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EFFECT OF QUANTITY AND QUALITY OF LIGHT ON SURVIVAL, GROWTH AND MORPHOLOGY OF MAHOGANY (*SWIETENIA MACROPHYLLA* (KING)) SEEDLINGS

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Abstract: Of the five introduced tree species of the subfamily Swietenoideae grown in Sri Lanka, big leaf mahogany (*Swietenia macrophylla* King) has become the most important timber tree. It has been recommended to establish mahogany plantations under shade to overcome attack by the major pest *Hypsipyla robusta* Moore. However, mahogany being a pioneer and light demanding species, planting it under shade may reduce the survival and growth of seedlings. Therefore it is important to determine shade conditions that provide optimum growth during establishment. A study was carried out to monitor survival, growth and morphology of *S. macrophylla* during the initial growing period in shade houses with different light regimes. Shade houses providing three shade regimes were replicated thrice and planted with 18 seedlings. Photosynthetically active radiation (light quantity) and R:FR ratio (light quality) in each shade regime were measured. Overall seedling mortality was low and not significantly different between shade treatments. No significant differences in height were observed under the three shade regimes. Root collar diameter was 20% higher in the low shade and significantly (P=0.02) longer internodes were observed under low shade. Results indicate that with the increase in the quantity of light reaching the seedlings, there is an increase in plant height, root collar diameter and internodal length while the leaf area index is reduced. The quality of light reaching the seedlings in different shade houses remained similar.

Key Words: Growth, PAR, R:FR ratio, shade, *Swietenia macrophylla*, survival

INTRODUCTION

Big leaf mahogany, *Swietenia macrophylla* (Family: Meliaceae, Subfamily: Swietenoideae) is one of the premier timbers of international trade, with a high value and a long tradition of commercial use.[5,24] Many Meliaceae grown in Sri Lanka, including *S. macrophylla* are susceptible to attack by the mahogany shoot borer, *Hypsipyla* spp. (Lepidoptera: Pyralidae), during the initial growing period.[3,12]

It has been suggested that planting *S. macrophylla* under shade; a possible silvicultural practice may reduce shoot-borer damage during plantation establishment.[11,13,16] Shade may have several effects on the growth, morphology and susceptibility of *S. macrophylla* to shoot borer. While shade may reduce damage by shoot borer, it may also reduce growth of mahogany through decreased radiation available for photosynthesis and biomass production. The influence of shade on the

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growth of *S. macrophylla* has not been investigated in any detail and there is only limited research data available. In order to develop a practical silvicultural regime using shade for the establishment of *S. macrophylla* in the field, initially it is necessary to determine the integrated effects of shade on *S. macrophylla* growth and survival, under controlled shade.

In this study, the effects of shade on survival, growth and morphology of *S. macrophylla* seedlings during initial establishment within shade houses, were determined.

METHODS AND MATERIALS

Site description:

The experiment was carried out from 1997 to 1999, at the Faculty of Agriculture Farm site of the University of Peradeniya, at an altitude of 487.6 amsl. The region receives an average annual rainfall of 1850 mm with temperatures ranging from a minimum of 20.5 °C to a maximum of 30.7 °C. A total of 1512 mm rainfall was recorded at the site during the study period. The mean relative humidity of the area is 70.2 % (Department of Agriculture, Peradeniya, 1998). Measurements of light quantity in the artificial shade houses were made during the study period, from 1st to 15th of June 1998, from 9:00 a.m. to 4:00 p.m.

Artificial shade:

Nine shade houses, each 5 x 5 x 2.5 m were constructed in three blocks in a square area of 2025 m^2. The houses were constructed out of wooden frames and each house was fitted with one of three kinds of shade giving light environments, which ranged from 20-90% of full sunlight. Each block had all three treatments randomly located. The high shade was provided by 1 cm^2 mesh coconut fibre and a layer of pale blue mosquito netting, whereas the medium shade was provided using 3 cm^2 mesh coconut fibre with a layer of mosquito netting. Low shade houses were covered only with a single layer of mosquito netting.

Planting material:

Eight-month-old seedlings of *S. macrophylla* originally raised under coconut cadjan shade screens were obtained from the Forest Research Nursery, Kurunegala. Seeds for these plants had been gathered from trees planted in the 1940's[2] near the Forest Research Centre, Kurunegala. Healthy, damage-free seedlings about 30-35 cm tall, were selected for planting. Eighteen plants were planted in each shade house in September 1997 on a hexagonal grid, with seedlings 1 m apart. Plant arrays were oriented by compass points and were numbered using aluminium tags starting from the first plant in the northern corner in all cases. Plants received natural rainfall supplemented by hand watering once a week during drought periods. The plants were also manually weeded once a month. Fertilizers were not added during the study period.

Measurement of light:

Measurement of photosynthetically active radiation (light quantity): The photosynthetically active radiation (PAR) between 400-700 nm in all plots were measured using a data logger with a PAR sensor (SDL 2512, 15450, version DH / MM 63, Skye Instruments Ltd., Ddole Industrial Estate, Llandrindod Wells, Powys, UK). PAR was measured following the method of Rich et al.[18] At the centre of each plot one data logger with a PAR sensor was mounted on a 12 x 12 cm platform on a post 2 m above ground level. Another data logger with a PAR sensor was placed at the same time in an open area (1) close to the experimental plots, in order to record the total amount of incident PAR. Measurements were made under similar weather conditions mostly under clear skies or continuous cloud cover, avoiding days of changing cloud cover in order to minimise variability. The sensor was set to record PAR at 30-second intervals and express them as an integrated mean over each 30-minute period in μ mol m^{-2} s^{-1}. Data were recorded over a seven-hour period (09:00-16:00). The percentage PAR received in the shade houses was calculated as the ratio of PAR associated with a shade house (Q_i) to open area (Q_o) following the formula shown below. The mean for each plot was calculated as a percentage over the seven-hour period of recording.

$PAR = (Q_i / Q_o) \times 100$:

Measurement of red: far red ratio (light quality): The Red: Far Red ratio (R:FR) of each plot was measured using a sensor type 660-730 nm (SKR 110 0797 15447, SK3, Skye Instruments Ltd., Ddole Industrial Estate, Llandrindod Wells, Powys, UK), which measures the instantaneous R:FR ratio. The sensor was mounted on a removable metal sensor mount with a leveller to ensure constant positioning. The sensor and the leveller were placed on top of a 12 x 12 cm platform, 2 m above ground at the center of the plot. A recording of open R:FR ratio was made in an open site close to the study plots. Measurements were carried out once every 2-3 months. Subsequently, the mean R:FR ratio for each plot was calculated as an average of the recordings throughout the experimental period.

Measurement of growth parameters:

Seedling survival: Seedling survival was recorded monthly, after establishing plants in September 1997 in all houses. Six months after planting, the number of surviving seedlings was recorded.

Plant height and root collar diameter: Plant height was measured for all seedlings, to the nearest 0.5 cm. The root collar of each seedling was marked with permanent paint and the height was measured from the root collar to the tip of the apical shoot. Height measurements were carried out monthly starting from the date of planting to June, 1998. The height increment was calculated 36 weeks after planting under artificial shade houses. Measurement of average root collar diameter was made to the nearest millimetre using a vernier caliper at seven months after planting.

Number of shoots and length of dominant shoot: The number of shoots on each seedling was recorded monthly until the end of June 1998. The number of live healthy shoots on each seedling was counted and recorded. The final number of shoots was recorded 36 weeks after planting.

The length of the dominant shoot of each seedling was taken at the same time as for number of shoots, described above. The length of the shoot was measured to the nearest 0.5 cm from the previous growth, indicated by thickening of bark, to the tip of the apical shoot.

Internode length: The length of internodes was measured to the nearest centimetre and the mean internodal length per plant was calculated. A total of 54 *S. macrophylla* seedlings six from each shade house were used for this study 40 weeks after planting.

Specific leaf area: Specific leaf areas of plants were measured as the ratio of leaf area to leaf dry mass. The leaf areas were obtained using a Delta-T Leaf Area Meter (Delta-T Instruments, Cambridge, UK). The foliage was oven dried at 80 °C for 24 h until constant mass was obtained and the dry mass was weighed to the nearest 0.005 g using a top loading balance (Mettler PM 400, Toledo AG SNR 1631, Switzerland). Ten fully open leaves from each shade house were randomly collected 62 weeks after planting for this study.

Shoot phenology: The phenology of each seedling in all houses was recorded a month after planting and thereafter every month until June, 1998. The various stages of the shoot growth of *S. macrophylla* seedlings were classified into one of four categories from the beginning of flushing to the mature stage of the shoot. Phenology class 1 was used to describe the very early stage of growth where the shoot was tender and flexible, pink to pale red in colour and the leaves were not fully expanded. Phenology class 2 included shoots which were tender and flexible but green in colour, some leaves were fully expanded while the uppermost leaves were just emerging and the upper surface of the leaf was green and the lower surface of the leaf was pink to pale red. Phenology class 3 was used to describe the later stage of shoot flush in which shoot elongation was completed, the shoot was inflexible and the leaves were fully expanded and pale green in colour but still soft. Phenology class 4 included non-flush shoots, where the shoot was mature and the leaves were stiff and dark green in colour.

Statistical analyses: Data on survival, increment and morphology were analysed by analysis of variance (ANOVA) procedure using SAS (1986). Multiple comparisons among means of different light treatments were carried out using Duncan's new multiple range test at the P level of ≤ 0.05. Graphs were plotted using Excel 1997 version 7.0 (Microsoft Corporation, USA). The data for specific leaf area, internode and root collar diameter length were subjected to ANOVA. Owing to some seedling mortality over the period of the study, data on height, number of shoots and dominant shoot height was subjected to an unbalanced ANOVA, using the GLM procedure of SAS (17). Data for survival were transformed to natural log and shoot counts were transformed to $\sqrt{Y+1}$ prior to analysis.

RESULTS

PAR readings in the artificial shade houses

Table 1 shows total PAR for artificial shade houses and respective values for open areas with percentage shading. Percentage PAR in each shade house was calculated in relation to PAR recorded in the open area nearby. The % PAR ranged from 26 to 29 % in three blocks in the high shade houses, from 43 to 45 % in the medium shade houses and from 85 to 88 % in the low shade houses. Analysis of variance showed significant differences in PAR readings between shade treatments ($P=0.0001$).

R:FR ratio recordings in the artificial shade houses

The mean R:FR ratio of the artificial shade houses is shown in Table 2. Analysis of variance showed no significant differences between shade treatments ($P>0.05$).

Seedling survival

Overall seedling mortality was low and was not significantly different under different shade treatments ($P>0.05$). Proportion of seedling survivals varied from 96.3 % in the high shade houses, 98.1 % in the medium shade houses and 91.0 % in the low shade houses.

Plant height and root collar diameter

The height of seedlings at planting under artificial shade was not significantly different between treatments or blocks. No significant differences in final height or height increment were found in response to treatment. The overall mean final height and standard error of seedlings in all treatments was 132 ± 10.2 cm. Figures 1 and 2 show the mean final height and height increment under different shade levels.

Table 1 : The amount of total PAR received in different shade houses, in the open and percentage shading of shade houses, measured from 01/06/98 to 15/06/98 from 09:00 to 16:00 h. Percentage shade is given as mean ± SE, n = 14 and was calculated in relation to PAR recorded in an open area.

Treatments	PAR received inside shade houses (μ mol m^{-2} s^{-1})	PAR in the open (μ mol m^{-2} s^{-1})	% PAR Mean ± SE (n=14)
High shade house 1	399.9	1505.6	26.2±2.2
High shade house2	447.1	1505.6	29.0±1.8
High shade house 3	338.9	1234.2	27.1±1.0
Medium shade house1	545.7	1234.2	43.5+3.2
Medium shade house 2	698.4	1568.7	44.3±2.0
Medium shade house 3	700.0	1568.7	45.5±4.4
Low shade house1	1166.5	1302.5	88.5±2.5
Low shade house 2	1164.0	1302.5	87.7±3.7
Low shade house 3	1175.3	1392.9	85.1±7.5

Table 2 : Mean R:FR ratio of artificial shade houses, measured from 16/01/98 to 07/05/98. Values are means ± SE, n = 5

	R: FR ratio		
Treatments	Block 1	Block 2	Block 3
High shade	1.02±0.04	0.99±0.05	1.00±0.02
Medium shade	1.04±0.04	1.05±0.04	1.03±0.07
Low shade	1.05±0.05	1.07±0.04	1.03±0.06

Root collar growth response to light availability in artificial shade is shown in Figure 3. Analysis of variance showed significant treatment effects under the artificial shade (P=0.01). The mean root collar diameter at 36 weeks under high shade was 3.2 ±0.04 cm and under low shade was 4.0±0.06 cm.

Number of shoots and dominant shoot height

Analysis of variance showed no significant effects of shade treatments on total number of shoots (P>0.05). Number of shoots varied from 1.9 in the high shade to 1.5 in the low shade. The dominant shoot height did not differ significantly with shade treatments (P>0.05).

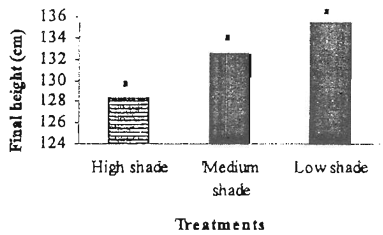

Figure 1 : Final height of *S. macrophylla* seedlings in artificial shade houses. Measurements were made 36 weeks after planting. Values presented are treatment means produced by ANOVA, DNMRT; n= 50; (high shade), n=45; (medium shade) and n=42; (low shade). Treatments with same letter are not significantly different from each other (at P<0.05).

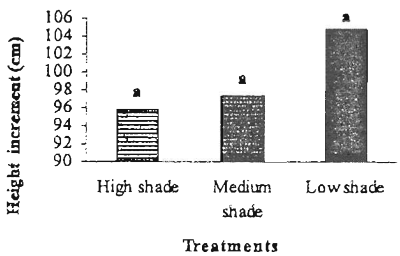

Figure 2 : Height increment of *S. macrophylla* seedlings in artificial shade houses. Measurements were made 36 weeks after planting. Values presented are treatment means produced by ANOVA, DNMRT; n= 50; (high shade), n=45; (medium shade) and n=42; (low shade). Treatments with same letter are not significantly different from each other (at P<0.05).

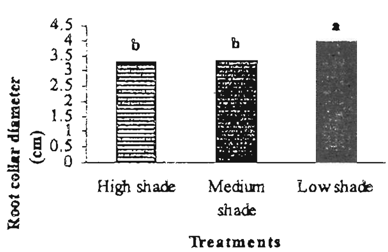

Figure 3 : Root collar diameter of *S. macrophylla* seedlings in artificial shade houses. Measurements were made 40 weeks after planting. Values presented are treatment means produced by ANOVA, DNMRT; n= 9. Treatments with same letter are not significantly different from each other (at P<0.05).

Internode length

Analysis of variance for internode length in artificial shade houses showed significant differences between shade levels (P=0.02). The mean internode length of *S. macrophylla* in the low shade treatment was greater than that under high shade by a factor of 4.3, at 40 weeks after planting (Figure 4).

Specific leaf area

The mean specific leaf area of seedlings under different artificial shade levels is shown in Figure 5. No significant effect of shade (P>0.05) on specific leaf area was recorded at 40 weeks after planting.

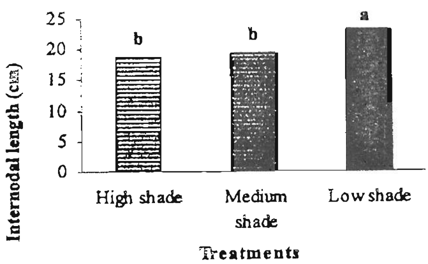

Figure 4 : Internodal length of *S. macrophylla* seedlings in artificial shade houses. Measurements were made 40 weeks after planting. Values presented are treatment means produced by ANOVA, DNMRT; n= 18. Treatments with same letter are not significantly different from each other (at P<0.05).

Shoot phenology

Figure 6 shows the mean monthly rainfall and the mean phenology under artificial shade treatments. The peak rainfall was recorded in November 1997 (435 mm), with no rains in the months of June and August, 1998 (0 mm). Higher rainfall corresponded to the Southwest monsoon of the wet zone. The stage of shoot phenology was related to the amount of rainfall received at the experimental site. The mean phenology of seedlings in the artificial shade houses remained in class 1-2 (flushing stage) in the months of October and November 1997 during peak rainfall and in non-flushing stage in the month of June 1998, where no rains were recorded.

The temporal variation of shoot phenology in different shade levels under artificial shade displayed a similar pattern throughout the study period, remaining in early flushing stage (phenology class 1-2) for 36 weeks after planting and in the non-flushing stage (phenology class 3-4) 43 weeks after planting (Figure 7). Analysis of variance showed no significant effects of shade treatments (P>0.05).

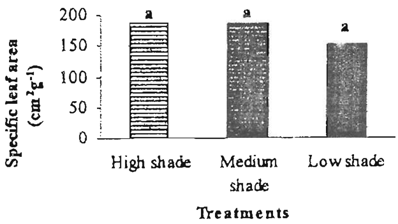

Figure 5 : The specific leaf area of *S. macrophylla* seedlings in artificial shade houses. Measurements were made 40 weeks after planting. Values presented are treatment means produced by ANOVA, DNMRT; n= 30. Treatments with same letter are not significantly different from each other (at P<0.05).

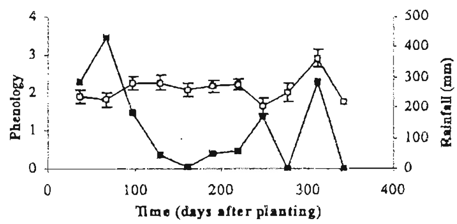

Figure 6 : The pattern of mean phenology in artificial shade houses following planting and monthly rainfall. Symbols: (a) open square, mean phenology over time; (b) closed square, monthly rainfall pattern. Phenology is assessed on a scale of 1-4. Values present are means ± SE, n=162 for phenology. Rainfall data were obtained from the Department of Agriculture, Peradeniya.

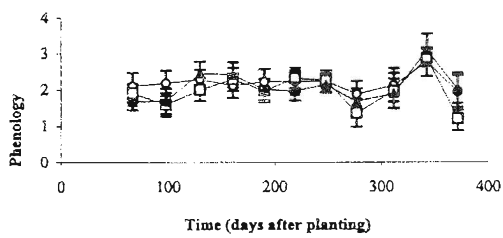

Figure 7 : The temporal pattern of mean phenology in three different shade treatments. Symbols: (a) open circle, high shade treatment (b) open square, medium shade treatment (c) closed triangle, low shade treatment. Phenology is assessed on a scale of 1-4. Values presented are treatment means ± SE, n=54

DISCUSSION

S. macrophylla has been categorised in the literature as a long-lived pioneer.[23] Recent research has shown that this species requires high light levels for satisfactory establishment.[2,9,21] Studies[6,7,20] have shown that under a dense forest canopy *S. macrophylla* seedlings usually fail to survive more than a few months, due to heavy shade. However, the PAR in the latter studies have not been precisely quantified. Results of the present study demonstrate that *S. macrophylla* seedlings have high survival when grown in shade houses irrespective of the shade levels.

Height increment of *S. macrophylla* seedlings under different shade regimes did not show a marked change in relation to light levels, showing high growth in the three shade treatments. This suggests that the amount of light available in the high shade treatment (20 % relative PAR) of the present study was not limiting the height increase of *S. macrophylla* significantly. The highest root collar diameter was obtained in seedlings grown under the lowest shade treatments. Studies[2] provided evidence in support of these findings. Their studies showed that *S. macrophylla* grown in the open had the highest root collar diameter (2-3 cm) than those grown under shade (1 cm), after 2 years of planting. These observations suggest that seedlings under a high light environment allocate greater biomass to girth increase than under a low light environment.[22]

Length of the dominant shoot and specific leaf area did not show any response to different light environments. R:FR ratio is known to strongly influence shoot length and specific leaf area in many species.[4,10] The absence of a significant variation in the R:FR ratio under different shade treatments may account for the absence of any significant differences in shoot length and specific leaf area recorded under shade houses. However, internodal length in the low shade treatment was 24 % higher than that in high shade treatment. Under dense natural shade, mahogany seedlings persist with a few thin, deep green leaves and short internodes.[11] In addition, there was no effect on branching under shade. Increased branching giving a bushy appearance is a typical response to high R:FR ratio, as observed in many plant species.[4,14,19]

Over 10 month's observations during the study indicated that, flushing of *S. macrophylla* coincides with the onset of rain. The reports[8] indicate that flushing of trees correspond with the beginning of the rainy season. As noted in the Peruvian Amazon,[25] in continuously rainy periods, *S. macrophylla* flushed continually while[15] another study reported that leaf abscission in *S. macrophylla* coincided with relatively dry periods.

During the study period R:FR ratio was measured monthly but PAR reaching the shade houses were monitored only once during the study. R:FR ratio is measured as an instantaneous measurement using a portable sensor while PAR is measured as a daily-integrated measurement using a data logger with a built in sensor. Any single daily-integrated measurements of PAR would not give an accurate measure of the total light availability during a season. However, it is not possible to make repeated measurements of PAR, as it is a tedious and expensive procedure.

It is generally known that low levels of light reduce biomass production, which is a good indicator of plant growth. However, we could not determine the biomass production of the seedlings during this study due to the fact that destructive sampling was not possible as the same seedlings were intended for a further study. This study where different shade treatments were used but light of the same quality was present, does not provide a clear answer to the question of whether shading would affect the seedling growth of *S. macrophylla* significantly.This has to be checked in future experiments through actual studies where the quality of light can be varied. Moreover measurements of biomass production through destructive sampling would give a more accurate account of seedling growth.

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