Waterlogging Tolerance of 57 Plant Species Grown Hydroponically

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Additional index words. hydroponic experiment, ecological restoration, phenotype, provenance

Abstract. Plans for hydroponic experiments, as well as the flooding of watersheds for ecological restoration, require abundant evaluation information regarding plant species adapted to waterlogged environments. In this study, we observed the growth rate and phenotypes of 57 plant species, including nine provenances of four species grown hydroponically. The 57 species were from 22 families and 33 genera, and their waterlogging tolerance (WT) was classified into five categories according to the results of the evaluation: excellent, good, ordinary, poor, and very poor. We found that 60% of these plant species were able to survive in hydroculture for more than 10 weeks. They showed new shoot growth and had a survival rate of more than 60%. Species with excellent or good WT developed new leaves rapidly under waterlogging stress, whereas species with ordinary or poor WT exhibited old leaves dropping from the stem soon after waterlogging stress. In addition, phenotypic divergence occurred among provenances of the same species under waterlogging stress.

With the increasing frequency and intensity of extreme weather events because of climate change, more frequent rainstorms occur in many areas where existing drainage systems cannot handle the excess. Thus, the

lower areas frequently encounter the potential risk of flooding during the rainy season. In forest management, information regarding WT of plant species is necessary to cope with flooding. In addition, ecological restoration in depression areas or flooded watersheds must involve waterlogging-tolerant plant species. To investigate these effects under controlled plant growth conditions, homogeneous components of growth nutrients in solution are necessary for plant physiology research, agricultural nutrition research, and even research under field conditions. A homogeneous nutrient solution is an ideal material for controlling experiments to explore the response of species to factors besides nutrition. Because of hypoxic stress, the growth of the same species differed in soil cultures and hydroculture, although the nutrition reagent was the same. Therefore, evaluation of plant species grown hydroponically can provide important reference information for flooding watershed ecological restoration, as well as for designing hydroponic experiments.

Hypoxic and anoxic conditions occur when the soil is water saturated, which induces various changes in physiology (Amador et al., 2012), morphology, anatomy, and other parameters (Guo et al., 2011; Kreuzwieser and Rennenberg, 2014). However, plants have evolved morphologically and physiologically to adapt to the flooding environment, including defoliation, and reduction in leaf number and size (Ye et al., 2003). For leaf characteristics, morphological adaptations varied among different ecotypes and different species.

In this study, we examined the growth rates and leaf phenotypes of 57 plant species with several different provenances grown hydroponically for more than 10 weeks. We hypothesized the following: 1) length of survival under waterlogging stress should be a criterion of primary importance for the screening of plant species for watershed ecosystem restoration and 2) phenotypic divergence will not occur among provenances of the same species under waterlogging stress. The goal of this study was to select species among the 57 plant species that could be used for flooding watershed ecological restoration.

Materials and Methods

Plant materials. All 57 plant species shown in Supplemental Table 1 are indigenous evergreen trees from Guangzhou City and are adapted to tropical or subtropical environments. Seedlings, age 12 to 15 months, were classified into group I. Seedlings age 6 to 11 months were classified into group II. Group I and group II seedlings were collected locally in Feb. 2014. Group III included those seedlings germinated from seeds in Nov. 2013. All seedlings were grown outdoors in a nursing bag (diameter, 8 cm; depth, 12 cm) containing soil with moderate watering before the treatment. In Mar. 2014, after the roots were cleaned thoroughly, seedlings with healthy foliage and sprouts were transplanted individually into plastic pots (diameter, 9.5 cm; depth, 13.5 cm) containing modified Hoagland solution (pH = 6.0; Table 1), such that only the roots were submerged thoroughly in the solution. Provenances of the four species, including *Melia azedarach*, *Toona sinensis*, *Anthocephalus chinensis*, and *Mytilaria laosensis* were obtained based on the available germplasm resources of our research team. Geographic and environmental information for each provenance are shown in Table 2. Fifty seedlings of each species or provenance were collected initially. During collection, seedlings of the same species or provenance were chosen based on uniformity of size. The modified Hoagland solution in each pot was renewed every 4 d to maintain stable nutrient supplies.

Hydroponic experiments were conducted in a well-ventilated glasshouse without shading from Mar. to May 2014. During the experiments, the indoor air temperature was 16 to 35 °C and the air relative humidity was 60% to 98%.

Received for publication 10 Jan. 2019. Accepted for publication 10 Jan. 2019.

This work was supported by the National Natural Science Foundation of China (grant no. 31600307), the Forestry Science and Technology Innovation Project from the Forestry Department of Guangdong Province (grant no. 2017KJCX033), and the Science and Technology Planning Project of Guangdong Province (grant nos. 2015A020209139 and 2015B020207002).

We thank Xiaomei Deng, Hao Huang, Boyong Liao, and Xiangbin Zhou for germinating seeds; Juncheng Li for technical assistance; Xinsheng Hu for language improvement; and Rongjing Zhang and Huiming Lian for their valuable information about growth rate of tree seedlings under natural conditions.

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Seedling growth rate under natural conditions. Seedling growth rate (SGR) was recorded for all groups based on changes in seedling height. Three levels were specified to mark the SGR for each species: Rapid, indicating the SGR was greater than 20 cm/month; Common, for which the SGR was between 10 and 20 cm/month; and Slow, for which the SGR was less than 10 cm/month.

Survival rate calculation. The survival of seedlings was documented every 2 d. During the first week, the number of dead seedlings (D_1) was recorded for each species. We attributed a D_1 value less than three to root injury during cleaning. However, a D_1 value greater than three indicated waterlogging stress.

The survival rate (SR_1) was calculated as follows:

$$SR_1 = \frac{50 - D_1}{50} \times 100\%. \quad [1]$$

After 10 weeks, the number of dead seedlings (D_2) was recorded again. To exclude those with root injuries caused by cleaning, the survival rate after 10 weeks (SR_2) was calculated as follows:

$$SR_2 = \frac{50 - D_1 - D_2}{50 - D_1} \times 100\%. \quad [2]$$

Phenotype assessment. The growth performance of all 57 species was assessed based on leaf growth status every 2 d during the experiment. Growth performance was grouped as follows: A, new leaves had expanded; B, leaves had wilted and dropped from the stem; C, seedlings had grown very slowly or had ceased growing; D, all leaves had dropped rapidly whereas the terminal bud remained alive, which meant that the stem, branch, and terminal bud had not withered until the end of the experi-

ment; and E, the entire plant had withered rapidly.

The regeneration time for leaves for each species was divided into four periods: old leaves, coexisting old and new leaves, no leaves, and new leaves (Fig. 1). Each period was defined as follows: old leaves indicates that all fully expanded leaves existed when the experiment started; new leaves indicates that all leaves expanded fully after the experiment start date; coexisting old and new leaves indicates that at least one old leaf and one new leaf coexisted; and no leaves indicates that no fully expanded leaves existed. Figure 1 lists the species in the same order as in Supplemental Table 1.

Fresh biomass growth rate calculation. Five seedlings in pots with 500 mL modified Hoagland solution were weighed at the end of the first week (W_1 , measured in grams). Those that survived were weighed individually 10 weeks later (W_2 , measured in grams). The fresh biomass growth rate (FBGR, measured as a percentage) was calculated as follows:

$$FBGR = \frac{W_2 - W_1}{W_1} \times 100. \quad [3]$$

However, for some species, the number of survivors among the individuals that had been weighed for W_1 was less than three for the W_2 data. In such cases, we weighed other surviving seedlings instead, and we set the mean value of W_1 of the five seedlings weighed as the alternate value for W_1 .

WT class. We evaluated and ranked WT of the 57 species, as well as the provenances based on SR_2 , phenotype, FBGR (mean value), and SGR according to Eq. 4. The metrics and weight values for Eq. 4 are shown in Table 3.

$$WT = a \times SR_2 + b \times \text{phy} + c \times FBGR - d \times SGR, \quad [4]$$

where a , b , c , and d are the weighting factors assigned according to the impact of each parameter on WT; and phy is phenotype. In this study, we assumed that the weight for SR_2 , phenotype, FBGR, and SGR would be 80%, 20%, 20%, and 10%, respectively. Nevertheless, in consideration of the differences between the ranges of values for each parameter, which influence the effect of the assigned weight value, we adjusted each weight value by dividing by the maximum value of each parameter (rounded to an integer). Thus, the values of a , b , c , and

d were 0.8, 0.133, 0.067, and 0.033, respectively. Furthermore, the value of a hybrid phenotype was determined using the product of each assigned phenotype value. For example, the value of phenotype ABC was 0.6, which was obtained by the product of 1.5, 0.8, and 0.5.

The WT class of the 57 plant species with nine provenances was determined as follows: Excellent, $WT \geq 0.95$; Good, $WT < 0.95$ but ≥ 0.8 ; Ordinary, $WT < 0.8$ but ≥ 0.4 ; Poor, $WT < 0.4$; and Very Poor, those species with phenotype E, which therefore lacked a WT value.

Results

Survival rate. In this study, the D_1 values of 22 species were less than three. The SR_2 values of nine species were greater than 95%. Of these, *Dalbergia odorifera* (no. 1), *Ficus concinna* (no. 2), *Canavalia ensiformis* (no. 3), *Jatropha curcas* (no. 4), *Acacia auriculiformis* (no. 5), and *Ficus altissima* (no. 6) had SR_2 values of 100%. Ten species (with different provenances) had SR_2 values that ranged from 85% to 95%. Sixteen species had SR_2 values between 60% and 85%, 24 species (with different provenances) had SR_2 values less than 60%, and the last three species—*Zenia insignis* (no. 60), *Castanopsis fissa* (no. 61), and *Magnoliaceae glanca* (no. 62)—had SR_2 values of zero (Supplemental Table 1). In total, 60% of the plant species were able to survive in the hydroculture for more than 10 weeks, exhibiting new shoot growth and a survival rate greater than 60%.

Phenotypes. Phenotypes were assessed based on living individuals, except for those species that died rapidly, including *Z. insignis* (no. 60), *C. fissa* (no. 61), and *M. glanca* (no. 62). Overall, from high to low, 32% of the species exhibited phenotypes of A, B, and C combined; 31% were A; 16% were A and B combined; followed by 8%, 5%, 3%, 3%, 2%, and 0% for A and D combined, E alone, B and C combined, D alone, A and C combined, and B alone, respectively (Fig. 3).

Figure 1, which shows regeneration time of leaves for each species, illustrates the information regarding phenotypes. It shows that the species listed in the top part of Supplemental Table 1 had an old-leaves period only and a coexisting old- and new-leaves period, whereas the species listed in the bottom part of Supplemental Table 1 had a short coexisting old- and new-leaves period, but a long new-leaves period.

Table 1. Modified Hoagland nutrient solution contents (Liu, 2004).

Component	Concn (mg·L ⁻¹)
Ca(NO ₃) ₂ ·4H ₂ O	472
KNO ₃	202
NH ₄ NO ₃	80
KH ₂ PO ₄	100
K ₂ SO ₄	174
MgSO ₄ ·7H ₂ O	246
FeSO ₄ ·7H ₂ O	27.8
EDTA-2Na	37.2
H ₃ BO ₃	2.86
MnSO ₄ ·4H ₂ O	2.13
ZnSO ₄ ·7H ₂ O	0.22
CuSO ₄ ·5H ₂ O	0.08
(NH ₄) ₆ Mo ₇ O ₂₄ ·4H ₂ O	0.02

Table 2. Geographic and environment information for provenances.

Provenance	Geographic location	Latitude (N)	Longitude (E)	Elevation (m)	Mean annual temp (°C)	Mean annual precipitation (mm)
<i>Melia azedarach</i> ¹	Conghua, Guangdong, China	23°33'	113°35'	35	21.5	1,670
<i>Melia azedarach</i> ²	Xingyi, Guizhou, China	25°04'	104°40'	1,217	16.8	1,512
<i>Toona sinensis</i> ¹	Lechang, Guangdong, China	25°12'	113°33'	98	19.6	1,522
<i>Toona sinensis</i> ²	Malipo, Yunnan, China	23°12'	104°70'	1,057	18	1,054
<i>Anthocephalus chinensis</i> ¹	Guangzhou, Guangdong, China	23°10'	113°21'	10	22.1	1,697
<i>Anthocephalus chinensis</i> ²	Jinghong, Yunnan, China	21°03'	101°04'	553	21	1,197
<i>Anthocephalus chinensis</i> ³	Nanning, Guangxi, China	22°85'	108°40'	80	21.7	1,304
<i>Mytilaria laosensis</i> ¹	Shangsi, Guangxi, China	21°53'	107°54'	412	21.5	1,218
<i>Mytilaria laosensis</i> ²	Ruyuan, Guangdong, China	24°57'	113°26'	84	16	2,800

Superscript numbers (1, 2, and 3) after species names represent different provenances of same species.

Fig. 1. Regeneration time of leaves. The old-leaves period indicates that all fully expanded leaves existed when the experiment started. The new-leaves period indicates that all leaves expanded fully after the experiment start date. The coexisting old- and new-leaves periods indicate that at least one old leaf and one new leaf coexisted. The no-leaf period indicates that no fully expanded leaves exist.

Fresh biomass growth rate. Species such as *D. odorifera* (no. 1), with common SGR, exhibited an FBGR of $\approx 150\%$, demonstrating excellent adaptation to hydroculture. Younger seedlings, such as those of *C. ensiformis* (no. 3) and *J. curcas* (no. 4), which are classified as III in Supplemental Table 1, showed a greater FBGR, indicating they

adapted well to hydroculture because of their rapid SGR and, to some extent, to a relatively low W_1 . However, some species, such as *P. clypearia* (no. 53), *M. laosensis* (nos. 54 and 55), *A. mangium* (no. 56), *Elaeocarpus apiculatus* (no. 57), *Terminalia mantaly* (no. 58), and *A. falcata* (no. 59), exhibited a negative FBGR (Supplemental Table 1), which

resulted from leaf loss that exceeded new shoot growth.

In addition, species from different provenances—such as *Melia azedarach*¹ (no. 9) and *M. azedarach*² (no. 12); *Toona sinensis*¹ (no. 11) and *T. sinensis*² (no. 14); *M. laosensis*¹ (no. 54) and *M. laosensis*² (no. 55); and *A. chinensis*¹ (no. 30), *A. chinensis*² (no. 38), and *A. chinensis*³ (no. 41)—exhibited little variation in SR₂ and FBGR, and phenotypes among provenances were similar (Fig. 2, Supplemental Table 1).

WT rating. In this study, six species with 100% SR₂ were ranked Excellent, including *D. odorifera* (no. 1), *F. concinna* (no. 2), *C. ensiformis* (no. 3), *J. curcas* (no. 4), *A. auriculiformis* (no. 5), and *F. altissima* (no. 6). Twelve species, including two with four provenances, were ranked Good. Nineteen species, including one with two provenances, were ranked Ordinary; and 18 species, two of which had three provenances, were ranked Poor. Three species were ranked Very Poor: *Z. insignis* (no. 60), *C. fissa* (no. 61), and *M. glanca* (no. 62) (Fig. 2).

Discussion

After being grown hydroponically for 10 weeks, the survival rates of 27 species were greater than 60%. However, a number of species did not grow well under waterlogging conditions. This result is consistent with our first hypothesis, that the length of survival under waterlogging stress should be a criterion of primary importance for screening plant species for watershed ecosystem restoration.

Synthesizing the information from Fig. 1 and Supplemental Table 1, we see that species with excellent or good WT soon developed new leaves under waterlogging stress, and old leaves remained alive, whereas species with ordinary or poor WT soon dropped old leaves from the stem under waterlogging stress, although some of them developed new leaves. This indicates that plant species with poor tolerance dropped leaves almost immediately when suffering from waterlogging stress, whereas those species with good WT developed new leaves soon after encountering waterlogging conditions, and dropped fewer old leaves.

Variation in phenotype is related closely to physiological responses under waterlogging. When waterlogged roots become hypoxic, normal cell metabolism is restricted and the physiological activities of aboveground organs are affected accordingly (Kreuzwieser and Rennenberg, 2014). Changes in phenotype occur over time. For example, some plants exhibited leaves that wilted and dropped from the stem under waterlogging, which may be correlated with changes in endogenous abscisic acid, indole acetic acid, gibberellic acid, nitric oxide, and ethylene, among other compounds (Bailey-Serres et al., 2012; Herrera, 2013; Pagnussat et al., 2004) or their ratios (Kim et al., 2015). The effects of endogenous hormones on phenotype under waterlogging vary by genotype and ecotype (Gomathi et al.,

Table 3. Metrics and weight values in the determination of waterlogging tolerance class.

Parameter	Abbreviation	Weighting factor	Wt value	Value or rank	Assigned value
Survival rate after 10 weeks	SR ₂	a	0.800	Calculated	N/A
Phenotype	phy	b	0.133	A B C D E	1.5 0.8 0.5 0.5 0
Fresh biomass growth rate	FBGR	c	0.067	Calculated	N/A
Seedling growth rate	SGR	d	0.033	Rapid Common Slow	3 2 1

Lower case letters (a, b, c, and d) are weighting factors for SR₂, phy, FBGR, and SGR, respectively. Their values are shown as W_i value. Upper case letters (A, B, C, D, and E) are rank marks for phenotype, while Rapid, Common, and Slow are rank marks for SGR. N/A = not applicable.

Fig. 3. Frequency distribution of phenotypes of surviving species. A, new shoots grew; B, leaves wilted and dropped from the stem; C, growth slowed or ceased; D, all leaves withered or dropped rapidly, with the terminal bud remaining alive; E, the entire plant withered rapidly.

Fig. 2. Quantized and weighted seedling growth rate (SGR) under natural conditions, survival rate after 10 weeks (SR₂), phenotypes (phy), fresh biomass growth rate (FBGR), and waterlogging tolerance (WT) of 57 plant species in hydroculture [shown in two graphs (A and B) and in the same order as in Supplemental Table 1]. The letters on the right of the bars indicate the WT class of each species: E, excellent; G, good; O, ordinary; P, poor; VP, very poor.

2015; Guo et al., 2011; Jaeger et al., 2009). In the current study, *A. chinensis*, *C. bakeriana*, *P. clypearia*, and *M. laosensis* were completely defoliated under waterlogging, after which

A. chinensis gradually grew new leaves, but the other species remained leafless. Overall, the mechanisms of endogenous hormone regulation of defoliation and growth under water-

logging have not been fully revealed, and further exploration is needed.

Under waterlogging conditions, additional stress can arise because hypoxia or anoxia in the rhizosphere can induce the accumulation of large quantities of reactive oxygen species in roots and aboveground organs. This condition leads to saturation of the active oxygen scavenging system, resulting in increased peroxidation of membrane lipids, soluble sugars, and soluble proteins, as well as increased malondialdehyde production (Irfan et al., 2010). Chlorophyll breakdown also increases (Ye et al., 2003), and photosynthesis is restricted (Visser et al., 2003), inducing rapid death in some intolerant species, such as *Z. insignis*, *M. glance*, and *C. fissa*, according to our study.

Differences in abiotic stress tolerance among provenances of the same species from different climatic zones have been observed (Carsjens et al., 2014; Du et al., 2016; Yildiz et al., 2014), which is contrary to our second hypothesis that phenotypic divergence would not occur among provenances of the same species under waterlogging stress. This variability may be caused by differences among habitats and the duration of provenance separation. In our study, little variation in WT was found for *M. azedarach*, *T. sinensis*, *M. laosensis*, and *A. chinensis* provenances, although their WT did not exhibit the same trends as precipitation in their location of origin (Table 2). We presumed that WT is, to a large extent, determined by DNA, not the habitat for the species investigated in this study.

Adult trees have been found to be more tolerant to waterlogging than seedlings of the same species (Kreuzwieser and Rennenberg, 2014), and growth conditions of plants in hydroculture differ in certain aspects from those under waterlogging conditions in natural soil because of the vast differences in microelements and microbial communities. In addition, some plant species formed aerenchyma to cope with hypoxia under waterlogging, and thus maintained biomass production (Laan et al., 1991). In our study, *Dalbergia odorifera*, *Ficus concinna*, *Canavalia ensiformis*, *Jatropha caracas*,

Acacia auriculiformis, and *Ficus altissima* exhibited new leaf growth and maintained high biomass production. We speculate that these species might form aerenchyma in hydroculture and should be suitable for use in ecological restoration of flooded watersheds in tropical or subtropical areas.

Taken together, our results indicate that some plant species cannot survive under hydroponic conditions. Evaluation of WT is essential before selecting species for use in hydroponic experiments or in flooding watershed restoration.

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Supplemental Table 1. Phenotypes and biomass growth rates for 57 plant species in hydroculture.

No.	Name of species	SC ^z	SGR	Survival rate (%)		Phenotypes ^y	FBGR (%)
				SR ₁	SR ₂		
1	<i>Dalbergia odorifera</i>	I	Common	98	100	A	95 ± 15
2	<i>Ficus concinna</i>	I	Common	100	100	A	31 ± 5
3	<i>Canavalia ensiformis</i>	III	Rapid	100	100	A	313 ± 54
4	<i>Jatropha curcas</i>	III	Rapid	100	100	A	109 ± 18
5	<i>Acacia auriculiformis</i>	I	Common	100	100	A	53 ± 8
6	<i>Ficus altissima</i>	I	Common	100	100	A	28 ± 7
7	<i>Michelia chapensis</i>	I	Common	98	96	A	22 ± 4
8	<i>Michelia macclurei</i>	I	Common	96	96	A	20 ± 2
9	<i>Melia azedarach</i> ¹	II	Rapid	100	96	AB	50 ± 4
10	<i>Phoebe bournei</i>	I	Slow	98	94	AB	11 ± 3
11	<i>Toona sinensis</i> ¹	II	Rapid	100	94	A	80 ± 7
12	<i>Melia azedarach</i> ²	II	Rapid	100	92	AB	50 ± 5
13	<i>Toona ciliata</i>	II	Rapid	98	92	A	68 ± 7
14	<i>Toona sinensis</i> ²	II	Rapid	100	92	AB	63 ± 5
15	<i>Erythrophloeum fordii</i>	I	Slow	96	90	A	20 ± 6
16	<i>Acacia decurrens</i>	II	Common	90	89	A	65 ± 17
17	<i>Albizia lebbbeck</i>	II	Common	90	89	A	45 ± 25
18	<i>Leucaena leucocephala</i> cv. <i>Salvador</i>	II	Common	92	87	A	50 ± 8
19	<i>Acacia sophorae</i>	II	Common	92	87	A	32 ± 4
20	<i>Acacia salicina</i>	II	Common	90	85	A	60 ± 16
21	<i>Bischofia javanica</i>	I	Common	94	83	AB	11 ± 3
22	<i>Acacia longifolia</i>	II	Common	88	82	AB	12 ± 2
23	<i>Acacia spectabilis</i>	II	Common	86	81	A	21 ± 8
24	<i>Podocarpus nagi</i>	I	Slow	96	81	AB	11 ± 3
25	<i>Xanthostemon chrysanthus</i>	I	Rapid	94	85	ABC	16 ± 9
26	<i>Camellia oleifera</i>	I	Slow	84	79	ABC	10 ± 6
27	<i>Acacia mearnsii</i>	II	Common	86	79	A	25 ± 3
28	<i>Acacia melanoxylon</i>	II	Common	92	78	A	39 ± 3
29	<i>Ilex rotunda</i>	I	Common	92	78	AC	14 ± 1
30	<i>Anthocephalus chinensis</i> ¹	II	Rapid	90	78	AD	5 ± 3
31	<i>Castanopsis hystrix</i>	I	Slow	96	73	ABC	3 ± 1
32	<i>Ficus virens</i> var. <i>sublanceolata</i>	I	Common	100	70	ABC	9 ± 4
33	<i>Cinnamomum camphora</i>	I	Slow	98	61	ABC	5 ± 1
34	<i>Acacia maidenii</i>	II	Common	98	61	ABC	12 ± 2
35	<i>Syzygium cumini</i>	I	Common	98	61	ABC	13 ± 7
36	<i>Cassia surattensis</i>	I	Common	90	60	AB	22 ± 6
37	<i>Pinus massoniana</i>	I	Common	98	55	ABC	5 ± 2
38	<i>Anthocephalus chinensis</i> ²	II	Common	92	52	AD	3 ± 4
39	<i>Ormosia pinnata</i>	I	Common	94	51	AB	16 ± 4
40	<i>Acacia crassicarpa</i>	II	Common	80	50	ABC	5 ± 4
41	<i>Anthocephalus chinensis</i> ³	II	Common	92	35	AD	1 ± 3
42	<i>Grevillea banksii</i> var. <i>forsteri</i>	I	Common	86	35	ABC	7 ± 9
43	<i>Acacia podalyriifolia</i>	II	Common	90	33	ABC	4 ± 2
44	<i>Acacia juncifolia</i>	II	Common	86	33	ABC	5 ± 3
45	<i>Acacia adunca</i>	II	Common	86	26	AB	16 ± 20
46	<i>Bauhinia purpurea</i>	I	Common	80	18	ABC	5 ± 4
47	<i>Cassia bakeriana</i>	I	Common	90	24	AD	-89 ± 20
48	<i>Rhodoleia championii</i>	I	Common	88	27	ABC	7 ± 13
49	<i>Radermachera hainanensis</i>	I	Rapid	80	25	ABC	9 ± 13
50	<i>Acacia decurrens</i>	II	Common	76	24	ABC	4 ± 7
51	<i>Syzygium rehderianum</i>	I	Common	78	15	ABC	8 ± 8
52	<i>Phoebe sheareri</i>	I	Slow	80	20	BC	3 ± 6
53	<i>Pithecellobium clypearia</i>	II	Common	80	25	AD	-40 ± 4
54	<i>Mytilaria laosensis</i> ¹	II	Rapid	82	29	D	-200 ± 13
55	<i>Mytilaria laosensis</i> ²	II	Rapid	78	26	D	-210 ± 15
56	<i>Acacia mangium</i>	II	Common	82	22	ABC	-11 ± 7
57	<i>Elaeocarpus apiculatus</i>	I	Rapid	78	18	ABC	-7 ± 4
58	<i>Terminalia mantaly</i>	I	Rapid	76	16	ABC	-15 ± 3
59	<i>Acacia falcata</i>	I	Common	50	12	BC	-32 ± 5
60	<i>Zenia insignis</i>	III	Rapid	72	0	E	—
61	<i>Castanopsis fissa</i>	I	Common	50	0	E	—
62	<i>Magnoliaceae glanca</i>	I	Rapid	60	0	E	—

^zSC = seedling age class at time of test. I = ≈15 mo. old; II = ≈8 mo. old; III = ≈3 mo. old.^yPhenotypes: A = new shoots grew; B = leaves wilted and dropped from the stem; C = growth slowed or ceased; D = all leaves withered or dropped rapidly with the terminal bud remaining alive; E = the entire plant withered rapidly.

Superscript numbers (1, 2, and 3) after species name represent different provenances of same species.

SGR = seedling growth rate under natural conditions; FBGR = fresh biomass growth rate.