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EFFECT OF PHOTON IRRADIANCE AND FERTILISER LEVELS ON THE GROWTH OF *SHOREA LEPROSULA* STOCK PLANTS AND THE ROOTING ABILITY OF THEIR SUBSEQUENT STEM CUTTINGS

H. Aminah,

Forest Research Institute Malaysia (FRIM), Kepong, 52109 Kuala Lumpur, Malaysia

J. McP Dick

Institute of Terrestrial Ecology, Bush Estate, Penicuik, Midlothian EH26 0QB, Scotland, United Kingdom

&

J. Grace

Institute of Ecology and Resource Management, University of Edinburgh, Darwin Building, Mayfield Road, Edinburgh EH9 3JU, Scotland, United Kingdom

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AMINAH, H., DICK, J. McP. & GRACE, J. 1999. Effect of photon irradiance and fertiliser levels on the growth of *Shorea leprosula* stock plants and the rooting ability of their subsequent stem cuttings. Potted stock plants of *Shorea leprosula* raised under a high irradiance range of 0 to 722 µmol photons m^{-2} s^{-1} (nominally 30% full sunlight) produced better height and diameter growth than those grown under a low irradiance range of 0 to 325 µmol photons m^{-2} s^{-1} (nominally 10% full sunlight). An enhanced net photosynthesis (P_n) may be the cause of better growth rate in plants raised under high irradiance range. However, cuttings obtained from stock plants grown under low irradiance range were more inclined to root (78%) and produced more roots per rooted cutting (4.8) than those from the high irradiance range (54% and 3.8 respectively). There was a negative correlation between rooting ability and stem volume of cuttings. Cuttings with high stem volume (2 to 3 cm^3) tended to remain unrooted. In another experiment, height and diameter growth of *S. leprosula* potted stock plants were enhanced by the application of 1.5 g compared to 0.5 g per plant per two weeks of NPK fertiliser (12%N : 12%P_2O_5 : 17%K_2O : 2%MgO + trace elements). However, rooting of subsequent cuttings was not affected by these fertiliser rates (73% and 70% for low and high fertiliser treatments respectively).

Key words: Irradiance - fertiliser - stock plants - rooting ability - *Shorea leprosula* - photosynthesis - leaf to air vapour pressure deficit

AMINAH, H., DICK, J. McP. & GRACE, J. 1999. Kesan paras cahaya dan baja terhadap pertumbuhan pokok stok *Shorea leprosula* dan keupayaan pengakaran keratan batang. Pokok stok tabung yang tumbuh pada paras cahaya yang tinggi antara 0–722

µmol fotons m^{-2} s^{-1} (30% cahaya penuh matahari) mempunyai pertumbuhan ketinggian dan diameter yang lebih baik berbanding dengan pokok yang ditanam di bawah paras cahaya rendah antara 0 hingga 325 µmol fotons m^{-2} s^{-1} (10% cahaya penuh matahari). Pertumbuhan yang lebih baik pada pokok yang dibesarkan di paras cahaya tinggi kemungkinan disebabkan oleh penambahan fotosintesis (P_n). Walau bagaimanapun, keratan yang diambil daripada pokok stok yang tumbuh pada paras cahaya rendah didapati mempunyai peratus pengakaran (78%) dan jumlah akar (4.8) yang lebih berbanding dengan keratan daripada pokok stok yang tumbuh pada paras cahaya yang tinggi (54% dan 3.8 masing-masing). Terdapat korelasi negatif di antara keupayaan pengakaran dengan isipadu keratan. Keratan yang mempunyai isipadu batang (2–3 cm^3) didapati tidak berakar. Pada percubaan yang lain, pertumbuhan ketinggian dan diameter pokok stok *S. leprosula* didapati bertambah dengan menggunakan baja NPK (12%N:12%P_2O_5:17%K_2O:2% MgO + unsur surih) pada paras 1.5 g berbanding dengan 0.5 g sepokok setiap dua minggu. Walau bagaimanapun pengakaran keratan didapati tidak menunjukkan perbezaan yang bererti di antara dua paras baja tersebut (73% dan 70% untuk rawatan baja paras rendah dan tinggi masing-masing).

Introduction

Many workers have demonstrated that the morphology and physiology of stock plants and the subsequent rooting of collected cuttings can be influenced by variation in irradiance given to the stock plants (Hansen & Eriksen 1974, Hansen *et al.* 1978, Leakey 1983, Moe & Andersen 1988, Leakey & Storeton-West 1992, Mesen 1993). The effects of increased irradiance during stock plant growth on the subsequent rooting of cuttings have been variable; irradiance may inhibit, delay, promote or have no effect on rooting (Moe & Andersen 1988). Experimental evidence has indicated that stock plants require a certain level of irradiance to produce cuttings that root well, but the optimum level varies between species (Moe & Andersen 1988). For example, at an irradiance of 60 to 100 µmol photons m^{-2} s^{-1}, no stock plant growth of *Prosopis alba* occurred and at 190 µmol photons m^{-2} s^{-1} growth was marginal (Klass *et al.* 1985). An irradiance of 520–560 µmol photons m^{-2} s^{-1} was needed for growth of *Prosopis alba* stock plants to provide sufficient cutting materials for a rooting experiment (Klass *et al.* 1985). Mesen (1993) showed that irradiance ranging from 0 to 2274 µmol photons m^{-2} s^{-1} promoted the growth of *Cordia alliodora,* but did not influence the subsequent rooting compared to the lower irradiance (0 to 825 µmol photons m^{-2} s^{-1}). Similarly, growth of dipterocarp seedlings was affected by level of irradiance. Sasaki and Mori (1981) showed that under low irradiance of 10 to 15% full sunlight, the height of *Vatica odorata, Hopea helferi* and *Shorea talura* was 20, 18 and 10 cm respectively. Maximum recorded height increment of *V. odorata* and *H. helferi* was obtained at 32% full sunlight and in the range of 32 to 52% full sunlight respectively (Sasaki & Mori 1981). However, no experimental data have been presented on how dipterocarp cuttings respond to stock plant irradiance treatments.

Besides irradiance, several workers have reported a species-dependent response of tropical forest tree seedlings to fertiliser application (Anthony 1971, Mendoza & Glori 1976, Sundralingam 1977, 1982, 1983, Mel Zwierink 1983, Sundralingam

et al. 1985). Observations in the Forest Research Institute Malaysia (FRIM) nursery in Peninsular Malaysia also indicated that the newly potted seedlings or rooted cuttings of several dipterocarp species required a supplement of fertiliser (Aminah, unpublished). Similarly, the need for nutrient supplement in raising stock plants for production of the regular cutting material has been widely recognised in a number of plant species (Leakey 1983, Lo 1985, De Souza & Felker 1986, Blazich 1988, Moe & Andersen 1988, Yasman & Smits 1988, Tchoundjeu 1989, Leakey & Storeton-West 1992, Mesen 1993). At the same time, unrestricted application of fertiliser is, however, not recommended: for example, high rates of nitrogen fertiliser application to *Khaya ivorensis* yielded cuttings which suffered high mortalities (Tchoundjeu 1989). The effects of fertiliser to stock plants and the subsequent rooting ability of cuttings were reported to be inconsistent between species (Moe & Andersen 1988). In the present study, two separate experiments were set up to examine whether levels of 1) irradiance, and 2) fertiliser may affect the morphological and physiological characteristics of *Shorea leprosula* stock plants and rooting ability of subsequent collected cuttings. *Shorea leprosula* (Dipterocarpaceae) was chosen for this study because it is one of the most important timber species in Southeast Asia.

Materials and methods

Both experiments were carried out in the FRIM nursery, Peninsular Malaysia in 1992.

Stock plants

Experiment 1: Effect of irradiance levels on the growth of stock plants

The stock plants were raised from stem cuttings taken from 10-month-old seedlings. One-month-old rooted cuttings were potted in black perforated polythene bags (9 cm diameter × 17 cm height). Potting mixture consisted of forest top soil and sand in the ratio of 3:1 with no added fertiliser. A total of 80 plants were used consisting of 2 replicates of 30 clones and 4 replicates of 5 clones. These plants were randomly allocated to treatments such that each of the two irradiance treatments had equal clonal composition. Each treatment consisted of 40 plants and they were randomly assigned in two blocks. The two irradiance conditions were created by covering a wooden frame box (1.5 × 1 × 1 m) with one and two layers of black plastic netting. These boxes were placed in open areas avoiding effects of shade from other objects. Mean red/far red ratio measured with a light sensor (SKR 110 660/730, Skye Instruments, UK) was 1.1, close to that of full sunlight (1.2). Granular compound fertiliser (NPK Blue, 12%N: 12%P_2O_5 :17%K_2O :2%MgO + trace elements, manufactured by ICI Fertilisers, Malaysia) was applied at the rate of 0.5 g per plant per two weeks to maintain healthy growth of the plants.

Experiment 2: Effect of fertiliser levels on growth of stock plants

The planting materials were raised from stem cuttings taken from coppice shoots of 5-y-old seedlings. Seven clones were used : 525, 549, 550, 559, 581, 587 and 590. The 1-month-old rooted cuttings were potted as in experiment 1. These plants were treated every two weeks with 0.5 g or 1.5 g per plant granular compound fertiliser (NPK Blue). Each treatment consisted of 42 plants and they were randomly assigned in six blocks on transplanting beds. One clone per treatment per block was used. Transplanting beds were shaded with black plastic netting and the red/far red ratio measured was 1.16.

Maintenance of stock plants

Plants were watered to field capacity twice daily in the morning and late afternoon except on rainy days. Weeding, insecticide and fungicide applications were made whenever necessary. The insecticide used was Tamaron special (50% methamidopos active ingredient, Bayer Company, Leverkusen, Germany). The fungicide was Benlate (50% benomyl active ingredient, E.I. Dupont, Denemours and Co. Inc., U.S.A.). Both biocides are systemic in nature.

Stock plant environment

Air and leaf temperatures were measured using thermocouples (Type K chromel-alumel, T.C., Ltd., Uxbridge, U.K.), relative humidity using commercial humidity sensors (MP 100 Rotronic probes, Campbell Scientific Ltd., Loughborough, U.K.) and irradiance using quantum sensors (Skye Instruments Ltd., Llandrindod Wells, U.K., supplied by Campbell Scientific Ltd., Loughborough, U.K.). A solid state data logger (21X micrologger, Campbell Scientific, U.K.) was used to record the data from the appropriate sensors. The data logger was programmed to scan each sensor every 60 s, to calculate and store mean readings every 5 min. For experiment 1, sensors were placed in the centre of each block. Data collection extended from day 1 to day 3 of the experiment. Another set of data collection was made for a period of 10 days towards the end of experiment starting on day 180 until day 189. For experiment 2, the sensors were placed in the centre of three blocks which were randomly chosen from the total of six blocks. Data collection extended from day 1 to day 6 of the experiment. As the lengths of night and day time in Malaysia are almost equal, day time was defined as from 0705 to 1855 h while night time was from 1900 to 0700 h. Leaf to air vapour pressure deficit (VPD) was calculated using the formula as provided in Aminah (1995).

Assessments of stock plants

Initial height (from base of the new shoot to the apex) and basal diameter of the new shoot on each plant were measured. Successive measurements of height

and diameter were made every two weeks until the experiment was terminated (30 and 22 weeks after planting for experiments 1 and 2 respectively). The number of nodes, leaf area and photosynthesis (P_n) were also measured.

For determination of leaf area, the length and width of leaves along the stem were measured on 20 plants for experiment 1 (5 plants randomly selected per treatment per block) and 12 plants for experiment 2 (2 plants randomly selected per treatment per block). Leaf area was then calculated using the equation developed for *Shorea leprosula* plants grown in the FRIM nursery, i.e. $y = 0.33 + 0.60\,x$, where y = leaf area (cm^2); x = product of length and width (cm^2). The results indicated that x and y were strongly correlated ($r^2 = 0.98$).

P_n was measured using a portable gas analyser (LCA-3, ADC, Hoddesdon, U.K.) on five most fully developed top leaves which were randomly chosen from each block. One leaf per treatment per block was measured at a time. Measurements were made from 0800 to 1500 h after which the boxes were covered with black cloth to acclimatise the plants to a dark environment. Dark respiration (R_d) was then measured starting at 1800 h onwards for experiment 1 only.

Rooting of stem cuttings

Cuttings from all the node positions with a leaf area of at least 30 cm^2 were harvested at week 30 for experiment 1 and at week 22 for experiment 2. The bases of cuttings were treated with 20 µg indole butyric acid (IBA) using micropipette (F10, Gilson medical Electronic, France). IBA was prepared using 100% ethyl alcohol. Initial diameter, length and node position of each cutting were recorded. Volume of cuttings was calculated assuming a simple cylindrical shape ($\pi r^2 h$, r,h = radius and length of cuttings respectively). The prepared cuttings were planted in a medium consisting of cleaned river sand. The treatments were arranged on the rooting bed by randomly picking the stock plant. Node positions were held in sequential order on the rooting beds as they were on stock plants. Clones were not uniformly replicated in each block due to stock plant mortality. For experiment 1, from each stock plant treatment, 155 cuttings were harvested (125 cuttings for rooting and 30 for dry weight assessments). These cuttings were randomly split into five blocks. For experiment 2, from each stock plant treatment, 162 cuttings were harvested (126 for rooting and 36 cuttings for dry weight assessments) and they were randomly split into six blocks. Each block was a closed polythene propagation chamber ($1 \times 1 \times 0.8$ m) with a misting unit in the centre. Details of the methods are described in Aminah (1995) and Aminah *et al.* (1995).

Propagation environment

Environmental data were measured using sensors as described for stock plants. The sensors were placed in the centre of two blocks which were randomly chosen Data collection extended from day 16 to day 32 and from day 1 to day 23 of the experiment for experiments 1 and 2 respectively.

Photosynthetic rate (P_n) and stomatal conductance (g_s)

P_n and g_s of cuttings prior to rooting were measured using a portable infrared gas analyser (LCA-3, ADC, Hoddesdon, UK). Four cuttings were randomly chosen per treatment per block and they were measured weekly for five weeks after planting in the rooting medium. Measurements of P_n and g_s were made between 0900 and 1200 h.

Dry weight of leaves and stems

In both experiments, six cuttings per treatment per block were harvested on day 0 at 1700 h after the experiment was laid out on the rooting beds. Dry weight of leaf and stem of each cutting was determined after drying in an oven (ULM 500 Memmert, Germany) at 40 °C for 48 h when constant weight was obtained. These samples were then used for the respective chemical analyses.

Starch, sugar, nitrogen, phosphorus and potassium (NPK) determinations

Since the amounts of leaves and stems were small, the samples of every two blocks were combined for starch and sugar analysis. Starch from the leaf and stem was extracted using perchloric acid (Humphreys & Kelly 1961). The filtrate obtained was treated with the respective reagents and the absorbance was measured at 650 nm against a blank of the reagent on Ultra Violet Visible Spectrophotometer (UV-160A, Shimadzu Corporation, Japan). Sugar of the leaf and stem was extracted with deionised water and was then analysed by High Performance Liquid Chromatography (HPLC, Dionex Ltd., U.K.).

NPK of leaves and stem were extracted by a wet digestion method. N was determined by a gas diffusion method using a flow injection analyser (Tecator 5020, Sweden), P by a colorometric method (ammonium molybdate, stannous chloride method) using flow injection analyser, and K by atomic absorption spectroscopy using a Unicam 919AA Spectrophotometer, U.K. Details of the methods used are described by Aminah (1995).

Assessment of cuttings

The numbers of rooted, unrooted and dead cuttings as well as the number of roots on each cutting were recorded weekly for 16 weeks. A cutting was scored as rooted when it produced a root 1 cm long or more and a cutting was considered dead when the whole stem turned brown.

Statistical analyses for data of stock plants and cuttings

Analysis of variance followed by Least Significant Difference comparison test (LSD) was carried out on height, diameter, leaf area, number of nodes, P_n, g_s, R_d and

PAR (photosynthetic active radiation) of experimental plants and mean accumulated number of roots per rooted cutting, leaf and stem dry weight. Significant difference in R_d between treatments was determined by *t*-test.

Analysis of deviance for stepwise regression in Genstat 5 (Payne *et al.* 1987) was used to determine whether node position, length, diameter and volume of cutting were significantly associated with rooting percentage. Results in all the tests were considered significant when the probability level was less or equal to 5% ($p \leq 0.05$). The association between rooting and the variables was indicated by the regression coefficients and this association was presented graphically.

Results

Stock plants

Experiment 1

The environmental data of the stock plants are as shown in Table 1. Irradiance levels were 10 and 30% of the full sunlight for low and high irradiance treatments respectively.

Initial height of shoot did not differ significantly between treatments. Mean heights were 1.0 and 0.9 cm for low and high irradiance treatments respectively. Measurements made at week 30 showed that plants grown under high irradiance were significantly taller, had larger stem diameter (Figures 1a,b) and more nodes than those under low irradiance. Mean numbers of nodes were 9.8 and 8.6 for high and low irradiance treatments respectively. Similar results were obtained with P_n, g_s, PAR as well as R_d measured at week 30 (Figures 2a,b,c d). The P_n /PAR curves of stock plants grown under low and high irradiance are shown in Figures 3a,b.

There was no significant difference in leaf areas between treatments. Mean leaf area were 68.7 and 79.6 cm^2 for stock plants under low and high irradiance respectively. Mortality was not significant by different treatments (percentages of dead plants were 10 and 17.5% for low and high irradiance treatments respectively).

Experiment 2

The environmental data of the stock plants are shown in Table 2. The mean irradiance in the stock plants growing environment was approximately twice that in the propagation chambers. The VPD was, however, considerably more in the stock plant environment with a range of 0–2.6 kPa compared to that in the propagation chambers (0–0.9 kPa).

The initial height and diameter of shoots did not differ significantly between treatments. The mean heights were 4.0 and 4.2 cm for 0.5 and 1.5 g fertiliser treatments respectively , while mean diameter was 0.1 cm for both treatments. There were significant differences, however, between clones in height and diameter of the shoot at the beginning of the experiments. The final height and

diameter (at week 22) were significantly different both between treatments and clones. Clone 549 was the tallest and had the largest diameter at the initial and final weeks of experiment. At the start of the experiment, clone 549 was 92% taller than clone 587, but after 22 weeks growth the difference between the tallest clone 549 and the smallest clone 525 was only 36%. Plants treated with 1.5 g fertiliser were taller and had larger diameter than those treated with 0.5 g (Figures 4a,b). No significant difference was obtained between treatments in the number of nodes, leaf area and P_n of stock plants measured at week 22. The means of these variables for low and high fertiliser treatments were 7.6 and 7.9 for the number of nodes, 74 and 65 cm^2 for the leaf area respectively, and 5.2 µmol CO_2 m^{-2} s^{-1} for P_n in both treatments. The mortality of plants showed no significant difference by different treatments and the percentages of dead plants were 7.1 and 16.7% for 0.5 and 1.5 g fertiliser treatments respectively.

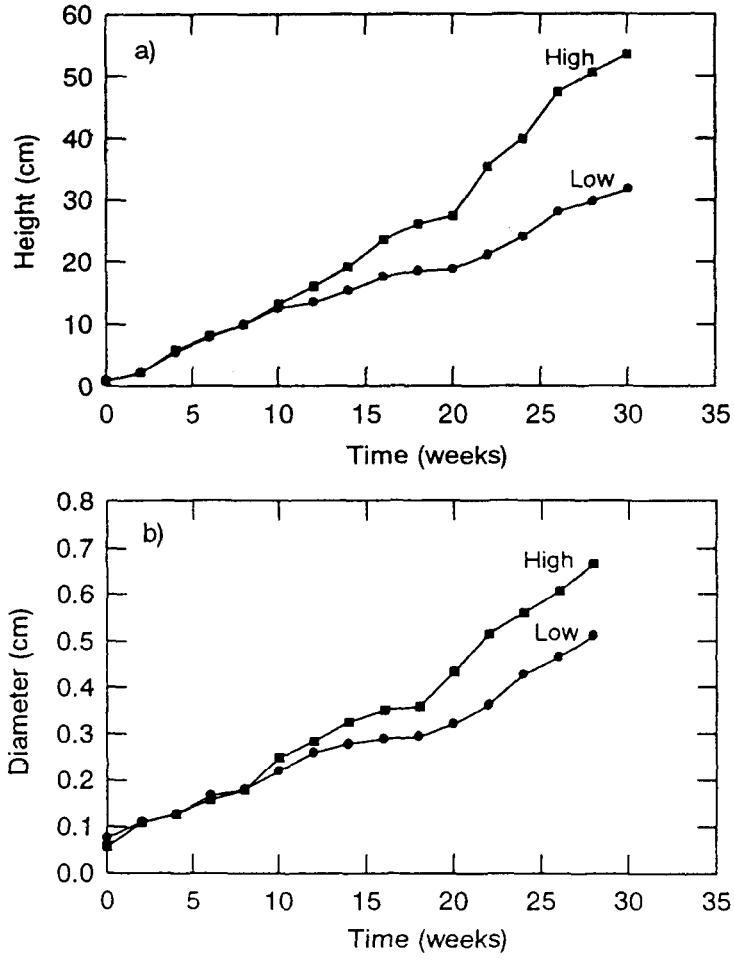

Figure 1. Effect of two irradiance levels on mean a) height, and b) basal diameter growth rate of *Shorea leprosula* potted stock plants raised from rooted cuttings (n = 40 per treatment)

Table 1. a) Environmental data of *Shorea leprosula* potted stock plants grown under two irradiance levels measured on days 1 to 3 and 180 to 190 after commencement of the experiment; b) environmental data in the enclosed mist propagation chambers where subsequent cuttings were rooted, measured from day 16 to day 32 of the experiment. Each variable is a mean value of two blocks per treatment calculated as a 5 min. average. Mean values were calculated on a 12-h period for each session of measurement.

	a) Stock plant environment								b) Propagation environment			
	0 - 722 µmol photons $m^{-2} s^{-1}$				0 - 325 µmol photons $m^{-2} s^{-1}$							
	0705 - 1855 h		1900 - 0700 h		0705 - 1855 h		1900 - 0700 h		0705 - 1855 h		1900 - 0700 h	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Irradiance (µmol photons $m^{-2} s^{-1}$)	0 - 721.5	140.6	0 - 11.4	0.1	0 - 324.5	44.1	0 - 3.3	0.1	0 - 310.1	48.7	0 - 12.2	0.2
Relative humidity (%)	42.8 - 100	80.7	81.7 - 99.9	95.3	43.4 - 100	82.2	77.2 - 99.9	96.5	81.5 - 99.4	97.4	95.7- 99.2	98.1
Air temperature (C)	21.2 - 36.5	27.5	21.0 - 28.2	23.9	21.2 - 36.1	27.4	21.2 - 28.3	24.2	23.0 - 35.4	28.2	23.1 - 30.8	25.6
Leaf temperature (C)	21.3 - 36.9	27.6	21.1- 28.2	23.9	21.3 - 35.9	27.3	21.2 - 28.3	24.2	22.7 - 37.4	28.6	22.9 - 31.2	25.5
VPD (kPa)	0 - 3.4	0.8	0 - 0.7	0.2	0 - 2.9	0.7	0 - 0.7	0.1	0 - 1.1	0.2	0 - 0.3	0.0

Table 2. a) Environmental data of *Shorea leprosula* potted stock plants subjected to two fertiliser levels measured from day 1 to day 6 of the experiment; b) environmental data in the enclosed mist propagation chambers measured from day 1 to day 23 of the experiment. Data of each variable is a mean value of two blocks calculated as a 5 min. average. Each variable is a mean value of 3 blocks calculated as a 5 min. average. Mean values were calculated on a 12-h period for each session of measurement.

	a) Stock plant environment				b) Propagation environment			
	0705 - 1855 h		1900 - 0700 h		0705 - 1855 h		1900 - 0700 h	
Irradiance (µmol photons $m^{-2} s^{-1}$)	0 - 834.0	186.3	0 - 23.2	0.4	0 - 281.2	72.2	0 -15.5	0.1
Relative humidity (%)	49.9 - 100	83.7	80.5 - 100	96.2	85.8 - 100	97.3	94.2 - 100	98.0
Air temperature (°C)	22.2 - 37.7	28.3	21.0 - 28.8	24.0	23.0 - 39.3	29.4	23.3 - 32.3	26.3
Leaf temperature (°C)	22.3 - 35.8	27.5	20.9 - 28.8	23.9	22.8 - 40.4	29.7	23.1 - 32.0	25.8
VPD (kPa)	0 - 2.6	0.7	0 - 0.8	0.1	0 - 0.9	0.2	0 - 0.3	0.0

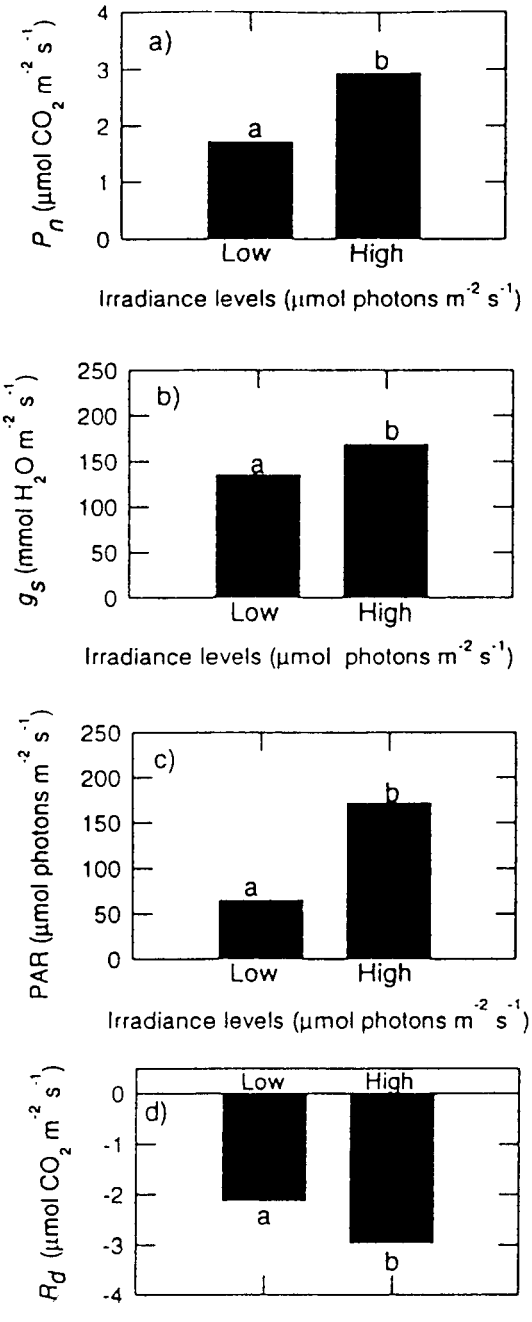

Figure 2. Effect of two irradiance levels on mean a) P_n, b) g_s, c) PAR, and d) R_d of *Shorea leprosula* potted stock plants measured on the top-most expanded leaf at week 30 (n=76 per treatment for P_n, g_s and PAR, n = 12 per treatment for R_d). Means of each variable with the same letters are not significantly different at $t \leq 0.05$.

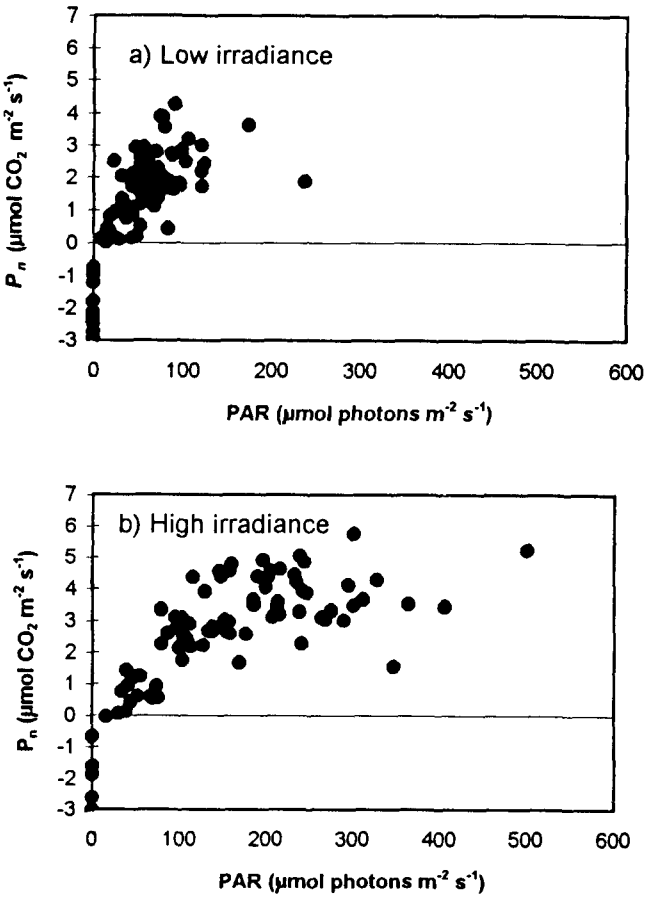

Figure 3. P_n versus PAR curves of *Shorea leprosula* potted stock plants. P_n was measured on the top-most expanded leaf at week 30; a) plants grown under low irradiance; b) plants grown under high irradiance (n=88 per treatment)

Stem cuttings

Experiment 1

The environmental data on the propagation beds are shown in Table 1. The range of irradiance in propagation systems was almost similar to that of low irradiance stock plants and about half that of high irradiance plants.

Cuttings harvested from stock plants grown under high irradiance had significantly greater volume and length compared with those grown under low irradiance. The initial dry weights of leaves and stem were also significantly affected by treatments. The initial leaf and stem starch and sugar contents followed a similar trend, but no statistical analysis could be carried out. Mean values of the above variables are given in Table 3.

Table 3. Mean values of initial length, diameter, volume, initial dry weight, percentages of starch and total sugar and NPK contents of *Shorea leprosula* stem cuttings taken from potted stock plants grown under the respective treatments as indicated in the table below. Each cutting had a 30 cm^2 leaf area. Cuttings were harvested on day 0 at 1700 h after the experiment was laid out. Low irradiance range = 0–325 µmol photons $m^{-2}s^{-1}$; High irradiance range = 0–722 µmol photons $m^{-2}s^{-1}$; ± standard error of mean.

Variable	Experiment 1			Experiment 2		
	Low irradiance	High irradiance	Number of samples per treatment (m)	0.5 g NPK Blue per plant	1.5 g NPK Blue per plant	(n)
Length (cm)	4.06a	6.08b	125	0.61a	0.68b	126
Diameter (cm)	0.32a	0.49b	125	6.21a	7.33b	126
Volume (cm^3)	0.38a	1.19b	125	1.72a	2.47b	126
Leaf weight (g)	0.16a	0.21b	30	0.24a	0.25a	36
Stem weight (g)	0.10a	0.35b	30	0.63a	0.66a	36
Leaf starch (%)	8.65 ± 0.94	10.30 ± 1.32	3	-	-	-
Stem starch (%)	2.05 ± 0.47	4.75 ± 0.60	3	-	-	-
Leaf sugar (%)	2.93 ± 0.90	2.79 ± 0.36	#	-	-	-
Stem sugar (%)	1.58 ± 0.24	2.11 ± 0.34	#	-	-	-
Leaf nitrogen (%)	-	-	-	1.42 ± 0.05	1.66 ± 0.08	6
Stem nitrogen (%)	-	-	-	0.41 ± 0.05	0.58 ± 0.04	6
Leaf phosphorus (%)	-	-	-	0.16 ± 0.01	0.30 ± 0.02	6
Stem phosphorus (%)	-	-	-	0.18 ± 0.02	0.28 ± 0.01	6
Leaf potassium (%)	-	-	-	0.40 ± 0.04	0.71 ± 0.04	6
Stem potassium (%)	-	-	-	0.36 ± 0.04	0.65 ± 0.06	6

Means of length, diameter, volume of cuttings, leaf and stem weights followed by the same letter are not significantly different at $p \leq 0.05$.

: n=2 and 3 for low and high irradiance treatments respectively.

- : Analysis was not carried out.

No statistical analysis was carried out on the percentages of starch, sugar and NPK values since inadequate samples were available.

Significantly higher rooting was obtained in cuttings from low than from high irradiance (Figure 5a). Regression analysis shows that rooting was negatively correlated to the volume of cuttings (Figure 5b). The cuttings that remained unrooted were not affected by treatments, but was positively influenced significantly by cutting volume. The mean percentages of unrooted cuttings were 38 and 18% for high and low irradiance treatments respectively. The mortality of cuttings did not differ significantly by different treatments (percentages of death were 4 and 10% from low and high irradiance treatments respectively). Similar to rooting, the number of roots was significantly more in low than high irradiance treatments (Figure 6). However, the number of roots produced was not significantly influenced by the morphological characteristics of cuttings.

There was no significant difference between treatments in P_n and g_s of cuttings prior to rooting. Mean P_n values were 1.9 and 2.0 µmol CO_2 $m^{-2}s^{-1}$ and mean g_s values were 344 and 329 mmol H_2O m^{-2} s^{-1} for cuttings from low and high irradiance treatments respectively. No significant difference in PAR occurred between treatments when the measurements were made. Mean PAR values were 145 and 143 µmol photons m^{-2} s^{-1} for cuttings from low and high irradiance respectively.

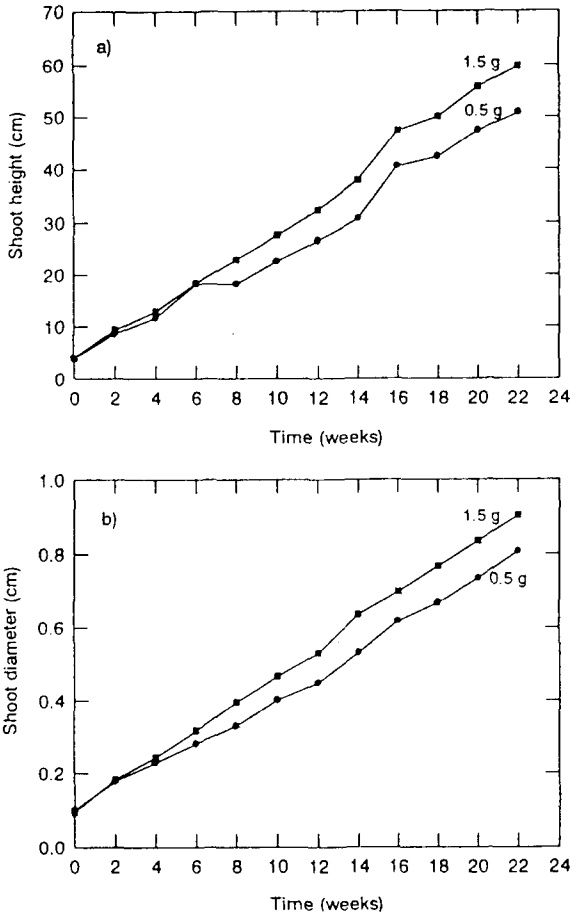

Figure 4. Effect of two fertiliser levels on the a) mean height growth, and b) mean basal diameter growth of *Shorea leprosula* potted stock plants raised from rooted cuttings (n = 42 per treatment)

Experiment 2

The environmental data collected in propagation chambers over a period of 23 days are shown in Table 2. The mean irradiance in the propagation chambers was approximately half that of stock plant environment. The VPD was, however, considerably less in the propagation chambers with a range of 0–0.9 kPa compared to 0–2.6 kPa in the stock plant environment.

The initial length, diameter and volume of cuttings from the 1.5 g fertiliser treatment were significantly greater than those of the 0.5 g fertiliser treatment. The initial dry weights of leaf and stem were not significantly affected by treatments. The initial leaf and stem NPK contents were higher in cuttings from plants treated with 1.5 g than 0.5 g fertiliser. Statistical analysis was not carried out on the NPK values since inadequate samples were available. The mean values of all the above mentioned variables are given in Table 3.

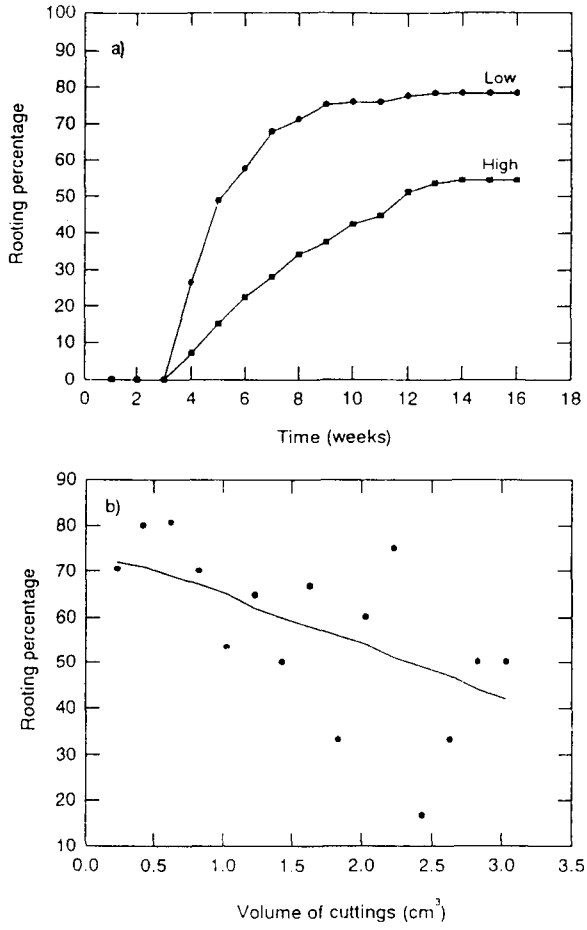

Figure 5. Influence of irradiance levels to *Shorea leprosula* stock plants on a) subsequent rooting rate of stem cuttings (n = 125 per treatment), and b) relationship of rooting and cutting volume. Scattered points are groups of observed data and line was drawn by connecting the predicted values computed from the multiple regression model.

The final rooting percentage and mortality of cuttings were not significantly affected by either fertiliser levels or morphological characteristics of cuttings. Figure 7 shows the rooting rates of *S. leprosula* stem cuttings as affected by the treatments. Percentages of mortality were 15.9% and 9.5% for the 0.5 g and 1.5 g fertiliser treatments respectively. The cuttings which remained unrooted were significantly more in cuttings from the1.5 g (20.6%) than the 0.5 g (9.5%) fertiliser treatments. The number of roots per rooted cutting was not significantly affected by treatments (Figure 8a), but it was significantly affected by diameter and the relationship was negative (Figure 8b).

There was no significant difference between the treatments in P_n and g_s of cuttings prior to rooting. There was also no significant difference in PAR values

when the measurements were taken. The mean P_n values were 2.3 and 2.2 µmol CO_2 m^{-2} s^{-1}, and the mean g_s values were 246 and 314 mmol H_2O m^{-2} s^{-1} (with a range of PAR values from 14 to 415 µmol photons m^{-2} s^{-1}) for cuttings from the 0.5 g and 1.5 g fertiliser treatments respectively.

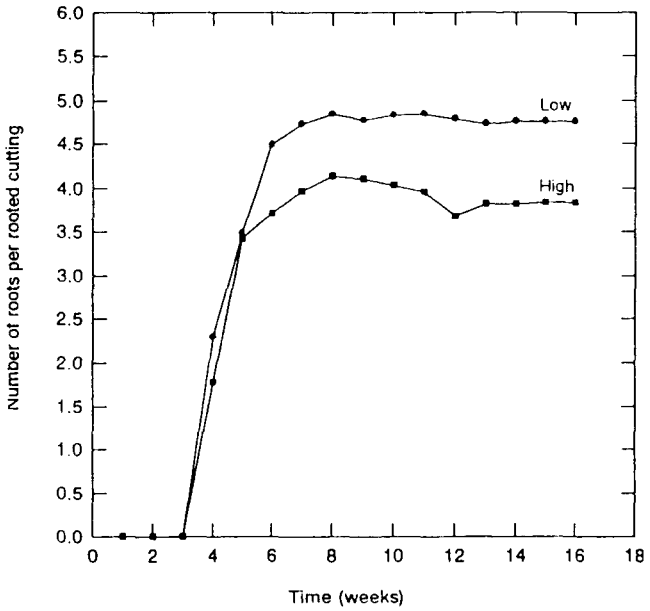

Figure 6. Influence of irradiance levels to *Shorea leprosula* stock plants on rate of mean accumulated number of roots per rooted stem cutting (n = 125 per treatment)

Discussion and conclusion

Growth of *S. leprosula* stock plants was enhanced by high irradiance, probably influenced by the overall P_n, which was higher under high irradiance. Enhanced growth could also be linked with high R_d as fast growth requires rapid rates of energy metabolism associated with cell division (Riddoch *et al.* 1991). Compared to high irradiance of 0 to 722 µmol photons m^{-2} s^{-1}, low irradiance of 0 to 325 µmol photons m^{-2} s^{-1} was more suitable for production of cutting materials.

An increase in both rooting percentage and number of roots was obtained in cuttings taken from stock plants grown under low irradiance. Besides that, the rate of rooting of cuttings from the low irradiance treatment was almost twice as fast as those from high irradiance level. This is of advantage as the earlier cuttings manage to form roots the greater is the chance for them to survive. These results are consistent with those from previous studies in a range of species (Hansen & Ericksen 1974, Hansen *et al.* 1978, Eliasson & Brunes 1980, Poulsen & Andersen

1980, Moe & Andersen 1988, Leakey & Storeton-West 1992). This effect has been associated with several conditions such as an increased leaf auxin content, possible changes in rooting inhibitors and/or promoters, a beneficial change in internal structure of the stem where roots would form and an increase in sensitivity of tissues to auxin (Blazich 1988, Maynard & Bassuk 1988, Moe & Andersen 1988, Hartmann *et al.* 1990). However, the actual mechanisms involved are poorly understood (Moe & Andersen 1988). The low rooting of *S. leprosula* stem cuttings from high irradiance was perhaps due to the high concentration of carbohydrates as reflected in the higher dry mass of initial stem and leaf. There was an indication that the initial leaf and stem starch contents as well as the total stem sugar contents of cuttings were higher in the high than in the low irradiance. The unfavourability of high initial carbohydrate content to rooting has been postulated by Hansen and Eriksen (1974) with cuttings of *Pisum sativum.* Although it has not been shown in this experiment, a high carbohydrate content could also result in the suppression of post-severance photosynthesis accompanied by low rooting of cuttings as demonstrated by Leakey and Storeton-West (1992) in *Triplochiton schleroxylon.*

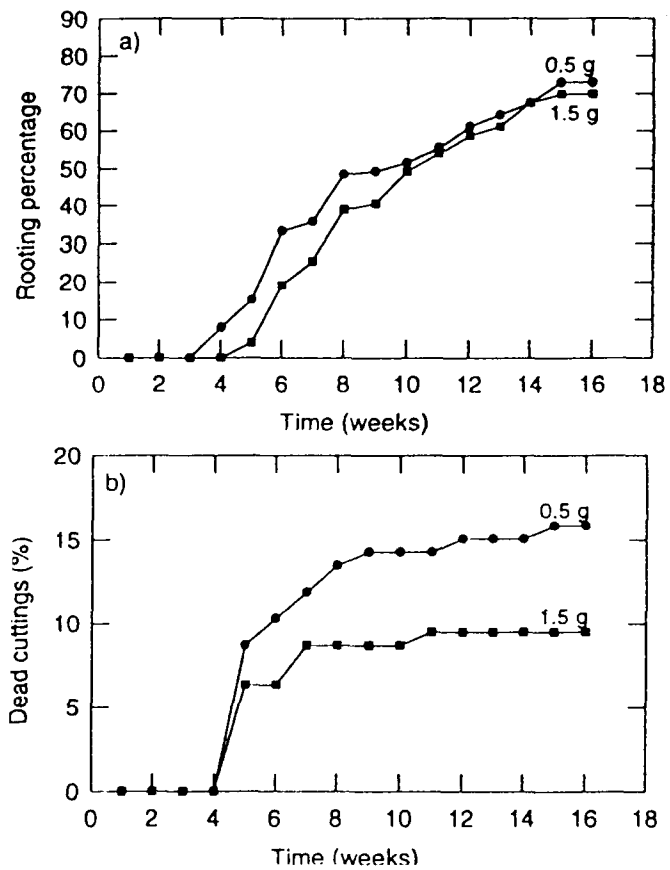

Figure 7. Influence of fertiliser applications to *Shorea leprosula* stock plants on a) subsequent rooting rate, and b) subsequent death rate of stem cuttings (circle = 0.5 g; square = 1.5 g fertiliser) (n = 126 per treatment)

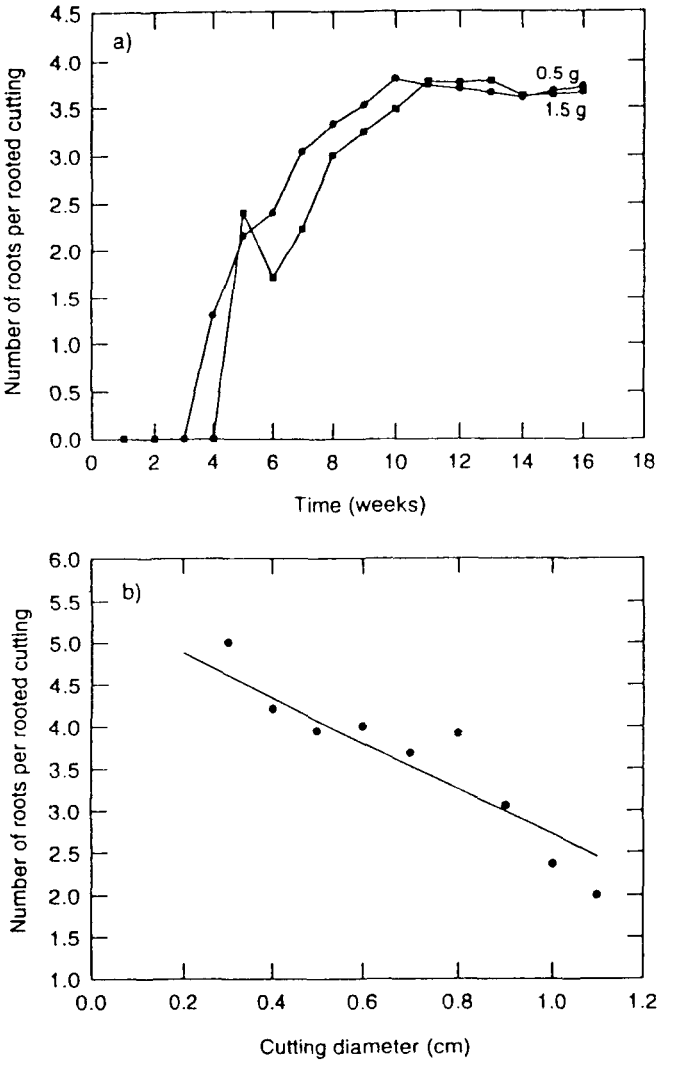

Figure 8. Influence of fertiliser applications to *Shorea leprosula* stock plants on a) rate of mean accumulated number of roots per rooted stem cutting (circle = 0.5 g; square = 1.5 g fertiliser; n = 126 per treatment), and b) relationship of mean accumulated number of roots per rooted cutting with diameter of stem cuttings. Points are groups of observed data whilst the line was drawn by connecting predicted values computed from the multiple regression model.

Shorea leprosula stem cuttings from stock plants grown at high irradiance produced fewer roots compared to cuttings from low irradiance stock plants. Similar results were obtained by Leakey and Storeton-West (1992), an effect which was attributed to the earlier establishment of dominance by the first formed roots.

Very little work on stock plant irradiance and subsequent rooting in dipterocarps has been reported. Leppe and Smits (1988) noted that shading of stock plants is required to achieve good rooting percentages in cuttings of several dipterocarp species. They grew their stock plants under canopies of trees, but the actual amount of light was not quantified (Leppe & Smits 1988). Kantarli (1993) grew stock plants of *Hopea odorata* under 50% black shade nets and obtained 59 to 81% rooting depending on stump height of stock plants from the ground. In many reports of cutting experiments with dipterocarps, no mention has been made on the history of stock plant irradiance (Momose 1978, Muckadell & Malim 1978, Halle & Kamil 1981, Srivastava and Manggil 1981, Smits 1983, Lo 1985, Omon *et al.* 1989, Siagan *et al.* 1989, Noraini & Ling 1993, Moura-Costa & Lundoh 1994).

Height and diameter growth of *S. leprosula* stock plants were enhanced by higher fertiliser rate. However, both rooting percentages and number of roots of cuttings taken from these stock plants were not affected by either of the fertiliser treatments. The importance of nutrients applied to stock plants is widely recognised, but their effects on subsequent rooting of cuttings have often been inconsistent and dependent on plant species (Moe & Andersen 1988). For example, application of NPK fertiliser to pruned stock plants of *Triplochiton scleroxylon* enhanced their growth, improved the rooting of cuttings from lower lateral shoots, but had no affect on cuttings from apical lateral shoots (Leakey 1983). In another experiment, addition of 0.2% solution of 1:1:1 NPK fertiliser improved rooting of *T. scleroxylon* cuttings from stock plants grown at high irradiance (650 µmol photons m^{-2} s^{-1}), but not when the plants were grown at low irradiance (250 µmol photons m^{-2} s^{-1}) (Leakey & Storeton-West 1992). Cuttings of *Albizia guachepele* rooted better when the stock plants were grown under low irradiance (200 µmol photons m^{-2} s^{-1}) and at low dose (0.25% per plant) of fertiliser (20%N: 20% P: 20%K). On the other hand, rooting was reduced when stock plants were treated with high irradiance (500 µmol photons m^{-2} s^{-1}) and high dose (1.25% per plant) of similar fertiliser (Mesen 1993). In another instance, Mesen (1993) found that the effect of fertiliser on rooting was more pronounced than that of irradiance. Application of NPK fertiliser (7.5 g per plant per 2 weeks) to stock plants grown under shade or full sunlight was detrimental to rooting of subsequent cuttings compared to those from non-fertilised plants. It seemed that a high dose of fertiliser application to stock plants was not favourable for rooting of subsequent cuttings. Moe and Andersen (1988) stated that, in general, stock plants which were suboptimally fertilised would yield cuttings that root best; however, levels of fertiliser were not indicated. The results of the present experiment suggest that the high rate used (1.5 g per stock plant per 2 weeks) may not have been at supraoptimal level as no negative effect in rooting of subsequent cuttings of *S. leprosula* was observed.

The work on stock plant fertilisation and subsequent rooting in dipterocarps has not been reported in detail. However, Yasman and Smits (1988) reported that routine fertiliser application is necessary to maintain the production of cutting materials. Lo (1985) applied a slow release fertiliser (12%N:12%P:17%K:2%Mg +

trace elements) to *S. macrophylla* stock plants and 80% rooting of subsequent cuttings was achieved. In other studies, no mention has been made as to how the stock plants were fertilised (Momose 1978, Halle & Kamil 1981, Omon *et al.* 1989, Siagan *et al.* 1989, Kantarli 1993, Noraini & Ling 1993, Moura-Costa & Lundoh 1994).

Although 1.5 g fertiliser applied to stock plants had enhanced their growth, no added advantage in the rooting of subsequent cuttings was obtained. Hence, from an economic point of view, 0.5 g per plant of NPK fertiliser (12%N: 12%P_2O_5 :17%K_2O: 2%MgO + trace elements) applied every two weeks to potted stock plants is recommended for the production of rooted cutting materials of *S. leprosula.*

Irradiance and fertiliser treatments to stock plants could also result in alteration of morphological characteristics of cuttings. Negative correlations between rooting and volume of cuttings in irradiance experiments, and between stem diameter of cuttings and number of roots in fertiliser experiment were obtained. A high percentage of cuttings with larger volume remained unrooted or died. These larger volume cuttings tend to have larger stem diameter. The thicker diameter cuttings had probably undergone secondary growth and thickening of lignin layer which may create a physical barrier to root initiation (Hartmann *et al.* 1990, Liew 1992). These lignified cuttings are generally poor rooters and they either remain unrooted or die when their carbohydrate reserves are depleted.

In terms of microclimates around the cuttings in both experiments, the mean leaf to air VPD in propagation chambers could be kept close to zero, but periods of water deficit did occur in the present study as indicated by the maximum VPD which was more than the threshold level (0.5 kPa) suggested by Grange and Loach (1983) for many temperate broadleaved species. This temporary water deficit could be tolerated by *S. leprosula* stem cuttings and did not appear to greatly affect their rooting ability. The ability of cuttings of other tropical species to tolerate and recover from temporary water deficit has also been observed by Mesen (1993), and Newton and Jones (1993).

From the results of both experiments carried out, there is a possibility that high irradiance may accelerate the formation of lignin layer. Cuttings harvested at week 30 from plants grown at high irradiance produced lower rooting compared to those from low irradiance. However, stock plants may be grown at high irradiance but should be harvested earlier (e.g. at week 22) to get a high rooting percentage as demonstrated in the fertiliser experiments. Further research is needed to determine the effect of stock plant age and irradiance level on the formation of lignin layer which may affect the rooting ability of stem cuttings.

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References

AMINAH, H. 1995. Vegetative propagation of *Shorea leprosula* Miq. by stem cuttings. Ph.D. thesis, University of Edinburgh, Scotland, United Kingdom. 261 pp.

AMINAH, H., DICK, J. McP, LEAKEY, R. R. B., GRACE, J. & SMITH, R. I. 1995. Effect of indole butyric acid (IBA) on stem cuttings of *Shorea leprosula*. *Forest Ecology and Management* 72:199–206.

ANTHONY, J. 1971. Growth and development of potted seedlings of *Pinus caribaea* Mor. *hondurensis* under different combinations and levels of nitrogen, phosphorus and potassium. *Malayan Forester* 34:182–202.

BLAZICH, F.A. 1988. Chemicals and formulations used to promote adventitious rooting. Pp. 132–149 in Davis, T. D., Haissig, B. E. & Sankhla, N. (Eds.) *Adventitious Root Formation in Cuttings*. Dioscorides Press, Portland, Oregon, United States of America.

DE SOUZA, S. M. & FELKER, P. 1986. The influence of stock plant fertilisation on tissue concentrations of N, P and carbohydrates and the rooting of *Prosopis alba* cuttings. *Forest Ecology and Management* 16:181–190.

ELIASSON, L. & BRUNES, L. 1980. Light effect on root formation in aspen and willow cuttings. *Physiologia Plantarum* 43:13–18.

GRANGE, R. I. & LOACH, K. 1983. Environmental factors affecting water loss from leafy cuttings in different propagation systems. *Journal of Horticultural Science* 58:1–7.

HALLE, F. & KAMIL, H. 1981. Vegetative propagation of dipterocarps by stem cuttings and layering. *Malaysian Forester* 44:314–318.

HANSEN, J. & ERIKSEN, E. N. 1974. Root formation of pea cuttings in relation to the irradiance of stock plants. *Physiologia Plantarum* 32:170–173.

HANSEN, J., STRÖMQUIST, L. H. & ERICSSON, A. 1978. Influence of irradiance on carbohydrate content and rooting of cuttings of pine seedlings (*Pinus sylvestris* L.). *Plant Physiology* 61:975–979.

HARTMANN, H. T., KESTER, D. E. & DAVIES JR., F. T. 1990. *Plant Propagation–Principle and Practices*. 5th. edition, Prentice-Hall International Editions. Eaglewood Cliffs, New Jersey, United States of America. 647 pp.

HUMPHREYS, F. R. & KELLY, J. 1961. A method for the determination of starch in wood. *Anaytical Chemical Acta* 24:66–70.

KANTARLI, M. 1993. *Vegetative Propagation of Hopea odorata by Cuttings: A Low-cost Technology*. Technical Publication No. 16. Asian Canada Forest Tree Seed Centre Project, Saraburi. Thailand. 7 pp.

KLASS, S., BINGHAM, R. L., TEMPLEMEN, L. F. & FELKER, P. 1985. Optimising the environment for rooting cutting of highly productive clones of *Prosopis alba* (mesquite/algarrobo). *Journal of Horticultural Science* 60:275–284.

LEAKEY, R. R. B. 1983. Stock plant factors affecting root initiation in cuttings of *Triplochiton scleroxylon* K. Schum., an indigenous hardwood of West Africa. *Journal of Horticultural Science* 58:227–290.

LEAKEY, R. R. B. & STORETON-WEST, R. 1992. The rooting ability of *Triplochiton scleroxylon* cuttings: the interactions between stock plant irradiance, light quality and nutrients. *Forest Ecology and Management* 49:133–150.

LEPPE, D. & SMITS, W. T. M. 1988. *Methoda Pembuatan dan Pemeliharaan Kebun Pangkas Dipterocarpaceae*. Forest Research Institute Samarinda. Special Edition No. 04. 49 pp.

LIEW, T. S. 1992. Effect of IBA, cutting position and rooting media on the rooting ability of *Shorea leprosula* Miq. and *Shorea curtisii* Dyer ex King cuttings. B.Sc. (For.) thesis, Universiti Pertanian, Serdang, Selangor, Malaysia. 64 pp.

LO, Y. N. 1985. Root initiation of *Shorea macrophylla* cuttings: effect of node position, growth regulators and misting regime. *Forest Ecology and Management* 12:42–52.

MAYNARD, B. K. & BASSUK, N. L. 1988. Etiolation and bending on adventitious root formation. Pp. 29–46 in Davis, T. D., Haissig, B. E. & Sankhla, N. (Eds.) *Adventitious Root Formation in Cuttings*. Dioscorides Press, Portland, Oregon, United States of America.

MENDOZA, V. B. & GLORI, A. V. 1976. Fertilisation of yemane (*Gmelina arborea*) in Carrangalan, Nueva Ecija. *Sylvatrop, Philippine Forestry Research Journal* 1:138–141.

MESEN, J. F. 1993. Vegetative propagation of Central American hardwoods. Ph.D. thesis, University of Edinburgh, Scotland, United Kingdom. 294 pp.

MOE, R. & ANDERSEN, A. S. 1988. Stock plant environment and subsequent adventitious rooting. Pp. 214–234 in Davis, T. D., Haissig, B. E. & Sankhla, N. (Eds.) *Adventitious Root Formation in Cuttings.* Dioscorides Press, Portland, Oregon, United States of America.

MOMOSE, Y. 1978. Vegetative propagation of Malaysian trees. *Malaysian Forester* 44:219–223.

MOURA-COSTA, P. H. & LUNDOH, L. 1994. A method for vegetative propagation of *Dryobalanops lanceolata* (Dipterocarpaceae) by cuttings. *Journal of Tropical Forestry Science* 6:533–540.

MUCKADELL, J. S. & MALIM, P. 1978. *Preliminary Results from Rooting Juvenile Cuttings of Some Dipterocarp Species.* Working Paper FAO No. 2. Forest Research Centre Sepilok, Sabah, Malaysia. 43 pp.

NEWTON, A. C. & JONES, A. C. 1993. The water status of leafy cuttings of four tropical tree species in mist and non-mist propagation systems. *Journal of Horticultural Science* 68:653–663.

NORAINI, A. B. S. & LING, T. T. 1993. A note on the rooting of *Shorea acuminata* and *Shorea parvifolia* leafy stem cuttings. *Journal of Tropical Forest Science* 6:206–208.

OMON, R. M., MAS'UD, A. F. & HARBAGUNG. 1989. The effect of solid media and Rootone F to rooted stem cuttings growth of *Shorea* cf. *polyandra. Buletin Penelitian Kehutanan* 5:195–201.

PAYNE, R. W., LANE, P. W., AINSLEY, A. E., BICKNEYI, K. E., DIGBY, P. G. N., HARDING, S. A., LEECH, P. K., SIMPSON, H. R., TODD, A. R., VERRIER, P. J. & WHITE, R. B. 1987. *Genstat 5 : Reference Manual.* Clarendon Press, Oxford. 749 pp.

POULSEN, A. & ANDERSEN, A. S. 1980. Propagation of *Hedera helix* : influence of irradiance to stock plants, length of internode and topophysis of cuttings. *Physiologia Plantarum* 49:359–365.

RIDDOCH, I., GRACE, J., FASEHUN, F. E., RIDDOCH, B. & LIPIDO, D. O. 1991. Photosynthesis and successional status of seedlings in a tropical semi-deciduous rain forest in Nigeria. *Journal of Ecology* 9:491–503.

SASAKI, S. & MORI, T. 1981. Growth response of dipterocarp seedlings to light. *Malaysian Forester* 44: 319–345.

SIAGAN, Y. T., MASANO, D. W., HARAHAP, R. M. S. & ALRASYID, H. 1989. The effect of Rootone F on stem cuttings and stumps of commercial forest trees. *Bulletin Penelitian Hutan* 505:41–52.

SMITS, W. T. M. 1983. Vegetative propagation of *Shorea* cf. *obtusa* and *Agathis dammara* by means of leaf cuttings and stem cuttings. *Malaysian Forester* 46:175–185.

SRIVASTAVA, P. B. L. & MANGGIL, P. 1981. Vegetative propagation of some dipterocarps by cuttings. *Malaysian Forester* 44:301–313.

SUNDRALINGAM, P. 1977. Responses of *Araucaria hunstenii* seedlings to fertiliser application. *Malaysian Forester* 40:167–176.

SUNDRALINGAM, P. 1982. Some preliminary studies on the fertiliser requirement of teak. *Malaysian Forester* 45:361–366.

SUNDRALINGAM, P. 1983. Responses of potted seedlings of *Dryobalanops aromatica* and *Dryobalanops oblongifolia* to commercial fertilisers. *Malaysian Forester* 46:86–92.

SUNDRALINGAM, P., HOTTA, I. & OSUMI, Y. 1985. Assessment of nitrogen and phosphorus requirements of *Shorea ovalis* using sand culture. *Malaysian Forester* 48:313–323.

TCHOUNDJEU, Z. 1989. Vegetative propagation of the tropical hardwood, *Khaya ivorensis* A. Chev. and *Lovoa trichilioides* Harms. Ph.D. thesis, University of Edinburgh, Scotland, United Kingdom. 270 pp.

YASMAN, I. & SMITS, W. T. M. 1988. *Methoda Pembuatan Stek Dipterocarpaceae.* Balai Penelitian Kehutanan Samarinda. Edisi Khusus No.3. 36 pp.

ZWIERINK, M. 1983. *Response of Potted Seedlings of Gmelina arborea Roxb. to Applications of Nitrogen and Phosphorus in Sarawak.* Forest Research Report, Sr. 23. Forest Department Sarawak, Malaysia. 31 pp.