early-stage tending operations, weeds are serious threats to the seedlings. Ladrach (1992) noted that weed control was exceedingly important during the

Table 1. Native species tested, family, and number planted at the experimental site

Species	Family	No. planted	Description and stratum
Lithocarpus castanopsisifolius	Fagaceae	200	Medium tree, canopy
Fraxinus formosana	Oleaceae	250	Medium tree, subcanopy
Pasania kawakamii	Fagaceae	150	Large tree, canopy
Schima superba	Theaceae	250	Large tree, canopy
Phellodendron amurense var. *wilsonii*	Rutaceae	250	Small-medium tree, understory
Zelkova serrata	Ulmaceae	250	Mid-large tree, canopy
Elaeocarpus sylvestris	Elaeocarpaceae	250	Mid-large tree, subcanopy
Schefflera octophylla	Araliaceae	250	Medium tree, subcanopy
Tricalysia dubia	Rubiaceae	250	Small tree, understory
Pasania ternaticupula	Fagaceae	200	Large tree, canopy
Machilus zuihoensis var. *zuihoensis*	Lauraceae	200	Large tree, canopy
Cinnamomum camphora	Lauraceae	250	Large tree, canopy
Cinnamomum micranthum	Lauraceae	50	Large tree, canopy

Table 2. Meteorological data from March 1993 to July 2004 collected at the Mailiu weather station nearby the planting site

Month	Precipitation (mm)	Days of precipitation (d)	Mean temperature (℃)	Max. temperature (℃)	Min. temperature (℃)	Relative humidity (%)
January	83.9	10.5	14.6	27.3	7.6	95.4
February	98.9	13.9	14.8	31.5	6.1	94.6
March	78.6	13.3	17.0	32.9	6.5	94.4
April	172.8	15.3	21.1	31.4	9.5	94.0
May	358.8	17.7	19.4	36.1	11.8	94.4
June	529.6	11.7	24.1	34.2	14.5	88.2
July	437.6	10.8	24.0	34.5	19.1	90.7
August	567.6	13.2	23.6	35.7	18.7	93.3
September	422.6	14.6	22.0	31.6	15.6	96.4
October	511.9	15.4	20.5	30.8	11.1	95.0
November	232.6	11.2	19.0	31.9	8.7	95.4
December	92.3	12.9	15.6	26.2	5.5	94.7
Avg.			19.7			93.9
Total	3587.2	160.5				

Date collected by the Division of Watershed Management, Taiwan Forestry Research Institute.

early stage of afforestation in the tropics as that effective suppression of weed competition could promote survival of planted trees to as high as 90% or more. It was also pointed out that because of adequate weed control, the gain in faster plantation tree growth can more than offset the costs of such operations (Schuler and Robison 2006).

Surveys and analyses

Surveys of plantation trees

The initial survey of the tree growth data was completed in May 1993 after trees were planted. Subsequently, the growth of trees was surveyed yearly during the early period. The frequency changed to once every 2 yr in 1996, and the survey items included survival, tree growth, diameter at breast-height (dbh), and height of the standing stock in each block. In a later stage, additional items of growth data of forking height and crown width were also included. Forking of plantation trees refers to the presence of bifurcation or multiple axes or branches as large as the principal axis.

Comparative analyses of the growth of plantation trees

Interspecific comparisons of tree height and dbh were undertaken using the software package, SAS (Enterprise Guide 4.1). Based on different times of the surveys, tree height growth was plotted against tree age in a polynomial regression analysis in order to establish a model for predicting the early growth performance of the different species.

RESULTS AND DISCUSSION

Height growth performances of various broadleaf trees

The surviving numbers of endemic broadleaf trees 10 yr after out-planting are shown in Table 3. Two months after out-planting, survival rates determined by the surviving trees shown in Table 3 divided by the number planted as shown in Table 1 were generally up to 90%. But the survival rates of species also decreased year by year. The mortality was particularly acute for certain species in the sapling stage during the first 5 yr of planting. The initial survival rate of *Schima superba* was 94%, but by 1996, the rate has plummeted to 57%. Although the mean tree height growth of the species still attained 680 cm in the 9th year, the survival rate had dropped to 41.2% (Table 3). The main causes of the decrease were competition from weeds and frequent typhoons striking the east coast site leading to windfalls of some saplings. Other species with a low survival rate included *Pasania kawakamii*, *Schefflera octophylla*, *Tricalysia dubia*, and *Pasania ternaticupula*. These species had survival rates of < 50% by May 2002. The falling survival rates, however, showed some improvement by the 6th year after out-planting and had essentially stabilized by 2002 (Table 3).

Based on the survey results of May 2002, trees with the best survival rates included *Zelkova serrata* (74%), *Machilus zuihoensis* var. *zuihoensis* (69.6%), *Elaeocarpus sylvestris* (65%) and *Fraxinus formosana* (64%), suggesting that these 4 species are well suited to be plantation tree species at this site. Although by the 9th year, the survival rate for *Cinnamomum camphora* was merely 53%, the average height of surviving trees was 720 cm, which was similar with other high performers such as the 730~750-cm heights of *M. zuihoensis* var. *zuihoensis*, *E. sylvestris*, and *F. formosana* (Table 3). In addition, typhoons often strike the east coast of Taiwan, and the performances of these tree species were outstanding compared to wind-damage destruction suffered by an earlier introduced fast-growing eucalypt planted in the eastern area of Taiwan (Chen et al. 1995, 1997, 1998, Yu et al. 2002). Their performances also illustrated that endemic broadleaf species are well adapted for reforestation of intensely typhoon-disturbed forest sites. Parrotta et al. (1997) pointed out that to undertake reforestation in frequently disturbed tropical regions, endemic species possess growth advantages over exotic or introduced tree species. In a Costa Rican study comparing reforestation

Table 3. Comparison of tree height growth (cm) among planted tree species

Species	1993.05	1996.05	1998.01	2000.07	2002.05
Lithocarpus castanopsisifolius	33.1±10.4	133.1±42.9^{e}	378.5±109.5^{dce}	595.4±161.5^{bc}	699.4±146.4^{ba}
	(179)	(127)	(118)	(113)	(105)
Fraxinus formosana	44.8±7.8	174.0±67.3^{c}	371.2±110.1^{dce}	654.2±192.7^{a}	748.1±219.6^{a}
	(190)	(176)	(176)	(167)	(162)
Pasania kawakamii	38.6±12.8	103.1±49.3^{f}	257.8±84.3^{h}	337.8±127.0^{f}	450.2±164.5^{f}
	(136)	(93)	(58)	(49)	(42)
Schima superba	33.4±7.6	171.0±56.2^{c}	357.0±110.0^{dfe}	580.5±176.6^{dc}	673.8±163.8^{bc}
	(235)	(143)	(125)	(118)	(103)
Phellodendron amurense var. *wilsonii*	41.8±11.2	202.9±59.9^{b}	382.1±85.1^{dc}	476.2±123.5^{e}	550.1±147.8^{e}
	(189)	(171)	(163)	(156)	(150)
Zelkova serrata	44.7±8.5	270.9±72.8^{a}	416.4±133.5^{ba}	555.4±161.6^{dc}	613.7±154.9^{d}
	(225)	(205)	(205)	(190)	(185)
Elaeocarpus sylvestris	55.3±9.7	190.8±63.7^{b}	435.6±116.4^{a}	676.7±150.2^{a}	749.4±195.3^{a}
	(188)	(184)	(181)	(171)	(164)
Schefflera octophylla	38.0±12.7	175.7±49.8^{c}	349.1±82.9^{gfe}	540.9±105.7^{d}	615.3±100.3^{d}
	(175)	(144)	(128)	(118)	(110)
Tricalysia dubia	36.1±8.1	102.4±33.4^{f}	233.2±60.8^{h}	340.4±100.2^{f}	384.1±96.6^{g}
	(206)	(144)	(142)	(127)	(122)
Pasania ternaticupula	29.3±11.9	110.6±42.9^{f}	332.2±110.1^{gf}	542.6±184.4^{d}	643.6±173.6^{dc}
	(138)	(123)	(70)	(68)	(61)
Machilus zuihoensis var. *zuihoensis*	36.7±12.6	136.8±38.2^{e}	357.7±103.5^{dfe}	632.4±133.8^{ba}	728.9±147.4^{a}
	(196)	(189)	(178)	(177)	(174)
Cinnamomum camphora	33.0±11.2	190.9±63.4^{b}	399.6±127.3^{bc}	641.0±195.0^{a}	716.4±173.9^{ba}
	(218)	(198)	(174)	(147)	(132)
Cinnamomum micranthum	14.8±5.2	153.9±57.3	319.8±75.1	496.0±95.6	615.9±115.6
	(49)	(46)	(45)	(45)	(45)

Suriving numbers of planted trees within years are given in parentheses under each mean.
Means of tree height within years followed by different letters significantly differ at the $p < 0.05$ level.

performances of 14 exotic and 66 endemic species, although exotic species, such as *Acacia mangium* and *Gmelina arborea* exhibited the best growth, they were beset by insect infestations and fared poorly in subsequent growth evaluation. In contrast, endemic species exhibited superior reforestation potential for a different forest products utilization scenario (Haggar et al. 1998). Careful screening of suitable species is necessary, however. In so doing, the risk of mismanaging introduced species that run amok, become invasive, and harm local the ecology can be avoided, as apply illustrated by the case of *Leucaena leococephla* on the Hengchun Peninsula, southern Taiwan.

Among the 3 Fagaceae species examined, *Lithocarpus castanopsisifolius*, *Pas. kawakamii*, and *Pas. ternaticupula*, the average growth performance of *L. castanopsisifolius* at 700 cm by the 9th year of growth and a survival rate of 52.5% were the best, while *Pas. kawakamii* reached merely 450 cm which did not much differ from the small tree species, *T. dubia*, while its survival rate was only 50% and was the slowest grower among the tested species. This may have something to do with *T. dubia* being a small tree, while *Pas. kawakamii* is rarely found as a big tree in natural forests (Liu et al. 1994). As was pointed out through long-term monitoring of tree growth in plantations, the information accrued might be used to form mixed- species plantations that enable individual species to attain their maximum growth and form a complex forest structure in the process. Thus, the fertility of the forestland can be fully utilized (Kelty 1992). Our results suggest that these species are suitable trees for building understory mixed forests. In addition to possessing slower growth characteristics of small to mid-size trees, *T. dubia* is a traditional small-diameter wood source for some delicate artifacts which through extension of reforestation efforts, can become a stable forest by-product, that can boost the forest products utilization values of regional forests and provide significant returns to the area residents (Butterfield and Fisher 1994). Fagaceae logs are important mushroom cultivation media in Taiwan; these are also special-purpose forest by-products. With their growth performance in a restorative reforestation scheme, they contributed to the value of forest products and were helpful to regional economic development, thus rendering reforestation using endemic broadleaf species more significant (Brown and Lugo 1994).

Among the tested tree species, Taiwan cork tree (*Phellodendron amurense* var. *wilsonii*), an endemic species that also is a special-purpose forest product, has bark rich in berberine, an alkaloid that provides raw materials for Chinese herbal medicine and the pharmaceutical industry. The species was harvested in earlier days with no attempt at restorative replanting, leading to it becoming a rarity in the wild (Kuo 1989). In our study, the early growth of the species was second only to *Z. serrata*, and its height growth in the first 3 yr after out-planting mostly maintained a front-ranking status, reaching 203 cm in average tree height. Although in later growth surveys, its height growth rate tended to slow down and it was only taller than the bottom-ranking 2 species mentioned earlier; through adequate reforestation planning, its presence in a plantation can help restore the species. Furthermore, after 9 yr of growth, the dbh of the species had reached 6.8 ± 2.6 cm (Table 4), and the average height was 550 cm (Table 3). Trees at this stage are almost ready for bark harvesting. Thus, a scheme in conjunction with mid-term tending and management practices of pruning and thinning of the upperstory plantation trees, which introduces these smaller tree species to form mixed forests can be carried out to increase the biodiversity of plantation forests, as well as enhance the economic returns from the post-mid-term forest products, providing positive contributions to plantation forests (Schelhas et al. 1997, Ashton et al. 1998).

Dbh growth and net growth performances of various broadleaf trees

Compared to the traditional broadleaf reforestation species of *Z. serrata*, *F. formosana*, *Cin. camphora*, and *Schima superba*, the fast-growing *E. sylvestris* was the best height-growth performer year to year. The mean dbh of 9-yr-old trees also reached 12.0 cm (Table 4). The species is also a good mushroom log source (Yang et al. 1990). Thus, it promises to provide early mid-term harvests of the plantations. Other big girth growers included the Lauraceae species of *M. zuihoensis* var. *zuihoensis*, and *Cin. camphora*, which showed a consistent trends with their height growth performance. These 2 species are commonly distributed in the mid- and low-elevation broadleaf forests of Taiwan, hence their use for reforestation at cut-over sites is deemed to promote stand composition of plantations and further reduce ecological risks from incompatible tree species.

Although the growth of both *L. cas-*

Table 4. Comparison of diameter at breast height (dbh) (cm) growth among planted tree species

Species	1995.04	1996.05	1998.01	2000.07	2002.05
Lithocarpus castanopsisifolius	1.7±0.7^{g}	2.1±0.7^{f}	4.5±1.8^{d}	7.6±3.3^{d}	9.4±4.0^{dc}
Fraxinus formosana	2.3±0.9^{ed}	2.6±1.1^{ed}	4.4±2.2^{d}	7.7±4.2^{d}	9.7±5.3^{dc}
Pasania kawakamii	1.4±0.5^{h}	1.7±0.5^{g}	2.2±1.2^{f}	3.7±2.1^{f}	5.0±3.0^{g}
Schima superba	2.2±0.9^{edf}	2.7±0.9^{ed}	3.6±1.7^{e}	6.6±3.4^{e}	8.7±4.3^{de}
Phellodendron amurense var. *wilsonii*	2.7±0.9^{c}	3.0±0.9^{c}	4.7±1.8^{cd}	6.0±2.5^{e}	6.9±2.9^{f}
Zelkova serrata	3.1±1.2^{b}	3.6±1.3^{b}	4.7±2.0^{cd}	6.5±2.8^{e}	7.5±3.2^{fe}
Elaeocarpus sylvestris	2.4±1.0^{d}	2.8±1.0^{d}	6.3±2.7^{a}	10.1±4.5^{a}	12.0±5.5^{a}
Schefflera octophylla	3.6±1.2^{a}	4.3±1.4^{a}	5.7±2.1^{b}	8.4±3.1^{bcd}	9.7±3.2^{dc}
Tricalysia dubia	2.0±0.7^{f}	2.3±0.7^{f}	2.2±1.1^{f}	4.1±1.3^{f}	4.8±1.6^{g}
Pasania ternaticupula	1.4±0.8^{h}	1.7±0.7^{g}	3.7±2.1^{e}	6.6±3.6^{e}	8.5±4.5^{de}
Machilus zuihoensis var. *zuihoensis*	2.1±0.7^{ef}	2.4±0.7^{ef}	5.2±2.2^{cb}	9.3±3.7^{ba}	11.0±4.4^{ba}
Cinnamomum camphora	3.6±1.4^{a}	4.0±1.6^{a}	5.4±2.8^{b}	8.8±4.5^{bc}	11.1±5.4^{ba}
Cinnamomum micranthum	2.0±1.0	-	4.6±1.7	8.1±2.5	10.3±3.2

Means within years for dbh growth followed by different letters significantly differ at the $p < 0.05$ level.

tanopsisifolius and *F. formosana* reached a height of 7 m, their dbh growths were inferior to the 3 species mentioned above. Poorter and Werger (1999) pointed out that certain trees engage in early-stage height growth instead of girth growth, even to the extent of reducing the horizontal expansion of the tree crown. These trees are mostly light demanding (Poorter et al. 2003). *Fraxinus formosana* was used as a reforestation tree species planted in large-scale forest structural improvement projects in the late 1960s. It grows well in open sites and is very suited to be an upper-story species in mixed forests. The species has soft and small leaves that allow greater amounts of light to penetrate the forest. *Zelkova serrata* has a similar nature, as these species possess wind-resistant and deciduous characteristics that are conducive to a mixed planting scenario in which fast-growing pioneering upper-story species and certain economically valuable species are planted in mid- and late-stage successional planting underneath these upper trees to allow for greater stand productivity (Kelty 2006).

Tree growth gathered from several surveys, in the first 38 mo. after out-planting, the net height growth of the test species, with the exception of *Z. serrata*, were only about 50 cm yr^{-1}. But in the subsequent 2 yr, all species achieved of over 80 cm yr^{-1} (Fig. 1), suggesting that after 3 yr of out-planting, hardwood saplings can gradually overcome adverse environmental stresses and enter a stage of rapid growth. In the cases of *E. sylvestris*, *M. zuihoensis* var. *zuihoensis*, and *Cin. micranthum*, the net height growth in the 4th and 5th years reached > 100 cm yr^{-1}, especially for *E. sylvestris*, which almost attained a growth of 150 cm yr^{-1}. Other species, with the exception of the innate small trees of *T. dubia* and *Phe. amurense* var. *wilsonii*, could grow 80 cm yr^{-1}. The traditionally adopted reforestation species of *Z. serrata* and *F. formosana* which reached average heights of 593.4 and 684 cm by the 88th mo of out-planting, respectively, were not significantly better than the other tested broadleaf species, indicating that many endemic broadleaf tree species possess very good potential for future afforestation in mid-

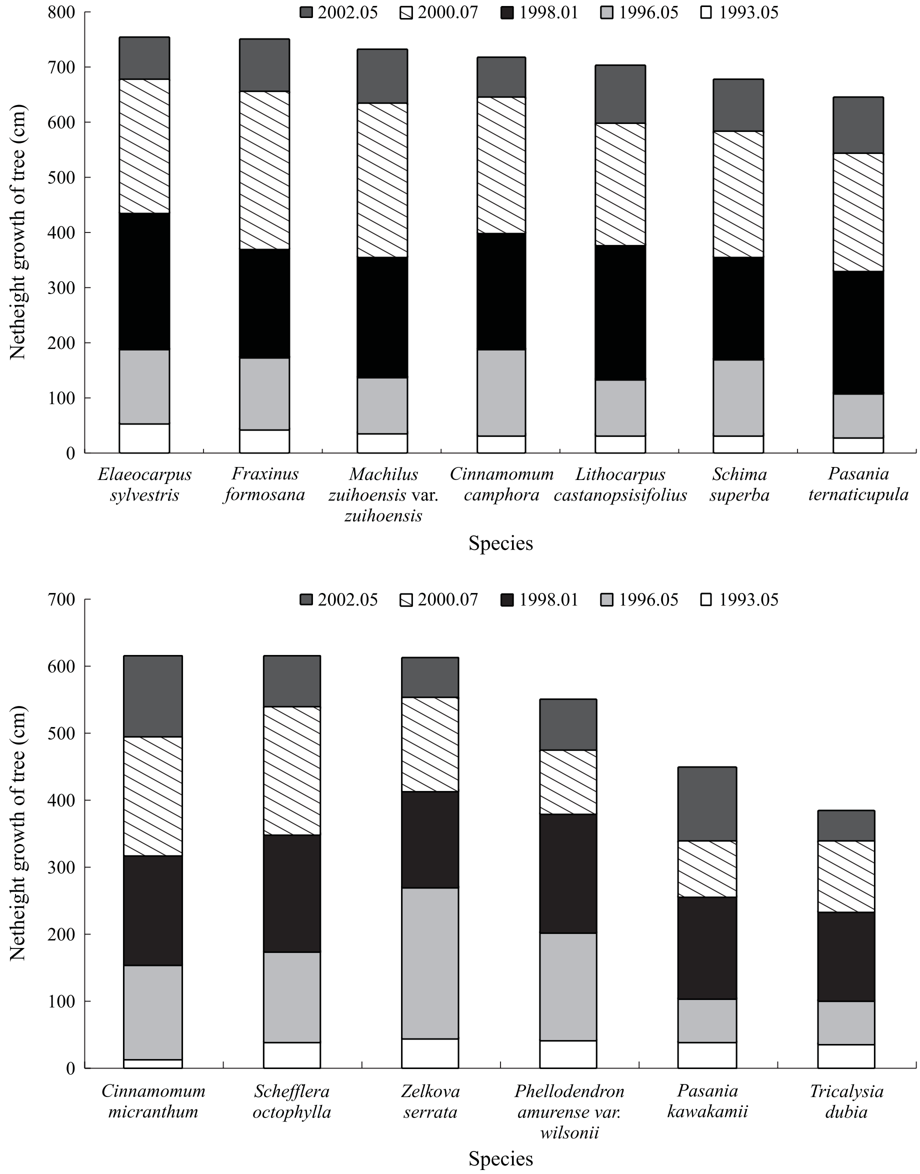

Fig. 1. The net height growth of endemic broadleaf tree species in different periods.

and low-elevation plantations.

Tree forms and regression prediction

Regardless of whether considering *Schefflera octophylla*, *Z. serrata*, or even *Phe. amurense* var. *wilsonii*, saplings of these trees had good initial girth growth. But at a later stage, their growth rates tended to slow. A probable cause of this phenomenon is thought to be related to the serious forking tendency of these species. González and Fisher (1994) observed the performances of 11 endemic tree species including *Acacia mangium* in plantation trials of Atlantic lowlands of Costa Rica and pointed out that 3 yr after out-planting, the fastest growing *A. mangium* reached a height of 14.5 m, but it tended to have a poor form and serious forking, causing a reduction in growth and survival rates. The probable causes were that those forest trees were beset by ant infestations coupled with broken limbs from wind-throwing. Hence pruning for tree form improvement was considered necessary to at least partially ameliorate the problems. In a survey of the forking habits of the tested species (Table 5), the forking rate of *Schefflera octophylla* reached 80.2%; and that of *Phe*. *amurense* var. *wilsonii* was 45.3%. Trees affected by this tendency also included *E. sylvestris* and *F. formosana*. Fujimori (2001) indicated that coniferous tree species commonly have an excurrent form with a single, straight main stem and narrow conical crown. For hardwood species with weak epinastic control, lateral branches grow nearly as fast as or faster than the terminal shoot, which results in a rounded crown form and makes it difficult to distinguish between the main stem and branches termed the decurrent form. Most hardwoods such as oaks, beeches, and maples have decurrent forms. From the perspective of forking heights, all species had very low forking heights. Thus, most of these potential plantation species should have reduced economic returns from plantation rotation. If the purpose of reforestation is to produce knot-free, large-diameter logs, these observations are not conducive to the effective utilization of the trees as timber sources (Kelty 2006). Determining whether the forking tendency can be suppressed through self-pruning when trees are densely planted is worthy of future experiments. Ensuing studies should also focus on the appropriate times to conduct pruning and subsequent thinning of such stands (Schuler and Robison 2006). In particular, Table 5 indicates that the average crown sizes of the plantation trees were all > 2 m, indicating that crown closure had begun. This suggests that stand density regulation at this stage is needed, and adequate thinning could thus avoid growth competition among trees (Erskine et al. 2005).

Figure 2 shows the correlation between tree height (dependent variable) and tree age (independent variable) of different tree species with polynomial equation regressions. They can be used to predict tree height

Table 5. Forking characters of planted tree species

Species	Forking (%)		Forking height (m)		Crown width (m)	
	2000.07	2002.05	2000.07	2002.05	2000.07	2002.05
Lithocarpus castanopsisifolius	19.5	11.4	1.2	1.4	1.6	2.8
Fraxinus formosana	67.3	42.9	0.8	0.9	1.2	2.2
Pasania kawakamii	44.1	40.8	0.7	0.7	1.5	2.9
Schima superba	80.8	45.3	1.1	1.1	1.5	3.0
Phellodendron amurense var. *wilsonii*	79.7	80.2	1.0	1.1	1.2	2.7
Zelkova serrata	58.3	63.4	0.4	0.4	1.0	2.0
Elaeocarpus sylvestris	45.9	38.8	0.9	1.0	1.3	2.6
Schefflera octophylla	38.3	29.8	1.2	1.2	1.5	2.9
Tricalysia dubia	32.7	22.7	1.5	1.2	1.9	2.7
Pasania ternaticupula	52.0	49.4	1.4	1.5	2.0	4.1
Machilus zuihoensis var. *zuihoensis*	35.6	21.7	1.6	1.8	1.4	2.7
Cinnamomum camphora	52.8	37.3	1.3	1.2	1.9	3.8
Cinnamomum micranthum	71.9	65.4	1.2	1.4	1.6	3.0

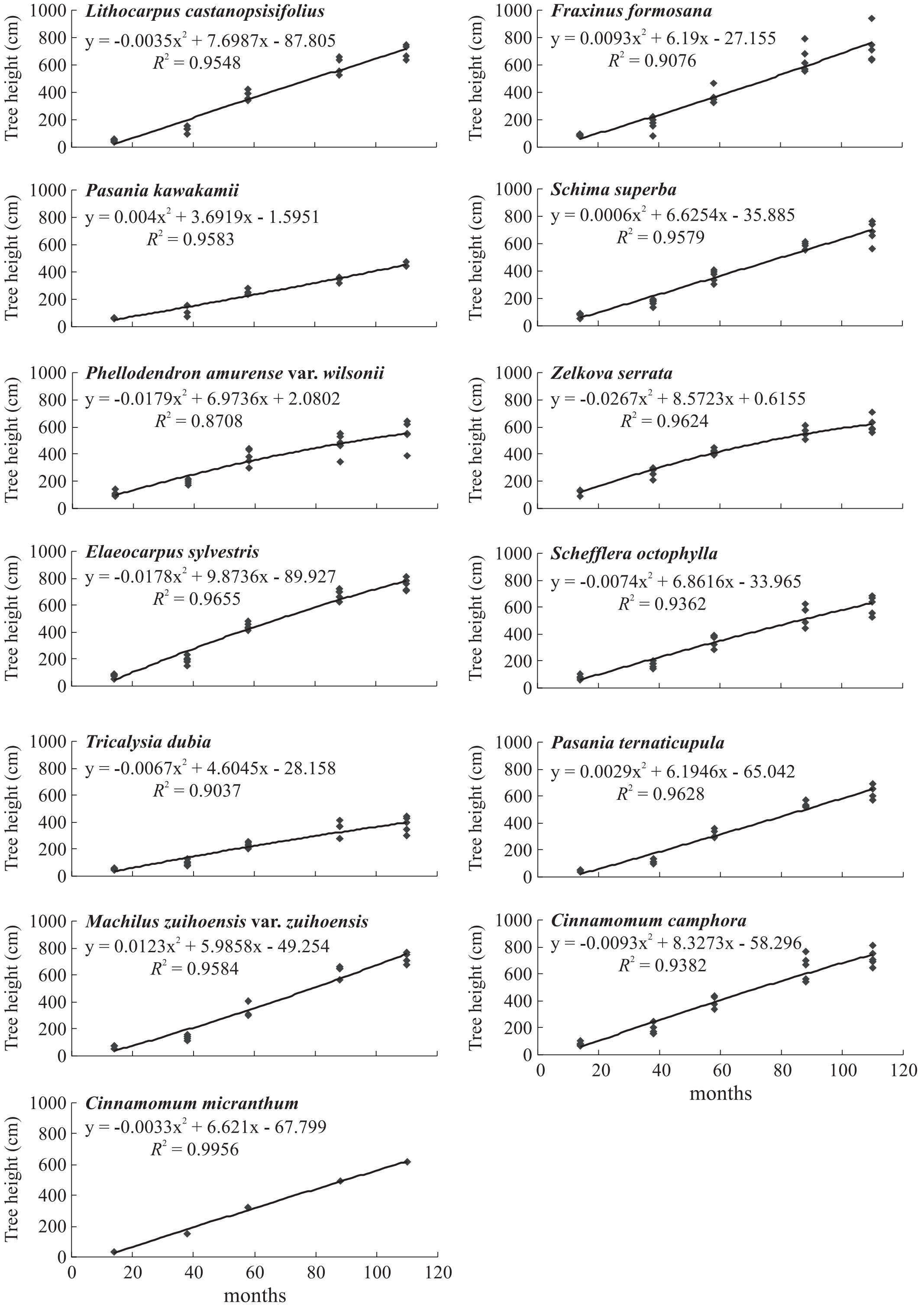

Fig. 2. Regression equations of tree height (y) vs. growth months (x) among tree species.

growth in different growth periods. The correlation coefficients, R^2, all reached 0.90 or better. Since Liu et al. (1984) used a curvilinear (or multiple regression) analysis to set the regression equations to predict relationships of tree height-age for planted *Taiwania cryptomerioides*, dbh in relation to age was also determined. Chen et al. (1996) and Chen and Huang (1999) found that the regression used for predicting tree growth, although showing growth correlated with time, will not converge with time. In general, when planting trees in the sapling stage, tree growth often shows a positive correlation with planting age, while the age of the planted trees in the field was only 108 mo, the predicted equations derived from the tree height growth data could only fit the prediction of the early growth trend of the planted trees. Through the regression equations (Fig. 2), the results indicated that forest managers can predict the growth performance of early-stage plantation trees. When these are used in conjunction with dbh vs. age regressions, the year-to-year tree volume growth can also be determined. This will contribute significantly to efforts to establish the amount of carbon dioxide sequestered by plantation trees (Petit and Montagnini 2006).

CONCLUSIONS

Mid- and low-elevation broadleaf forests make up roughly 2/3 of Taiwan's forests, and there are over 1000 woody species. Tree species suitable for afforestation, however, were seldom studied in the past in Taiwan. This study examined 13 endemic broadleaf tree species for their silivicultural growth performances over a 10-yr period, in order to understand the growth characteristics of different species. Species such as the slow-growing *T. dubia* are suitable for understory planting to provide good raw materials for making artifacts. On the other hand, small logs of *E. sylvestris*, which had better growth performance in tree height and dbh growth than typical planted species of *Z. serrata* and *F. formosana*, can reach a harvestable size to serve the commercial purpose of mushroom cultivation. At 10 yr, *Phe. amurense* var. *wilsonii* had a mean dbh of 7 cm of girth growth, which is a decent size for bark harvesting as a source of medicinal raw materials. These results illustrate that in afforestation programs, correctly selecting tree species with different characters such as growth rates, shade-tolerance, and end-uses to form mixed man-made forests can achieve both species diversity and multipurpose economic productivity of the forest. Thus, establishment of mixed plantations are more attractive than monocultural plantations.

The initial growth rates of the different broadleaf tree species greatly varied, thus in the first 1~3 yr after out-planting, tending and weeding frequencies should be strengthened to prevent the need for subsequent replanting. Most broadleaf species grow slowly in the first 3 yr after our planting which adversely affects their competition with weeds and is probably a major cause of decreased survival rates. From 3 yr on, trees are free from the shackles of such competition, and the net growth accelerated with several species gaining more than 1 m of net height growth, fully exerting their growth superiority. Along with faster growth, however, crown closure gradually develops, so the plantation should be thinned to allow light penetration and maintain consistent growth. Forking habits of endemic broadleaf trees, however, pose a wood quality problem for their utilization; hence, the silvicultural operation of pruning should be considered to produce knot-free timber and enhance the financial income of the plantation during the rotation. More endemic broadleaf trees should be tested in different sites through multiple-species mixed planting and long-term monitoring experiments to determine their growth habits and allow the selection of suitable species for particular sites.

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