热带亚热带植物学报 2005, 13(2): 95-104
Journal of Tropical and Subtropical Botany

广东亚热带森林木本植物幼苗生长特性研究

彭姣凤, 陈章和*, 韦明思
(华南师范大学生命科学学院, 广州 510631)

摘要:研究了广东亚热带42种木本植物幼苗的生长及其与物种的生态特性、生活型、种子大小的相互关系。较强光下(H, 66.8 μmol $m^{-2}s^{-1}$)乔木幼苗的茎高和茎生物量显著高于灌木幼苗的相应值,但在较低光下(L, 33.7 μmol $m^{-2}s^{-1}$)两者无显著差异。而阳性植物、耐阴植物和中间型植物之间,茎高和茎生物量无显著差别。乔木幼苗的叶面积和叶生物量比灌木幼苗大,但灌木幼苗的叶片数较乔木幼苗多。大种子种和小种子种幼苗之间,阳性植物、耐阴植物和中间型植物幼苗之间的叶片数和叶面积一般无显著差异。阳性植物幼苗比耐阴植物幼苗侧根数多。乔木幼苗的根生物量和根/茎比显著高于灌木幼苗。在较高光下,阳性植物幼苗的根/茎比较耐阴植物幼苗高,但在较低光下无明显差异。45 d幼苗的根生物量与种子重量呈显著的正相关,而90 d幼苗无明显的相关。乔木幼苗个体生物量显著高于灌木幼苗。幼苗相对生长率和叶面积比的大小呈现如下顺序:阳性植物 > 中间型植物 > 耐阴植物,但只有阳性植物和耐阴植物之间有显著差异。阳性植物、中间型植物和耐阴植物幼苗之间的单位叶率无显著差异。

关键词:幼苗生长; 木本植物; 亚热带森林; 广东
中图分类号: Q948.1　　**文献标识码**:A　　**文章编号**:1005-3395(2005)02-0095-10

Characteristics of the Seedling Growth of Woody Plants in the Subtropical Forests in Guangdong Province

PENG Jiao-feng, CHEN Zhang-he*, WEI Ming-si
(*College of Life Science, South China Normal University*, Guangzhou 510631, China)

Abstract: Seedling growth of 42 woody species of subtropical forests in Guangdong Province was studied in relation to their ecological characteristics, growth forms and seed weight. Seedlings of tree species had significantly higher stem and greater stem biomass than those of shrub species under high light (H, 66.8 μmol $m^{-2}s^{-1}$), but not low light intensity (L, 33.7 μmol $m^{-2}s^{-1}$). There was no significant difference among heliophilic species, shade-tolerant species and intermediate light-demanding species in stem height and stem biomass. Tree seedlings had more leaf area and leaf biomass per plant than shrub seedlings, but the latter had more leaves. Difference in leaf number and leaf area was generally not obvious between large-seeded and small-seeded species, and between different types of species based on light demand. Seedlings of heliophilic species had more lateral roots than those of shade-tolerant species. Seedlings of tree species had significantly greater root biomass and higher root/shoot ratio of biomass than those of shrub species. Seedlings of heliophilic species had also higher root/shoot ratio than those of shade-tolerant species under H as compared with L condition. Root biomass was significantly positively correlated with seed weight for 45 d seedlings in both H and L light, but not for 90 d seedlings. Very significant linear correlation between seedling biomass and seed weight was found for 45 d seedlings under both H and L light conditions, but not significant for 90 d seedlings under H light condition. Tree seedlings had significantly greater biomass per plant than shrub seedlings. Relative growth rate and leaf area ratio of seedlings were found to be in

Received:2004-04-09　**Accepted:**2004-09-14
Foundation item: Supported by the National Natural Science Foundation of China (No. 39270140, 39670138)
* Corresponding author

order of heliophilic species > intermediate light-demanding species > shade-tolerant species, and there were significant difference between heliophilic species and shade-tolerant species. Difference in unit leaf rate was not significant among species of various light-demanding types.

Key words: Seedling growth; Woody plants; Subtropical forest; Guangdong Province

Inhabitation and growth of seedlings are very susceptible to environmental variation. Seedlings have to cope with the effects of favorable and unfavorable environmental factors in their habitat during their growth. Therefore, studies on characteristics of seedling growth are of importance for reforestation and for research of forest dynamics. This study is carried out based on the following considerations: First, although studies on this aspect have led to an encouraging understanding on the ecological adaptability to their environment of the species, researches have been focused mostly on the species in tropical forests[1-8] and temperate forests[9-13], not much research work has been carried out in subtropical humid forests[14,15]. Have the seedlings the same adaptive strategies as those in tropical and temperate forests? If not, what is the difference between them? Second, studies have been carried out mostly on the comparison of a few species with obviously different ecological characteristics, such as pioneers and late-successional species[8]. However, species might present continuous variation in the characters of adaptation to a certain environment[5,16,17]. How does the ecological adaptation of seedlings vary continuously? This paper studied 42 woody species of different light demands or successional phases and of different growth forms as well as seed weights in the subtropical forest in China, in order to examine these questions which are important for understanding the ecological adaptation pattern of woody plant seedlings in a certain environmental gradient.

1 Materials and Methods

Seeds of 42 woody species (appendix 1) were collected during July 1999 to August 2000 from Dinghushan Nature Reserve, Heishiding Nature Reserve, Luofushan Nature Reserve, and Baiyunshan Forest Park in Guangdong Province, which are located at similar latitudes (23°08'–23°22' N) with similar climatic conditions: annual average temperature is about 20–22℃, the coldest (January) and the hottest month (July) temperatures are 12–14℃ and 27–28℃, respectively. The mean annual rainfall is about 1 700-1 900 mm, the wet season is from April to September and the dry season from October to March. The species studied were divided into shade-tolerant species, heliophilic species and intermediate species according to their light demands which were estimated by their appearing frequency inside or outside the forests; into tree species and shrub species according to growth form; and into large-seeded species (seed weight >25 mg) and small-seeded species (seed weight <7 mg) according to their seed weight (appendix 1). Seeds or fruits were mostly collected directly from mother plants, and in some cases, freshly shedding seeds or fruits were collected on the ground around the mother trees. They were held in hermetic plastic bags, and then taken back to the laboratory. Fresh weights were measured by weighing 50 seeds with electronic balance (mode: FA1104, Shanghai), except for the species with very tiny seeds such as the *Ficus* species, such tiny seeds were measured by thousand seed weight. Dry weight was obtained after the seeds were dried in an oven (mode: SKG-01, Huangshi) for 48 h at 80℃.

Seeds were germinated and seedlings were grown in growth room with day and night temperatures of 25±1℃ and 20±1℃, respectively, a relative humidity of about 80%, and day/night hours of 12/12. Seedlings with similar height were transplanted into plastic pots (diameter 12 cm, height 12 cm) filled with cleaned sand with 1 plant for each pot, 50–60 individuals for each species. Potted plants were put in sufficient space to avoid interference from each other and competition for light. They were randomly divided into two groups, one under high light (H, 66.8 μmol $m^{-2}s^{-1}$) and the other under low light intensity (L, 33.7 μmol $m^{-2}s^{-1}$) of 40 W mercury fluorescent lamps and 100 W tungsten filament lamps. Each seedling was alternately supplied with 10 ml Rorison nutrient solution[18] one day and

10 ml deionized water the next day during the first 45 d, and then the volume of nutrient solution and water was raised to 15 ml thereafter. Seedlings were harvested after 45 d and 90 d of transplanting. Generally, each time 10–15 seedlings for each species grown at each light level were harvested and examined for shoot height, root length, root number, leaf number and leaf area (the later was measured with Delta-T Area Measure System, England). Fresh weights of leaf, stem and root of each seedling were measured. Dry weight of the organs was measured (FA1104 electric balance, Shanghai) after drying for 48 h at 80℃.

Analysis of variance (ANOVA) and a two-sample *t*-test were made for the significance of the differences for different species groups[19]. For abnormal data, a transition by $\sqrt{(1+x)}$ to normal distribution was made before ANOVA. Correlation analysis was made between two variances[19].

2 Results and Analysis

2.1 Growth of seedlings

2.1.1 Stem growth

Stem growth varied in species with different growth forms. Shrub seedlings had lower height and stem biomass than tree seedlings, and the difference was significant in treatment with high light intensity (H) (Fig.1A,D). In consideration of that tree species in general have larger seeds than shrub species[20,21], correlation analyses were made respectively for tree species and shrub species between seed weight and stem height, and between seed weight and stem biomass. The results showed that no significant correlations were found between seed weight and stem height both in tree and shrub species. Correlation between seed weight and stem biomass was significant for tree species, but not significant for shrub species. These indicated that significant differences between the growth forms in stem height and stem biomass were in some extent independent of seed weight. Tree seedlings had significant biomass increment from 45 d to 90 d.

There was no significant difference in stem height and biomass between the types of light demand, although seedlings of heliophilic plants had faster height growth and more biomass increment than those of shade-tolerant plants, and intermediate light-demanding plants had medium values (Fig. 1B, E). Seedlings of different types responded differently to light intensities. The heliophilic species grew taller and had greater stem biomass in H than in L light, while the shade-tolerant species had higher values under L than under H condition. Biomass increment from 45 d to 90 d of heliophilic seedlings was significantly faster

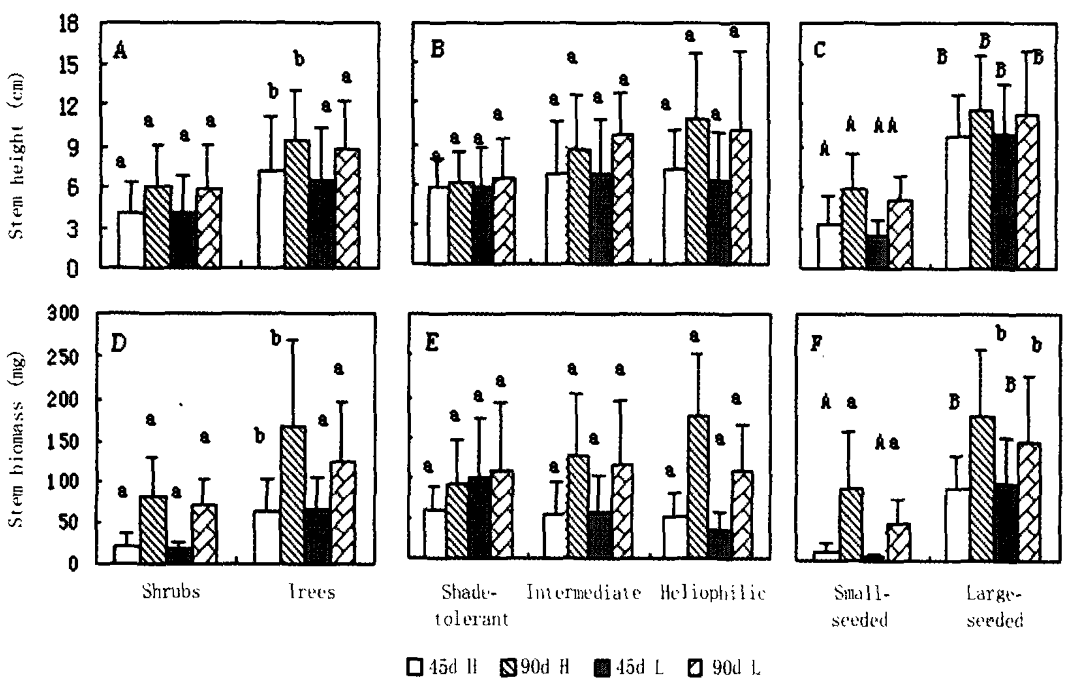

Fig. 1 Comparison of seedling stem height and stem biomass among different types of woody species in the subtropical forests

in H than in L, and no significant difference between the two light conditions was found for shade-tolerant species. Intermediate light-demanding species showed transitional characteristics between heliophilic and shade-tolerant plants (Fig. 1B, E).

Stem height and stem biomass were positively correlated with seed weight in different species, however, the effect of seed weight on stem height and stem biomass was less for 90 d seedlings than that for 45 d ones (Fig. 1F, Fig. 2). This indicated that seedlings of small-seeded species had higher stem growth rate.

2.1.2 Leaf growth

Tree seedlings had fewer leaves but more leaf area and greater leaf biomass than shrub seedlings (Table 1). These differences were affected by light intensity and varied with seedling age. Tree seedlings from 45 d to 90 d had significant increase in leaf number, leaf area and leaf weight, and had more leaf area and leaf weight under H light than L light condition. 90 d shrub seedlings did not have significantly more leaf number and leaf area but had significantly greater leaf weight under both L and H light conditions as

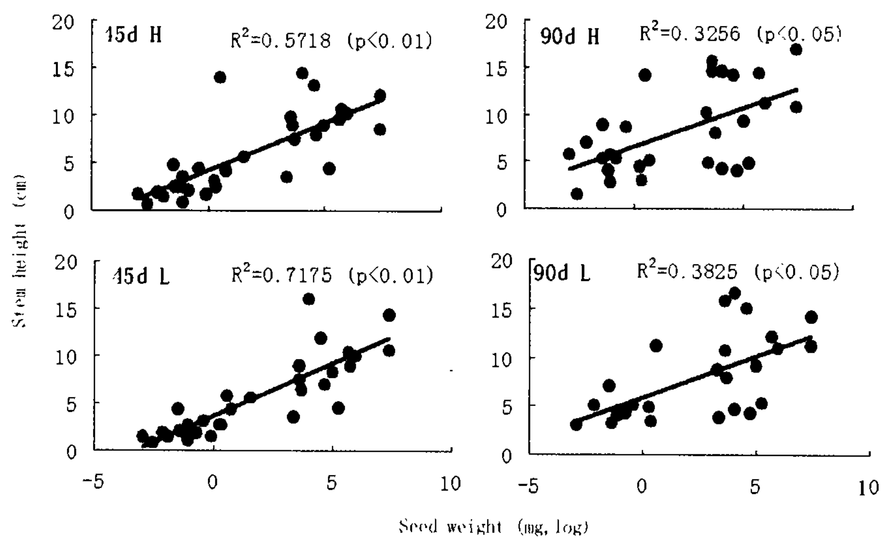

Fig. 2 Correlation between seed weight and stem height of 45 d and 90 d seedlings under low (L) and high (H) light intensities

Table 1 Leaf number, leaf area and leaf weight of seedlings

	Seedling age (d)	Leaf number		Leaf area (cm^2)		Leaf weight (mg)	
		H	L	H	L	H	L
Shrubs	45	9.97±4.51a	9.77±4.71A	16.39±12.36a	13.59±8.86a	65.39±49.31a	50.55±35.47a
	90	10.90±5.33a	10.91±5.73a	54.11±34.67a	39.27±24.10a	235.2±122.4a	170.7±107.9a
Trees	45	7.16±2.71b	6.61±2.35B	49.82±21.95b	42.30±18.98b	184.01±94.03b	158.8±106.6b
	90	9.08±4.07a	8.33±3.18a	126.7±66.17b	95.95±54.60b	454.4±281.4b	311.8±207.2b
Sh	45	5.05±2.02a	5.21±1.90a	35.75±21.84a	42.53±32.53a	197.1±151.0a	246.8±164.7a
	90	6.43±3.08a	6.32±3.04a	36.86±19.93a	46.37±29.98a	263.7±185.2a	278.4±168.9a
In	45	8.20±3.03b	7.60±3.03a	24.29±23.44a	20.31±20.04a	133.2±149.3a	111.1±148.4a
	90	9.56±4.63a	9.63±3.97a	95.54±77.33a	73.67±60.90a	353.8±320.1a	268.8±211.3a
He	45	8.55±1.84ab	7.92±2.46a	41.48±25.45a	30.64±20.81a	130.4±105.0a	95.18±70.56a
	90	10.28±3.23a	9.85±3.58a	112.6±74.26a	78.00±58.14a	380.9±212.9a	241.3±112.3a
Sm	45	7.99±3.10a	7.58±2.88a	31.92±46.80a	14.86±14.51A	57.0±81.5A	26.2±25.3A
	90	9.99±3.64a	9.34±2.77a	119.9±119.8a	83.74±91.20a	365.5±380.6a	218.8±217.3a
La	45	8.22±4.40a	7.68±4.40a	44.74±29.87a	48.84±37.16B	235.4±166.8B	220.6±186.5B
	90	9.51±6.04a	9.31±6.52a	80.71±56.25a	65.93±45.77a	381.5±225.2a	293.4±216.3a

Sh, shade tolerant species; In, intermediate light demanding species; He, heliophilic species; Sm, small-seeded species; La, large-seeded species; H, high light intensity; L, low light intensity. Numbers followed by the same letter within the column are not significantly different at $p<0.05$ for small letter, and at $p<0.01$ for capital letter. The same for Tables 2 and 3.

compared to 45 d seedlings. Shrub seedlings under H condition had more leaf weight increment than under L condition.

There was no significant correlation in scatter diagrams of leaf number, leaf area and leaf weight against the species in the order from shade-tolerant species to heliophilic species (the order is arranged in appendix); and there was no significant difference in leaf number, leaf area and leaf weight among the heliophilic species, shade-tolerant species and intermediate light-demanding species (Table 1). However, leaf growth responded differently to light intensities. Heliophilic species had more leaf number and greater leaf weight under H than those under L condition, and had significantly more leaf area and greater leaf weight in seedlings transplanted after 90 d than after 45 d. Leaf number of the shade-tolerant plants was similar under the two light conditions, whereas leaf area and leaf weight were higher under L than under H condition. There was no significant difference in leaf area and leaf weight between 45 d and 90 d seedlings of the shade-tolerant plants. These facts showed that H light condition was more favorable for leaf growth of heliophilic seedlings than L light condition, and that shade-tolerant plants needed less light for leaf growth than heliophilic plants. Seed weight had no significant effect on leaf number. Difference in leaf weight between large- and small-seeded species was significant for 45-day seedlings in both H and L light, and difference in leaf area was found only for 45-day seedlings in L light (Table 1).

2.1.3 Root growth

Root biomass was related to growth form of the species. Shrub seedlings had lower root biomass per plant than tree seedlings. Seedlings of heliophilic species had significantly more lateral roots than those of shade-tolerant species; they also had larger increment of root biomass from 45 d to 90 d seedlings under both H and L lights. There was generally no significant difference in length of main root and root weight between heliophilic species and shade-tolerant species. Correlation analysis indicated that root biomass was very significantly correlated with seed weight for 45 d seedlings in both H and L light, but not significant for 90 d seedlings in neither H nor L light (Fig. 3). Differences in length of main root and root biomass between the large-seeded species and the small-seeded species were significant in the 45 d seedlings, but not significant in the 90 d seedlings. These indicated that seed weight had more important effect on root growth at early stage of the seedlings, and showed less effect with the development of the plants.

2.2 Biomass and its allocation

2.2.1 Total biomass

Total biomass showed great variation among species. Under H light, 90 d-seedlings of species such as *Broussonetia papyrifera*, *Podocarpus fleuryi*, *Sterculia lanceolata*, *Ficus hispida* and *Ligustrum sinense* had biomass more than 1 200 mg, but the values of which in *Ilex triflora* and *Saurauia tristyla* were less than 40 mg. Under L light, such species as *Ormosia*

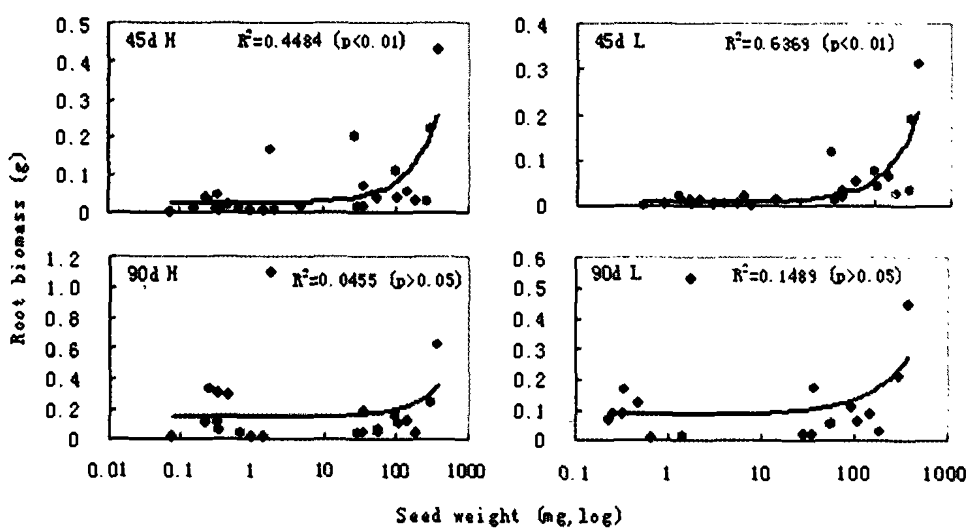

Fig. 3 Correlation between seed weight and root biomass of seedlings

pachycarpa, *Broussonetia papyrifera*, *Podocarpus fleuryi* and *Sterculia lanceolata* had total biomass more than 1 000 mg, and *Cratoxylum ligustrinum* and *Saurauia tristyla*, less than 50 mg.

The tree seedlings had significantly higher biomass per plant than the shrub seedlings (Fig. 4A). Correlation analysis respectively for the tree and shrub species demonstrated that there was significant correlation between seed weight and total biomass in tree seedlings (except seedlings of 90 d in H light), but not in shrub seedlings. Difference in total biomass between large- and small- seeded species was significant for 45 d seedlings, but not for 90 d ones (Fig. 4C). These suggested that the difference in total biomass between tree and shrub seedlings was indeed related to growth forms of the species, although the effect of seed weight might involved during the early period of seedling growth. Tree seedlings had very significant biomass increment from 45 d to 90 d under H light, but the shrub species had no significant difference in biomass between 45 d and 90 d seedlings under both H and L light conditions.

There was no significant correlation in scatter diagrams of total biomass per plant against species in the order from shade-tolerant species to heliophilic species. However, differences were found in response to light intensity among heliophilic species, shade-tolerant species and intermediate light-demanding species. Shade-tolerant species had higher biomass in L than in H light, whereas heliophilic species had higher biomass in H light than in L light (Fig. 4B). Biomass per plant of shade-tolerant seedlings was not significantly different between 45 d and 90 d seedlings, whereas that of heliophilic plants was significant. Seedlings of the intermediate light-demanding species had a growth rate lying between the other two types (Fig. 4B).

Correlation analysis indicated that biomass per seedling was positively correlated with seed weight, but the correlation was not significant for the 90 d seedlings in H light. Difference in total biomass between seedlings of large-seeded species and those of small-seeded species was very significant for 45 d seedlings but not significant for 90 d seedlings (Fig. 4C).

2.2.2 Biomass allocation

Biomass allocation varied among species. The proportion of root biomass comprised more than 30% of the total biomass for both 45 d and 90 d seedlings of *Gossampinus malabarica*, *Sterculia lanceolata*, *Broussonetia papyrifera*, *Ficus lacor* and *Ficus microcarpa* (90 d seedlings of *Gossampinus malabaricum* under L light comprised 64% of the total), whereas *Psychotria rubra*, *Acacia confusa* and *Ligustrum sinense*, only about 15%. The proportion of root biomass to total biomass and stem biomass to total biomass increased generally with the growth of seedlings, but that of leaf biomass to total biomass showed a contrary tendency.

Biomass allocation had relation to growth forms of the species. Seedlings of trees had higher root/shoot ratio than those of shrubs. A linear upward trend was showed in the scatter diagrams of root/shoot ratio against the species in the order from shade-tolerant species to heliophilic species, but this trend was not significant. It was shown also by ANOVA and *t*-test for the types of light demanding that significant

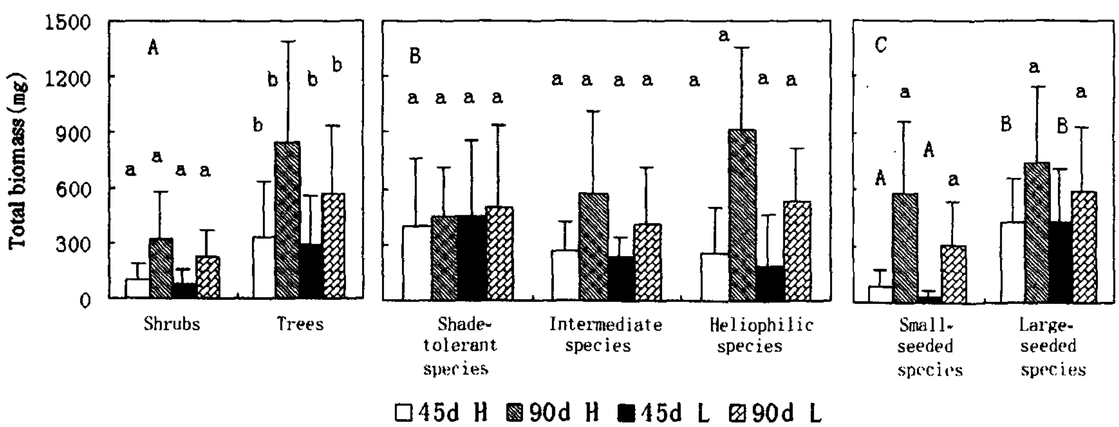

Fig. 4 Comparison of total biomass between different types for 45 d and 90 d seedlings under low and high light intensity treatments

difference was found only between heliophilic species and shade-tolerant species in H light (Table 2). There was no significant difference between large- and small-seeded species.

2.3 Growth analysis

2.3.1 Relative growth rate

There was no significant linear trend in scatter diagrams of relative growth rate (RGR) against the species in the order from shade-tolerant species to heliophilic species, although the heliophilic species had highest RGR, and was in the order of heliophilic species >intermediate species > shade-tolerant species. Significant differences were found between heliophilic species and shade-tolerant species, and between large- and small-seeded species (Table 3). Correlation analysis showed that there was a significant negative correlation between RGR and seed weight both in H and L lights. There was no significant difference between tree seedlings and shrub seedlings, although the former had slightly higher values.

2.3.2 Unit leaf rate

Most of the species grown under H light had higher unit leaf rate (ULR) than those under L light, and a few species (for example *Ormosia pachycarpa*, a shade-tolerant forest tree) showed significant higher ULR under L light compared to H light. There were generally no significant differences between different growth forms and between different types of light demanding (Table 3). Correlation analysis between seed weight and ULR indicated that significant correlation was found in L light but not in H light (Table 3).

2.3.3 Leaf area ratio

Leaf area ratio (LAR) was in the same order as in RGR and ULR for the light-demanding types. There was significant difference between shade-tolerant and heliophilic species. No significant difference was found between tree and shrub seedlings, although the former showed slightly higher values (Table 3). Correlation analysis showed that LAR in seedlings was very significantly negatively correlated with seed

Table 2 Root/shoot ratio of seedlings for different ecological types and life forms

	High light intensity		Low light intensity	
	45d	90d	45d	90d
Trees	0. 354±0. 151a	0. 378±0. 203a	0. 327±0. 142A	0. 427±0. 373a
Shrubs	0. 226±0. 058b	0. 247±0. 102b	0. 223±0. 062B	0. 216±0. 084a
Sh	0. 250±0. 123a	0. 237±0. 137a	0. 223±0. 087a	0. 217±0. 126a
In	0. 269±0. 079ab	0. 273±0. 068ab	0. 285±0. 107a	0. 298±0. 077a
He	0. 375±0. 176b	0. 420±0. 240b	0. 326±0. 162a	0. 488±0. 463a
La	0. 318±0. 172a	0. 317±0. 235a	0. 315±0. 148a	0. 393±0. 448a
Sm	0. 323±0. 117a	0. 372±0. 132a	0. 279±0. 124a	0. 376±0. 109a

For abbreviations see Table 1.

Table 3 Growth analysis of seedlings of species with large or small seeds, and with different light demands and growth forms

	Relative growth rate (mg $g^{-1}d^{-1}$)		Unit leaf rate（g $m^{-2}d^{-1}$）		Leaf area ratio（$cm^2 g^{-1}$）	
	H	L	H	L	H	L
Trees	28.65±18.04a	27.00±18.54a	1.46±0.90a	1.34±0.81a	191.27±54.87a	208.06±54.43a
Shrubs	25.83±12.20a	23.97±20.61a	1.35±0.80a	0.96±0.56a	172.41±98.08a	191.06±106.84a
Sh	8.84±1.50a	6.79±3.01a	0.62±0.15a	0.55±0.18a	104.62±35.19a	114.25±41.29a
In	22.99±18.59ab	23.46±21.00ab	1.32±0.68a	1.12±0.70a	186.75±96.81ab	199.01±98.47ab
He	32.12±17.88b	28.31±19.11b	1.58±0.76a	1.06±0.62a	188.70±75.23b	219.52±87.42b
La	13.99±10.95A	8.64±5.91A	1.24±0.87a	0.650±0.350A	114.19±33.13A	120.43±32.26A
Sm	38.15±18.72B	39.01±17.10B	1.57±0.751a	1.47±0.620B	238.21±67.29B	271.61±58.77B

For abbreviations see Table 1.

weight both in H and L lights.

3 Discussion

Shrub seedlings have more leaf number, less leaf area, lower leaf area ratio, and less leaf weight than tree seedlings and have similar length of main root, number of lateral roots compared to tree seedlings although shrub seedlings have remarkably lower root weight. This indicates that shrubs have no growth advantage in shoot growth but advantages to some extent in root growth as compared to tree species. Generally speaking, shrubs have less growth advantages in comparison with tree species, which is indicated by their lower values of shoot height, shoot weight, total biomass and RGR. Their adaptive advantage might lie on higher ability to cope with environment stress (such as deep shade, dry, insect attack, etc.).

Different plant types of light demand show different responses to light intensity in plant growth. Heliophilic species show higher values such as leaf biomass, stem biomass, root biomass, total biomass in H than in L light, whereas in shade-tolerant species such values are higher in L than in H light, and the intermediate light-demanding species having medium characteristics between them. However, most of the values measured show no significant difference among the three light-demanding types. This suggests that, firstly, even the seedlings of the heliophilic species need only moderate amount of light[7], and difference in light demands among various light demanding types is not so great at their seedling stage as at sapling and adult stages, which has been observed in seedling and sapling growth of some species[22]; and secondly, there is a gradient variation in light demanding from heliophilic species to shade-tolerant species. This is supported by the results that the indices of growth of the seedlings measured in this study, such as growth rate and total biomass, are in the sequence of heliphilic plants > intermediate light-demanding species > shade-tolerant species.

Seed weight has obvious effect on root and shoot growth, and on biomass increment of the seedlings, especially at the early stage (45 d). Fenner[20] reported that seedlings from large-seeded species had higher shoot/root ratio for initially prior capture of light rather than minerals. But there was no significant difference in the ratio of shoot/root biomass between seedlings of large- and small-seeded species in this experiment. However, seedlings of small-seeded species had larger difference between H light and L light in leaf growth (including leaf area and leaf weight) than those of large-seeded species. It is suggested that one of the effective strategies by which seedlings from small-seeded species strengthen their ability to capture light is to increase leaf area ratio and not shoot/root ratio. Seedlings from small-seeded species have also relatively more lateral roots and longer main root per unit root weight to achieve larger root surface area to attain higher growth rate than large-seeded-seedlings, as has been observed by Swanborough and Westoby[23] and Wright and Westoby[24].

Result of the experiment is showed that there is a gradient in growth and response to light intensity in the species. Some values are significantly different only between the heliophilic and shade-tolerant species. This suggests that methodically, integrated screening program (ISP) [25] for a big lot of species would help to reveal the gradient variation of plants and that comparative studies on ecologically distinct species would help to probe the differences between them. Both the research procedures could complement each other in revealing the relationship between differences in environment and species performance.

References

[1] Ng F S P. Strategies of establishment in Malaysian forest trees [A]. In: Tomlinson P B, Zimmermann M H. Tropical Trees as Living Systems [C]. Cambridge: Cambridge University Press, 1978. 129–162.

[2] Garwood N C. Seed germination in a seasonal tropical forest in Panama: a community study [J]. Ecol Mono, 1983, 53(2):159–181.

[3] Augspurger C K. Light requirements of neotropical tree seedlings: A comparative study of growth and survival [J]. J Ecol, 1984, 72: 777–795.

[4] Vazquez-Yanes C, Segovia O A. Ecophysiology of seed germination in the tropical humid forests of the world: a review [A]. In: Medina E, Mooney H A, Vazquez-Yanes C. Physiological Ecology of Plants in the Wet Tropics [C]. The Hague, Netherlands: Dr Junk Publishers, 1984. 37–50.

[5] Foster S A, Janson C H. The relationship between seed size and establishment conditions in tropical woody plants [J]. Ecology, 1985, 66(3):773–780.

[6] Kelley C K, Purris A. Seed size and establishment conditions in tropical trees: on the use of taxonomic relatedness in determining ecological patterns [J]. Oecologia, 1993, 94:356–360.

[7] Agyeman V K, Swaine M D, Thompson J. Responses of tropical forest tree seedling to irradiance and the derivation of a light response index [J]. J Ecol, 1999, 87(5):815–818.

[8] Juliette M, Bloor G, Grubb P J. Growth and mortality in high and low light: trends among 15 shade-tolerant tropical rain forest tree species [J]. J Ecol, 2003, 91(1):77–85.

[9] Grime J P, Jeffrey D W. Seedling establishment in vertical gradients of sunlight [J]. J Ecol, 1965, 53:621–642.

[10] Hester A J, Gimingham C H, Miles J. Succession from heather moorland to birch woodland. III. Seed availability, germination and early growth [J]. J Ecol, 1991, 79:329–344.

[11] Figueroa A J, Lusk C H. Germination requirements and seedling shade tolerance are not correlated in a Chilean temperate rain forest [J]. New Phytol, 2001, 152(3):483–490.

[12] Lusk C H, Pozo A Del. Survival and growth of seedlings of 12 Chilean rainforest trees in two light environments: Gas exchange and biomass distribution correlates [J]. Aust Ecol, 2002, 27(2): 173–179.

[13] Beon M S, Bartsch N. Early seedling growth of pine (*Pinus densiflora*) and oaks (*Quercus serrata, Q. mongolica, Q. variabilis*) in response to light intensity and soil moisture [J]. Plant Ecol, 2003, 167:97–105.

[14] Chen Z H, Chen H Q, Liu H Q, et al. Seed germination and seedling development of several tree species in the lower subtropical evergreen broad-leaf froest [J]. Acta Bot Sin, 1995, 37(8): 630–635. (in Chinese)

[15] Chen Z H, Zhang D M. Seed germination and seedling growth of 24 tree species in lower subtropical forest [J]. J Trop Subtrop Bot, 1999, 7(1):37–46. (in Chinese)

[16] Poorter L. Growth responses of 15 rain-forest tree species to a light gradient: the relative importance of morphological and physiological traits [J]. Funct Ecol, 1999, 13(3):396–402.

[17] Catherine A G. Growth responses to arbuscular mycorrhizae by rain forest seedlings vary with light intensity and tree species [J]. Plant Ecol, 2003, 167:127–139.

[18] Booth R E, Mackey J M L, Rorison I H, et al. ISP germination and rooting environments; sand, compost and solution culture [A]. In: Hendry G A F, Grime J P. Methods in Comparative Plant Ecology [M]. London, Glasgow, New York, Tokyo, Melbourne, Madras: Chapman & Hall, 1993. 19–23.

[19] Gai J Y. Methods of Experimental Statistics [M]. Beijing: Agricultural Press, 2000. 81–101. (in Chinese)

[20] Fenner M. Seed Ecology [M]. London, New York: Chapman and Hall, 1985. 107.

[21] Leishman M R, Wright I J, Moles A T, et al. The evolutionary ecology of seed size [A]. In: Fenner M. Seeds — The Ecology of Regenaration in Plant Communities [M]. 2nd ed. New York: CABI Publishing, Wallingford, 2000. 59-84.

[22] Li M J, Mo J M, Wang Z H. Studies on some ecological and biological characteristics of *Schima superba* in Dinghu Shan [A]. In: Tropical and Subtropical Forest Ecosystem Vol. 5 [C]. Beijing: Science Press, 1989. 55–61. (in Chinese)

[23] Swanborough P, Westoby M. Seedling relative growth and its components in relation to seed size: Phylogenetically independent contrasts [J]. Funct Ecol, 1996, 10(2):176–184.

[24] Wright I J, Westoby M. Differences in seedling growth behaviour among species: trait correlations across species, and trait shifts along nutrient compared to rainfall gradients [J]. J Ecol, 1999, 87: 85–97.

[25] Hendry G A F, Grime J P. Methods in Comparative Plant Ecology [M]. London, Glasgow, New York, Tokyo, Melbourne, Madras: Chapman and Hall, 1993. 1–19.

Appendix: Mother plant species for seedling raising

Species	Adaptation to sunlight	Growth form	Seed size	Plant height (m)	Girth at breast height (cm)	Habitat
1 *Microdesmis caseariifolia*	Sh	Shr	L	4	27	Forest
2 *Psychotria rubra*	Sh	Shr	L	2		Forest
3 *Ardisia crenata*	Sh	Shr	L	1.5		Forest
4 *Ardisia punctata*	Sh	Shr	L	1.5		Forest
5 *Ardisia quinquegona*	Sh	Shr	L	2.5		Forest
6 *Ormosia pachycarpa*	Sh	Tr	L	21	85	Forest
7 *Ormosia glaberrima*	Sh	Tr	L	6	65	Forest
8 *Machilus chinensis*	Sh	Tr	L	10	80	Forest
9 *Saurauia tristyla*	In	Tr	S	5	38	Ravine forest
10 *Diospyros morrisiana*	In	Tr	L	15	98	Forest
11 *Ficus hitra*	In	Shr	S	1		Forest and forest edge
12 *Aporosa chinensis*	In	Tr	L	6	62	Forest
13 *Ilex triflora*	In	Shr	S	1	10	Slope woodland
14 *Podocarpus fleuryi*	In	Tr	L	9	35	Slope woodland
15 *Litsea glutinosa*	In	Tr	L	12	70	Forest edge

Continued

Species	Adaptation to sunlight	Growth form	Seed size	Plant height (m)	Girth at breast height (cm)	Habitat
16 *Ficus nervosa*	In	Tr	S	18	112	Forest
17 *Ficus variegata*	In	Tr	S	6	52	Forest
18 *Garcinia multiflora*	In	Tr	L	18	58	Forest
19 *Pyrus calleryana*	In	Tr	S	2.5	29	Forest
20 *Schima superba*	In	Tr	S	12	48	Forest
21 *Ficus variolosa*	In	Shr	S	2	10	Forest and forest edge
22 *Cleistocalyx operculatus*	In	Tr	L	12	68	Valley stream (in forest)
23 *Syzygium championii*	In	Tr	L	6	28	Valley forest
24 *Ficus fulva*	In	Tr	S	5	41	Forest edge
25 *Ficus hispida*	He	Tr	S	5	37	Forest
26 *Melastoma candidum*	He	Shr	S	1		Open slope
27 *Ficus lacor*	He	Tr	S	20	178	Woodland
28 *Ficus microcarpa*	He	Tr	S	20	213	Forest edge
29 *Ficus altissima*	He	Tr	S	16	112	Planted
30 *Cratoxylum ligustrinum*	He	Tr	S	2.8	18	Open secondary forest
31 *Adinandra millettii*	He	Shr	S	1	11	Forest edge
32 *Broussonetia papyrifera*	He	Tr	S	10	80	Forest edge
33 *Rhodomyrtus tomentosa*	He	Shr	S	0.9		Open slope
34 *Viburnum odoratissimum*	He	Tr	L	6	68	Forest edge
35 *Acacia confusa*	He	Tr	L	18	67	Open slope
36 *Leucaena leucocephala*	He	Tr	L	3	18	Open slope
37 *Gossampinus malabarica*	He	Tr	L	22	189	Open slope
38 *Ligustrum sinense*	He	Shr	L	4	28	Slope woodland
39 *Lindera communis*	He	Tr	L	14	85	Lower slope woodland
40 *Rhus succedanea*	He	Tr	L	4	25	Slope woodland
41 *Sterculia lanceolata*	He	Tr	L	6	49	Forest
42 *Rhus chinensis*	He	Tr	L	6	23	Forest edge

Shr, shrub; Tr, tree; Sh, shade-tolerant species; In, intermediate light demanding species; He, heliophilic species; S, small-seeded species; L, large-seeded species.