JARQ 39 (4), 299 – 305 (2005) http://www.jircas.affrc.go.jp

Growth and Biomass of *Acacia mangium* Willd. Stands Planted as Bare-Root and Container Seedlings

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Abstract

To identify suitable cultural methods for seedlings of *Acacia mangium* Willd., the most important tree species for reforestation in the humid tropics of Southeast Asia, we studied the survival, growth, biomass, and yield of plantations of bare-root and container seedlings. The study was conducted at the Forest Research Centre Sabah in Malaysian Borneo for 14 years after planting. Survival rates did not differ significantly between seedling types. Individual height growth and stem weight increment were slightly larger for container seedlings for at least the first year after planting, but thereafter there was no significant difference in growth between the two types of seedlings. Biomass did not differ significantly between seedling types over the 14-y study period. As well, yield (estimated from the number of stems potentially usable as timber) did not differ significantly between seedling types over 7- and 14-y rotation periods. Bare-root seedlings have lower production costs than container seedlings and are easier to transport in large numbers. These advantages would make bare-root seedlings an important alternative to container seedlings, which are commonly used for the production of *A. mangium* in large-scale reforestation programs, at least as far as our research site is concerned.

Discipline: Forestry and forest products
Additional key words: artificial regeneration, humid tropics, Sabah, yield

Introduction

As natural forests are being rapidly deforested and degraded in the tropics, reforestation by artificial regeneration has played an increasingly important role in tropical silviculture, ensuring more predictable results than with natural regeneration. Artificial regeneration is expected to produce timber and biomass but is also expected to facilitate the establishment of naturally regenerated seedlings and promote secondary succession[9,16]. Artificial regeneration is generally conducted using seedlings raised in the nursery. Since soil preparation, fertilization, and tending are usually not conducted as completely at reforestation sites as at agricultural sites, many newly germinated seedlings are likely to fail in competition with other plants. As a result, they must be tended in the nursery until they become sufficiently sturdy to survive outplanting in the field. This is a different approach from that used in agriculture, in which seeds are sown where the crops are to grow and be harvested[5]. Properly raising seedling stock in the nursery is thus the most important initial stage in reforestation.

In general, two main types of seedling stock are raised from seeds: bare-root seedlings, which grow with the soil that is different from the soil of the ultimate planting site, and container-grown seedlings (“container” seedlings henceforth), which are grown in small polythene or paper containers to facilitate lifting and transplanting of the seedlings[5,8,20]. Bare-root seedlings were originally most common in nursery practice, but container seedlings became an important alternative after the 1960s[13,18] and have become the predominant planting method for reforestation worldwide, particularly in the tropics[5,8,18,22,24].

Compared with traditional planting of bare-root seedlings at reforestation sites, container seedlings should mitigate the problem of reestablishment of contact between roots and the soil[20] because they are raised in the containers which are directly transferred to the planting sites. After planting, the rooting medium remains around the roots, providing an enhanced microsite that favors

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Received 25 October 2004; accepted 9 March 2005.

good root-soil contact[13]. In contrast, reestablishment of contact between roots and soil is believed to be a crucial problem for bare-root seedlings[20]. These beliefs suggested that container seedlings had an advantage over bare-root seedlings in terms of their survival and growth after outplanting[5,8,13].

Although differences in survival and growth between bare-root and container seedlings have been well studied in Europe and North America[18], much less research has been done on this difference in the tropics, where soil and environmental conditions differ dramatically from those in temperate zones. In particular, there is no information on whether the type of seedling used in reforestation would affect the biomass and final yield of plantations. In practical forestry, we must evaluate both the initial growth performance of the seedlings and the yield of the stand at harvesting.

The present study aimed to clarify whether container or bare-root seedlings were superior in terms of seedling growth and survival and of biomass and timber production at harvesting time in stands of *A. mangium* Willd., which is the most widely planted plantation tree species in the humid tropics of Southeast Asia, as well as in Sabah, in Malaysian Borneo. The goal was to help select the most suitable cultural method for the seedlings of this species.

Materials and methods

1. Study stand

The study stand was an *A. mangium* plantation at the Forest Research Centre Sabah at Kolapis, about 60 km west of Sandakan (latitude 5°54′N, longitude 118°04′E), in Malaysian Borneo. The area has a tropical wet climate, and meteorological data indicate a mean annual temperature of 27.8ºC and a mean annual precipitation of 2,970 mm from 1988 through 2002[10]. Monthly precipitation is generally greatest from November through February. The soil type at the experimental site is a profondic alisol[6]. The experimental site is located along a gentle ridge and at the upper part of a slope.

Two types of plots (each 21 m × 21 m) were established in November 1988: one planted with bare-root seedlings and another planted with container seedlings. There were three replicates of each plot in which each 49 seedlings were planted with 3 m × 3 m spacing. Planting was done after cutting the degraded natural forest. Container seedlings were produced in black perforated polythene bags 15 cm × 23 cm (diameter × depth) in size. Germinant seedlings were raised for 3 weeks on the seedbed and thereafter transplanted to the bags and grown for 4 months in the nursery before outplanting in December 1988. The soil in the containers was the topsoil taken from natural forest near Kolapis. The bare-root seedlings were grown for 5 months in the nursery. Seeds were directly sowed to the seedbed in July 1988 and germinant seedlings were grown in the seedbed through December 1988. The root pruning was conducted 2 weeks before outplanting with remaining roots of 10–15 cm lengths. In planting, seedlings were lifted from the seedbed at 15:00 p.m. and collected in a gunny sack and then directly transferred to the field. Outplanting was conducted between 16:00 and 18:00 p.m. to avoid excessively hot weather during the day.

2. Study method

To study the survival and growth of the two types of seedling, after planting in 1988, the height of each seedling in each plot was measured every 2 months until 1 y after planting. Thereafter, the height and diameter at breast height (DBH) of every tree were measured at irregular intervals until 2002.

To study the yield of the two types of stands, we destructively sampled 15 sample trees of different sizes within and outside the stands during an April 2002 thinning of the *A. mangium* stand and measured the dimensions of each tree and the fresh weights of the stems. We then estimated the oven-dry weight of each stem by multiplying the fresh weights by a dry:fresh ratio calculated for stem samples that had been dried for 10 days in a drying oven at a temperature of 95ºC. We then used the following allometric equation to estimate the total stem biomass in each plot:

$$Ws = 0.0219(D^2H)^{0.9827} \quad (1)$$

with $R^2 = 0.9941$. Ws denotes the oven-dry weight of the stem (kg), and D^2H denotes the square of the DBH (cm) multiplied by the tree's height (m). We estimated the stem biomass in each plot by applying equation (1) to the measured DBH and height of every tree, using the values measured at irregular intervals more than 1 y after planting. This particular allometric equation can be applied to trees at different stages of forest development to estimate stem biomass[14,15].

To estimate the stem biomass in each plot during the first year after planting, when only heights were measured because many seedlings had not yet grown above breast height, we used the following allometric equation:

$$Ws = 0.0173(H)^{2.7804} \quad (2)$$

with $R^2 = 0.9202$.

Results

1. Survival

The postplanting survivorship curves for the bare-root and container seedlings for 14 y in the field are shown in Fig. 1. The mean survival rate was 89% for the bare-root seedlings and 92% for the container seedlings during the first year after planting. The corresponding mean survival rates were 63% and 71% 14 y after planting. The values for corresponding survival rates were transformed into arc sine and then analyzed by means of a two-sided paired *t*-test. Survival rates did not differ significantly between bare-root and container seedlings throughout the 14 y ($p > 0.05$) (Fig. 1).

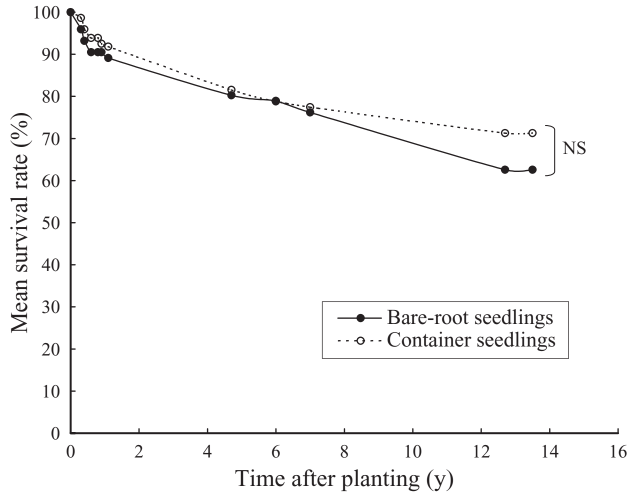

Fig. 1. Survivorship curves for the container and bare-root seedlings
NS: Not significantly different ($p > 0.05$) for 14 y after planting (*t*-test).

2. Growth of individual seedlings

The height growth and stem weight increment up to 14 y after planting were analyzed by means of ANOVA. The results showed that both the height growth and stem weight increment were significantly larger for the container seedlings for at least 1 y after planting, although the magnitude of the difference was small (Table 1). Mean height growth and mean stem weight increment remained slightly larger in the container seedlings 4.7 y after planting. Thereafter, there were no significant differences between the two types of seedlings (Table 1). This pattern may have arisen from the fact that the initial height and stem weight were significantly larger for the container seedlings, but the difference was sufficiently small that, once planted, the bare-root seedlings soon caught up with the container seedlings (Table 1).

We also examined the relationship between height growth, stem weight increment, and initial seedling size for the 14-y period. We obtained a positive correlation coefficient by means of regression analysis for the entire 14-y period (Fig. 2). Within 1 y after planting, there was a significant but weak positive correlation between growth and initial size. Thereafter, the correlation tended to become weaker and, with few exceptions, was not significant after 4 y (Fig. 2). These findings suggest that the difference in height growth and stem weight increment between the bare-root and container seedlings resulted from the initial size differences between the two types of seedling. To test this hypothesis, we selected seedlings with similar sizes from the six study plots and compared their mean height growth and stem weight increment after planting by means of ANOVA (Table 2). Once again, the differences (slightly better growth for the container seedlings) were only significant for the first year after planting, despite the lack of any significant difference in initial size.

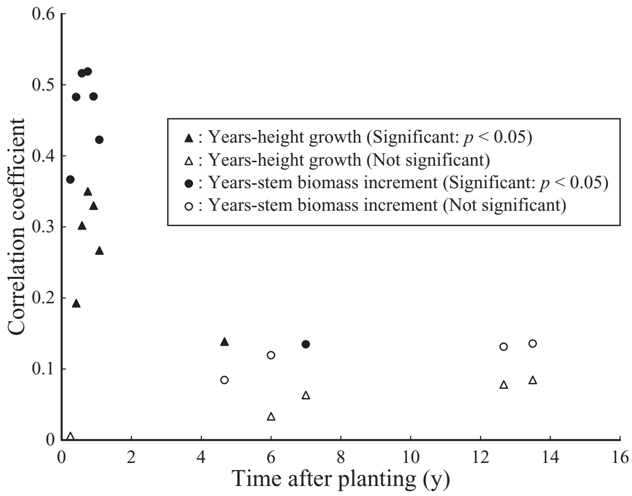

Fig. 2. Correlation coefficients for the relationship between initial size and height growth and between initial size and weight increment (measured in terms of stem biomass) for the 14 y after planting

Therefore, it is reasonable to suggest that container seedlings grew larger than bare-root seedlings for at least the first year, after which the growth did not differ significantly, irrespective of any differences in initial seedling size. However, since we performed no measurements between 1 and 5 y after planting, we cannot state with any certainty how long the initial superiority of the container seedlings would last after planting.

3. Biomass increment and stand yield

We approximated the stem biomass for both bare-root and container seedlings using the Richards function[17] that showed the best fit with the biomass as a function of

Table 1. Mean initial size, mean height growth and stem weight increment over the 14-y period

		Time after planting (y)											
		0.00	0.25	0.42	0.58	0.75	0.92	1.1	4.7	6.0	7.0	12.7	13.5
Mean height growth after planting (m/y after planting)	Bare-root seedlings	0.39*	0.12	0.48	0.98	1.84	2.74	3.84	19.0	20.2	22.1	21.5	21.7
	Container seedlings	0.50*	0.14	0.59	1.20	2.16	3.06	4.13	18.4	19.5	21.7	21.9	22.2
p-value		0.000	0.150	0.001	0.000	0.000	0.000	0.004	0.033	0.135	0.439	0.493	0.454
Mean stem biomass increment after planting (kg dry weight/y after planting)	Bare-root seedlings	0.001*	0.002	0.012	0.045	0.17	0.44	1.01	115.8	165.6	208.5	305.9	325.5
	Container seedlings	0.003*	0.003	0.023	0.086	0.29	0.65	1.31	116.0	165.3	209.3	315.0	337.5
p-value		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.971	0.982	0.962	0.773	0.730

*: Initial size. Significance was tested by ANOVA.

Table 2. Mean initial size, mean height growth and stem weight increment for seedlings of similar size selected from the six study plots

		Time after planting (y)											
		0.00	0.25	0.42	0.58	0.75	0.92	1.1	4.7	6.0	7.0	12.7	13.5
Mean height growth after planting (m/y after planting)	Bare-rooted seedlings	0.46*	0.10	0.49	1.05	1.92	2.85	3.96	19.3	20.1	22.5	21.3	21.5
	Container seedlings	0.47*	0.18	0.64	1.29	2.25	3.16	4.33	19.1	20.0	21.9	21.5	21.7
p-value		0.189	0.010	0.033	0.008	0.012	0.043	0.021	0.685	0.913	0.567	0.826	0.846
Mean stem biomass increment after planting (kg dry weight/y after planting)	Bare-rooted seedlings	0.002*	0.002	0.014	0.056	0.20	0.50	1.11	117.3	165.9	213.6	306.3	326.1
	Container seedlings	0.002*	0.003	0.023	0.087	0.29	0.65	1.39	117.9	162.4	197.7	276.8	290.7
p-value		0.181	0.007	0.012	0.002	0.004	0.024	0.012	0.964	0.875	0.621	0.654	0.619

*: Initial size. Significance was tested by ANOVA.

time (Fig. 3). The *A. mangium* stands planted with bare-root and container seedlings had nearly reached their maximum stem biomass after 14 y. In the early stages of growth (up to about 6 y after planting), the growth curves for the two seedling types showed a similar trend, but thereafter the biomass of the plantations of container seedlings tended to become larger than that of the bare-root seedlings. However, a two-sided paired *t*-test showed that this difference was not significant ($p > 0.05$) at any point during the 14 y after planting.

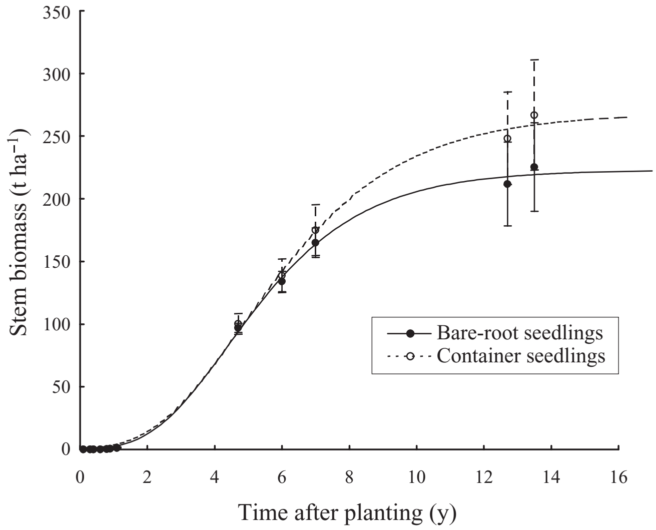

Fig. 3. Stem biomass as a function of stand age
Data are plotted using the Richards function[17]. Vertical bars represent standard errors.

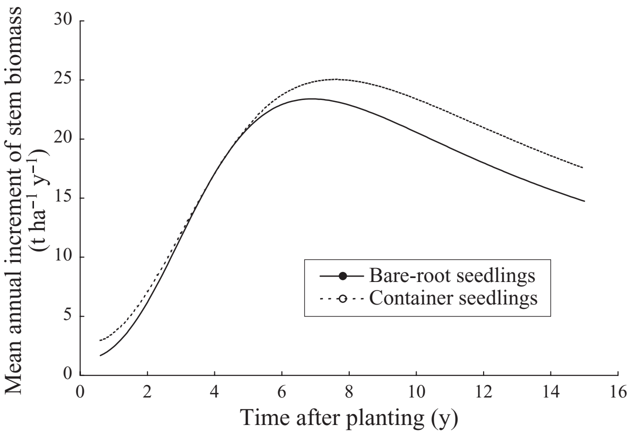

Fig. 4. Mean annual increment (MAI) of stem biomass as a function of stand age

We also compared the potential yield in terms of stems that could be used as lumber (e.g., suitable for furniture and construction). *Acacia mangium* can be used for furniture and cabinet construction, as well as for construction lumber[12]. The minimum DBH for using this species to create these products is 24 cm[23]. Thus, we compared the number of trees that reached at least 24 cm in DBH at 7 and 14 y after planting (Table 3). The 7-y-old plantation represents the expected optimal rotation period for maximum sustained biomass production, which is indicated by the stand age at which peak mean annual increment (MAI) occurs[2]. In both stands, peak MAI appeared at around 7 y after planting (Fig. 4). The 14-y-old plantation represents the period of nearly maximum stem biomass that is expected to produce the approximately maximum lumber production for the short rotation tree species of *A. mangium* in both plots (Fig. 3). Although there were slightly more large trees in the container plantation, there was no significant difference in the mean number of stems suitable for lumber at 7 and 14 y after planting (Table 3).

Discussion

In the humid tropical areas of Southeast Asia, which include our study area in Sabah, Malaysian Borneo, *A. mangium* is often used for reforestation. The most common method for raising seedlings of this species in the Sabah region is in containers[3], and bare-root seedlings are rarely used for this species. However, it was not known whether container seedlings were truly superior to bare-root seedlings in terms of survival, growth, and final yield. We intended to challenge this matter. However, the results obtained here are based on a small-scale experiment with 3 replications on one specific site in eastern Sabah. Thus the interpretation of the results from this study is not free from the experimental limitations.

In our experiment, the survival rate did not differ between the bare-root and container seedlings throughout the experimental period, which lasted 14 y after plant-

Table 3. Mean number of stems potentially suitable for lumber production

Plantation age (y)	Plantation of bare-root seedling no. (no. 441 m^{-2})	Plantation of container seedling no. (no. 441 m^{-2})	*p*-value
7-y-old	10	13	0.4227
14-y-old	18	20	0.6167

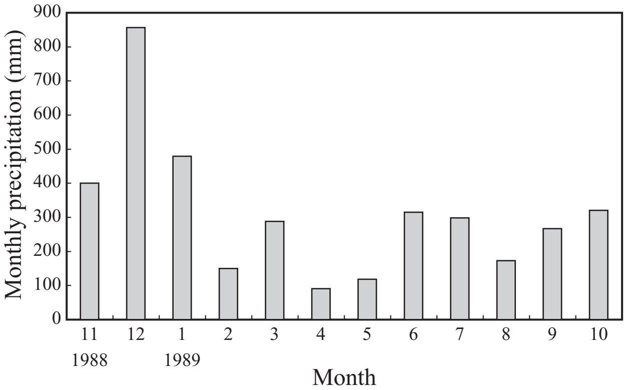

Fig. 5. Monthly rainfall for the first 12 months after planting (November 1988 to October 1989) in the Sandakan study area

Data provided by the Malaysian Meteorological Service[10].

ing. Initial survival was comparably high, at around 90%, for both types of seedlings. The individual growth would be larger in container plantations for at least 1 y after planting, though this difference seemed to disappear after about 6 y.

It has often been claimed that container seedlings retain the rooting medium around their roots, and that this favors good root-soil contact at the time of planting and thereafter[13, 21], whereas bare-root seedlings have a sometimes crucial problem reestablishing contact between their roots and the soil after planting[20]. This close contact between roots and soil after planting might be one factor that increased the initial growth of container seedlings compared with that of bare-root seedlings. However, this factor did not affect seedling survival. High initial survival of both types of seedling might have reflected the amount and pattern of rainfall after planting, as it rained heavily from November 1988 to January 1989 in Sandakan (Fig. 5), which would provide the seedlings with adequate levels of soil moisture. Thus, neither type of seedling, especially the bare-root seedlings that are believed to be seriously influenced by soil moisture deficits[5,19], suffered from severe soil conditions after planting. The lack of such stress may have kept the initial survival rate high.

Planting time might also have affected the initial survival rate. Wyatt-Smith[22] stated that bare-root seedlings should be planted before about 11:00 a.m. in tropical Malaysia. At our study site, planting was done between 16:00 and 18:00 p.m. to avoid heat stress on the seedlings, and the bare-root seedlings showed the same high initial survival rate as the container seedlings. This suggests that planting in the late afternoon is a viable alternative to morning planting. Daily weather in this region varies over time and is not predictable throughout the year as a result of convection and the mixture of cold and warm atmospheric processes in the tropics[11]. Soil water decreases over the course of the day after rainfall throughout the year at our research site (Inagaki, M., Forestry and Forest Products Research Institute, Japan, personal communication). These suggest that seedlings planted in the morning might suffer from soil water deficits immediately after planting. Soil water remained nearly constant or decreased little at night at the research site (Inagaki, M., Forestry and Forest Products Research Institute, Japan, personal communication). We also observed that dew supplied a certain amount of water in the soil at night. Thus, planting in late afternoon appears to be a robust alternative to morning planting.

In general, the initial size of seedlings affects their growth after outplanting[4,21]. In our experiment, however, the influence of differences in initial size on seedling growth was limited to the first few years after planting, although our results did suggest that the initial size of the seedlings was a potentially important factor. The two types of seedlings are raised differently, so it is often difficult to use comparable sizes of seedlings in studies. In temperate areas, the performance of bare-root and container seedlings have been compared frequently, but there have been inconsistent results according to the studies in temperate zones[7]. Differences in the initial sizes of the seedlings being compared might be one reason for this inconsistency.

In our experiment, after the initial growth stage, individual growth did not differ significantly between the bare-root and container seedlings. This may be due to differences in microsites among the individual trees and in the extent of intraspecific competition and their effects on tree growth rather than differences in growth performance between the two types of seedlings after the establishment of seedlings.

At the stand level, there was no significant difference in total biomass between the two types of seedlings up to 14 y after planting even if the mean biomass was larger in container seedlings than in bare-roots on the latter stage of forest development that might be affected by microsites and intraspecific competition. Similarly, the number of trees potentially suitable for lumber at two rotation periods (7 and 14 y) did not differ significantly. These results suggest that there would be no difference in the final yield of plantations created by planting bare-root and container seedlings at our study site.

From these results, it appears that the survival rate, biomass production, and final yield of the plantations were not affected by the type of planted seedlings, regardless of any initial superiority in the individual growth of container seedlings. Therefore, other factors might suggest the choice of one seedling type over the other. In general, the production of bare-root seedlings has certain advantages over that of container seedlings. It is easier to transport large numbers of bare-root seedlings[5,20], if the seedlings are carefully packed. The production cost for bare-root seedlings is also lower than that of container seedlings[1,5,13,19]. These advantages, and the lack of any clear survival or growth advantage for container seedlings, suggests that bare-root seedlings might be a viable and important alternative to container seedlings in humid tropical areas like our research site with the soil type of a profondic alisol and much rainfall throughout the year. Since bare-root seedlings are believed to be seriously influenced by soil moisture deficits[5,19], dry soil conditions in humid tropical areas or dry climatic conditions of monsoon tropical areas might bring about different results. At least as far as our research site and similar sites are concerned, bare-root seedlings may be suitable for large-scale reforestation programs using *A. mangium* for the production of biomass and timber as well as for use as nurse trees to shelter native trees, including Dipterocarpaceae, for large-scale rehabilitation of degraded land.

Acknowledgments

This study was conducted under an international collaborative project entitled "Development of Agroforestry Technology for the Rehabilitation of Tropical Forests" funded by Japan International Research Center for Agricultural Science (JIRCAS). We thank Dr. Y. Lee and Mr. J. Lapongan of FRC and Dr. K. Nakashima of JIRCAS for their kind support in conducting this work. We are grateful to Mr. T. Kanazashi (Tohoku Research Centre, Forestry and Forest Products Research Institute), who provided valuable comments on the statistical treatment of our data.

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