Tropical Agricultural Research Vol. 12: 127-137 (2000)

# Responses of *Swietenia macrophylla* (King) Seedlings to Different Sizes of Canopy Openings in Mixed Mahogany Plantations

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***ABSTRACT.*** *Shoot borer, Hypsipyla robusta (Moore) is a serious pest of mahogany, Swietenia macrophylla (King) which effectively prevents the establishment of plantations. Observers have suggested that shade might reduce the pest damage by reducing flushing and growth in seedlings, but existing evidences were conflicting and anecdotal. Therefore, a study was done to determine the effect of different degree of shade on survival, growth and flushing of mahogany seedlings. This study was done from 1997–99, at 2 sites at Rambukkana and Kurunegala (Sri Lanka) and was designed by creating wider opening, moderately opening and narrowly opening gaps under mature mixed mahogany plantations. Thus, each site composed of plots with different canopy openings of high to low shade conditions. Within each plot 18 mahogany seedlings of similar age, height and origin were planted. Survival, stem growth and shoot phenology of seedlings were recorded monthly. Seedling survival a year after planting showed higher mortality under high shaded gap (3–8% PAR). At 51 weeks after planting, final stem height and root collar diameter were highly significant under low shaded gaps. Increased number of shoots and shoot lengths were observed under low shade (50–78% PAR). Increased flushing was seen in all shade regimes during the rainy period. This study illustrates that low shaded gap openings favour seedling survival, stem growth, shoot growth and number of shoots. On the contrary, high shaded gaps reduce the growth of seedlings and thereby may be less attractive to shoot borers.*

## INTRODUCTION

*Swietenia macrophylla* King (Meliaceae: Swietenoideae) provides one of the premier timbers of the world. The shoot-borer *Hypsipyla robusta* Moore (Lepidoptera: Pyralidae) is an economically important pest of mahogany throughout the moist tropics including Sri Lanka (Mahroof, 1999). Larvae of the shoot-borer destroy the terminal shoot of the tree by boring the pith, resulting in highly branched tree of little economic value (Newton *et al.*, 1998). Various control methods have been attempted in the past, but most of them were largely failed.

Many workers have stated that to avoid shoot-borer problem in mahogany, seedlings should be kept shaded (Perera, 1955; Whitmore, 1978; Mahroof *et al.*, in press). Although shade reduces the attack it may also reduce the growth rate of seedlings.

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Therefore, the effect of shade on growth has been observed to be an important factor. Several mechanisms of growth have been proposed with respect to how shade may affect resistance of the mahogany to attack by shoot-borer (Hauxwell *et al.*, in press). Holsten and Gara (1974) demonstrated that under an open condition the flushing foliage of another Meliaceae, *Cederela angustifolia* (Moc.) was more attractive to mahogany shoot-borer than non-flushing foliage. Whitmore (1978) suggested that faster-growing *Cedrela odorata* (L.) in the light had promoted the growth of longer flush shoots, providing more susceptible sites and thus increased the severity of attack. Grijpma and Gara (1970) suggested that light promoted the growth of longer flush shoots, providing more sites for the insect to attack. However, the direct influence of light on growth and flushing has not been investigated in detail.

Guidelines, which give effective and consistent results regarding the suitable shade condition, which promote growth and avoid attack, are not available. In order to provide a framework for suitable shade conditions to establish mahogany, an experimental approach was used by manipulating shade by creating different canopy openings under mixed mature mahogany plantations. The hypotheses tested was that under high light availability, *S. macrophylla*, grows more rapidly by producing higher number of longer shoots hence increase branching and flushes more often, producing more susceptible tissues.

## MATERIALS AND METHODS

### Establishment of seedlings under different canopy openings

The 1st site under mature mahogany was at Marukwathura plantation, Rambukkana, Sri Lanka. The canopy gaps under this plantation were planted with seedlings of mahogany in November 1997. The plantation was principally a mixture of mahogany and *Artocarpus integrifolia* (L) established in 1926 (Sandom and Thayaparan, 1995). The area of plantation receives an average annual rainfall of between 1700–2300 mm and the mean relative humidity of the area is 78%. The topography of the study site is one of undulating flat land with an altitude of 202 m.a.s.l. (Agricultural Farm School, Rambukkana, 1999). The 2nd site under mature mahogany was established in Boyagane Plantation Kurunegala, in April 1998. The plantation was originally planted in the 1940's with a mixture of mahogany and *A. integrifolia* (Ashton *et al.*, 1998). The mean annual rainfall at Kurunegala is 1980 mm and the topography is undulating hills with a mean altitude of 60 m.a.s.l.. The latitude of region is 7° 30' North and the longitude is 80° 46' East (Forestry Research Centre, Kurunegala, 1999).

The method comprised of planting seedlings of *S. macrophylla* under mature mahogany trees with different degrees of canopy opening. The gaps were created either by using existing natural gaps or by felling trees, branch pruning, chopping shrubs nearby and clearing weed growth. The canopy openings were initially classified by visual observation to give a range of openings and each plot was classified as high, medium or low shade on the basis of visual assessment and subsequently measured using light quantum sensors. The 1st site at Marukwathura comprised 10 different degrees of canopy gap opening and the 2nd site at Kurunegala comprised 6 different degrees of canopy gap opening.

*S. macrophylla* seedlings of 8 months old from the forestry nursery of the non-governmental organisation, Gannoruwa, were used for planting in both sites. Seeds for these plantings had been gathered from the surrounding mature mixed forest of *S. macrophylla*. Damage-free, healthy seedlings of 24–27 cm tall were selected for planting within each 5m×5 m cleared area. Eighteen plants were planted in each plot under different degrees of opening on a hexagonal grid with plants exactly 1 m apart. Plant arrays were oriented by compass points. The plants received natural rainfall, supplemented by hand watering once a week during drought periods. All the plots were manually weeded once a month. Gaps were re-opened 20–30 weeks after planting to maintain the degree of canopy opening throughout the experimental period.

## Measurement of PAR and R:FR ratio within the canopy openings

The photosynthetically active radiation (PAR) between 400–700 nm in all plots were measured using a data logger with PAR sensor (SDL 2512, 15450, version DH / MM 63, Skye Instruments Ltd., UK) following the method of Rich *et al.*, (1993). The Red : Far Red ratio (R:FR) of each plot was measured using a hand held portable sensor type of 660–730 nm (SKR 110 0797 15447, Skye Instruments Ltd., UK).

## Measurements of growth parameters

In this study, the effect of shade on survival, height increment and morphology of *S. macrophylla* seedling grown under various sizes of canopy openings was determined. Seedling survival was recorded monthly after planting in all plots. Twelve months after planting, the proportion of seedlings surviving was calculated for different gap openings. Plant height was measured for all seedlings, to the nearest 0.5 cm. The root collar of each seedling was marked with 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 April 1999. The height increment was calculated 51 weeks after planting. Measurement of root collar diameter was made to the nearest mm using a vernier caliper at 28 and 40 weeks after planting in all plots.

The number of live healthy shoots and the length of the dominant shoot on each seedling were recorded a month after planting and thereafter every month until the end of January 1999 before shoot-borer damage was observed in the field. The length of the dominant shoot was measured to the nearest 0.5 cm from the previous growth, indicated by thickening of a bark ring, to the tip of the apical shoot. The final number of shoots and the shoot length were counted 40 weeks after planting. The shoot phenology was recorded every month until April 1999. The various stages of the shoot growth of *S. macrophylla* seedlings were classified into 1 of 4 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 while 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 analysis

Data on PAR, R:FR ratio, survival, increment and morphology were analysed by two-way analysis of variance (ANOVA) procedure using SAS (1986) to detect statistically significant differences in response to shade treatments or site effects. 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. Owing to some seedling mortality over the period of the study, height, root collar diameter, number of shoots and dominant shoot height data were subjected to an unbalanced ANOVA, using the GLM procedure of SAS (Ray, 1982). Data for percentage survival were transformed to natural log and shoot counts were transformed to $\sqrt{Y+1}$ prior to analysis.

## RESULTS

### PAR readings for the different canopy openings

The PAR, in the study plots under mature mahogany at site 1 (Rambukkana) and at site 2 (Kurunegala) is shown in Table 1. Mean values of PAR ranged between 3.1–78.4% in high shaded to low shaded plots. Analysis of variance showed significant differences in PAR between gap openings ($P<.001$).

### R:FR ratio of the different canopy openings

High shade treatments in both sites displayed the lowest R:FR ratio of all the treatments and the low shade treatments displayed the highest values. Values of mean R:FR ratio ranged between 0.3 in high shade plots to 1.02 in low shaded plots. Analysis of variance of R:FR ratio under natural shade regimes of mature mahogany showed highly significant differences between treatments ($P<.001$) and between sites ($P<.01$).

### Seedling survival, plant height and root collar diameter

Highly significant differences were observed in the percentage survival of seedlings between different shade treatments under mature mahogany ($P<.0001$), with increasing mortality in high shade regimes. Mean percentage survival of seedlings under high shade, medium shade and low shade were 57.6 (± 11.1), 76.4 (± 19.5), and 90.3 (± 6.8) respectively.

**Table 1.** **Mean percentage PAR measured in the different sizes of canopy openings from 29/09/98 to 17/10/98 at Rambukkana and from 22/07/98 to 31/07/98 at Kurunegala.**

| Sites / Replicates | Treatments (% PAR values) | | |
|---|---|---|---|
| | High shade | Medium shade | Low shade |
| Rambukkana | | | |
| Replicate 1 | 3.1 ± 0.6 | 16.2 ± 1.3 | 41.0 ± 9.8 |
| Replicate 2 | 3.5 ± 0.6 | 13.0 ± 6.1 | 37.1 ± 29 |
| Replicate 3 | 4.8 ± 1.7 | | |
| Replicate 4 | 5.4 ± 4.3 | | |
| Replicate 5 | 4.7 ± 0.6 | | |
| Replicate 6 | 4.6 ± 0.8 | | |
| Kurunegala | | | |
| Replicate 1 | 8.5 ± 4.9 | 9.8 ± 3.3 | 78.4 ± 11 |
| Replicate 2 | 5.0 ± 1.4 | 14.4 ± 4.0 | 51.5 ± 11 |

Values presented are means ± SE n = 13
Percentages were calculated in relation to PAR recorded in an open area nearby.

The analysis showed highly significant differences in final height under the different classes of shade treatments ($P<0.0001$). At 51 weeks after planting, mean height under high shade gap was 32 cm and under low shade gap was 66 cm (Fig. 1). The height increment of seedlings over the same period also showed highly significant results ($P<0.0001$) between shade treatments.

Root collar growth response to different light availability of the gaps under mature mahogany is shown in Fig. 2. A highly significant treatment effect was observed on final root collar diameter and root collar diameter increase under mature mahogany ($P< 0.001$) at 51 weeks. The analysis of variance also showed significant site effects on root collar diameter ( $P< 0.001$); root collar diameter increment ($P<0.001$), with overall diameter reduced in plots at site 1, but at both sites root collar diameter at low shade was greater than that of high shade. The mean root collar diameter and standard error of plants under high shade treatment was 0.5 ± 0.06 cm, while under low shade was 1.05 ± 0.07 cm.

### Number of shoots and dominant shoot height

Analysis of variance showed a significantly higher number of shoots in the low shade treatment than high shade and medium shade treatments ($P < 0.0001$) (Table 2) at 40 weeks after planting. No significant site effects were observed at $P=.05$.

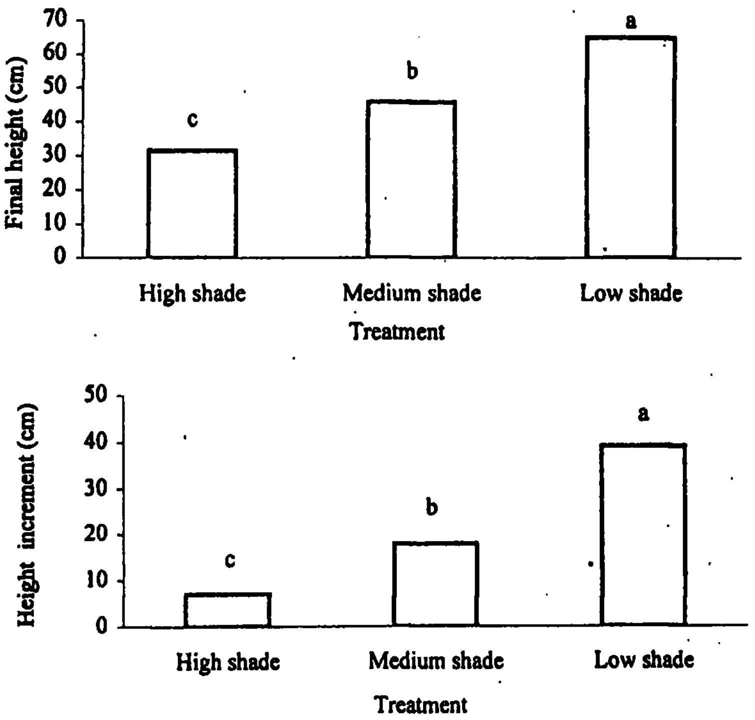


**Fig. 1. Mean final height (a) and height increment (b) of *S. macrophylla* seedlings under different gap openings at 2 sites of mature mahogany.**
[Note: Measurements were taken 51 weeks after planting. n=74 (high shade), n=49 (medium shade) and n= 63 (low shade). Treatments with the same letter are not significantly different from each other at P≤0.05].

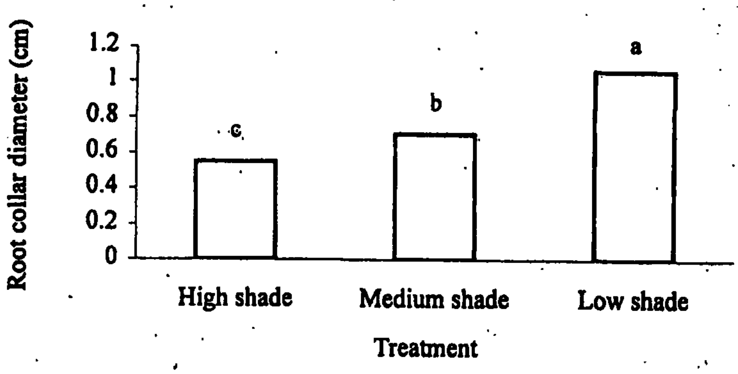


**Fig. 2. The effect of shade on mean root collar diameter of *S. macrophylla* seedlings at 2 sites of mature mahogany.**
[Note: Measurements were taken 40 weeks after planting. n=82 (high shade), n=55 (medium shade) and n=82 (low shade). Treatments with the same letter are not significantly different from each other at P<0.05].

At 40 weeks of planting *S. macrophylla* seedlings under mature mahogany, the mean dominant shoot height for the high shade gaps was 1.5 cm and for the low shade gap was 7.0 cm (Fig. 3). The difference between treatments was highly significant ($P < 0.001$), and a highly significant difference was shown for the site effects for shoot height ($P < 0.001$), with overall height reduced in plots at site 1, but at both sites shoot height at low shade was greater than that of high shade.

**Table 3. Values for the mean number of shoots in seedlings of *S. macrophylla* 40 weeks after planting, grown under 3 different degrees of canopy gap opening at 2 sites of mature mahogany.**

| Treatments | Site 1 | Site 2 |
|---|---|---|
| | Number of shoots | Number of shoots |
| High shade | 1.4 ± 0.02 | 1.4 ± 0.03 |
| Medium shade | 1.55 ± 0.06 | 1.42 ± 0.01 |
| Low shade | 1.61 ± 0.04 | 1.75 ± 0.07 |

Values are means ± SE n = 36

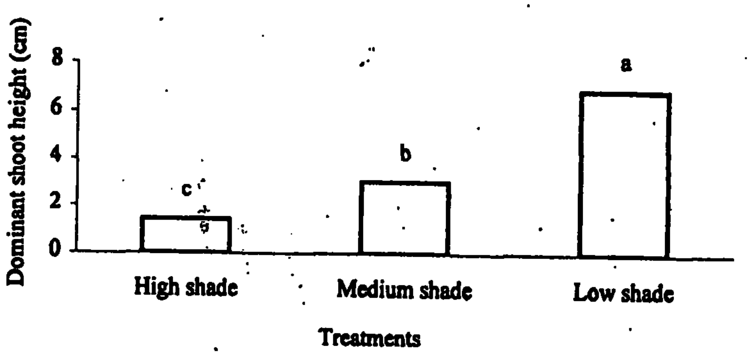


**Fig. 3. The effect of shade on mean dominant shoot height of *S. macrophylla* seedlings at 2 sites of mature mahogany.**
[Note: Measurements were taken 40 weeks after planting; n=76 (high shade), n=52 (medium shade) and n=64 (low shade). Treatments with the same letter are not significantly different from each other at $P<0.05$].

## Shoot phenology

Under mature mahogany a total of 3232 mm rain fell in a total of 16 months at site 1 (Rambukkana) and 2269 mm over 13 months at site 2 (Kurunegala) recorded at 29–30 day intervals. Pronounced variation in rainfall was observed from month to month with no rain recorded in February 1998 and April 1999 at site 1. At both sites the mean shoot phenology of seedlings remained in lower class 3–4 (*i.e.*, seedlings did not flush) when the sites received lower rainfall. Flushing was recorded when the rainfall was highest, 413 mm at Rambukkana and 385 mm at Kurunegala in the month of May, 1998 during the north east monsoon period. Figs. 4 and 5 show the mean monthly rainfall and the mean phenology at Rambukkana and Kurunegala, respectively.

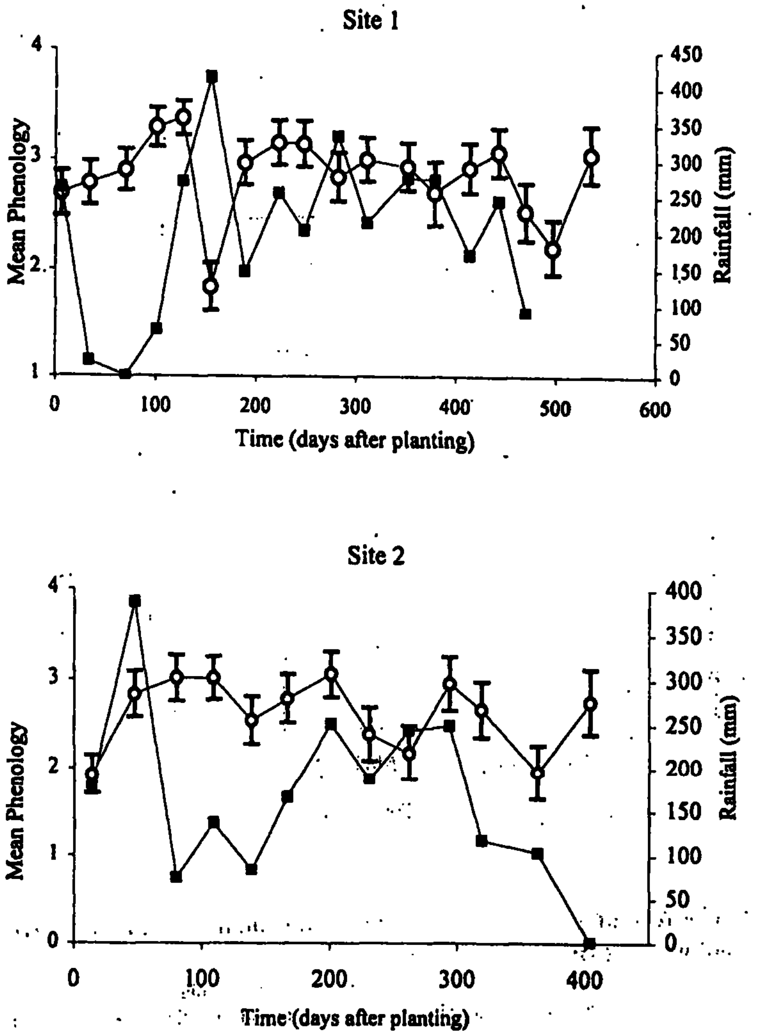


**Fig. 4. The pattern of mean phenology of *S. macrophylla* seedlings under different canopy gap openings.**

[Note: Symbols - (a) open circle: mean phenology overtime, (b) closed square: monthly rainfall pattern. Phenology is assessed on a scale of 1–4. Values presented are means at each time point ± SE, n=180 for phenology. Rainfall data obtained from the Department of Agriculture, Sri Lanka].

The mean phenology of treatments in both sites showed a response to shade. The high shade treatment remained in higher phenology *i.e.*, non flushing stage, class 3–4, and flushed less frequently, while low shade treatments remained in lower phenology class 1–2, and flushed more often throughout the study period. Significant effects of shade treatments on frequency of flushing were observed ($P < 0.001$) with more frequent flushing under low shade treatments.

## DISCUSSION

Results of the present study demonstrated that *S. macrophylla* seedlings had higher survival in wider open gaps (50–78% PAR) during initial establishment period, nevertheless seedlings had shown only 58% mean survival in deep shaded gaps with closed canopy (3–8% PAR). It was reported that under a dense forest canopy *S. macrophylla* seedlings usually fail to survive more than a few months, because of lack of light (Smith-Wenban, 1993), although the amount of PAR in the latter studies was not quantified precisely.

In the experiments described here, significant height growth differences were observed between light treatments of various gap openings. Seedlings grown under low shaded gaps with open canopy were approximately 50% taller than those under high shaded gaps with open canopy. Similar observations were made by Ashton *et al.* (1998) in Sri Lanka, who found that *S. macrophylla* was significantly taller in 12 m wide strip openings than under closed understorey treatments. Smith-Wenban (1993) reported that with full light and abundant moisture *S. macrophylla* seedlings can reach a height of almost 50–100 cm within 6 months, growing much less under medium light (15 cm), although under such conditions they may persist for many months, growing very slowly. The growth of young *S. macrophylla* seedlings has been thought to be directly proportional to the degree of canopy opening (Bauer, 1991; Gerhardt, 1996).

Measurements of root collar diameter of seedlings under different canopy openings had the largest root collar diameter recorded in the low shade treatments. There is some evidence to support these findings. *S. macrophylla* had the largest root collar diameter (2–3 cm) in clear cut opening than planting under closed canopy of pine (1 cm), after 2 years of establishment (Ashton *et al.*, 1998). This observation suggests that seedlings under a high light environment allocate greater biomass to girth increase than under a low light environment.

The spectral quality of light (660–730 nm) is known to have a major effect on plant growth and morphology (Morgan and Smith, 1981; Morgan *et al.*, 1985). On the basis of more than a year's observations, under different canopy opening treatments, R:FR ratios were generally lower in high shaded closed canopy. Apparently, the length of the dominant shoot of seedlings planted under mature mahogany was greatest in higher R:FR ratio and PAR values. Lamb (1966) reported that under complete overhead light with side protection, leading shoots might grow at a rate of 30 cm length in 2–3 weeks. In this study significantly higher number of shoots were observed under the higher R:FR ratio/high PAR measurement. Increased branching and a more bushy appearance are a typical response to higher R:FR ratio, as observed in many plant species (Dale and Causton, 1992; Robin *et al.*, 1994).

In the current study, the relationship between shoot phenology and rainfall was not so clear. However, flushing of *S. macrophylla* coincided clearly with the onset of rainfall. The reports of Grijpma and Gara (1970) indicated that flushing of mahogany trees corresponded with the beginning of the rainy season. As noted by Yamazaki *et al.* (1992) in the Peruvian Amazon, during the rainy periods, *S. macrophylla* flushed continually while Newton *et al.* (1998) reported that leaf abscission in *S. macrophylla* and *C. odorata* coincided clearly with the onset of relatively dry periods.

## CONCLUSIONS

The findings of this study show that the light availability greatly influences the survival, height growth and morphology of *S. macrophylla* seedlings during the initial establishment period. Seedling mortality is higher under closed canopy while stem growth, stem elongation and branching are reduced in the same thereby the production of susceptible tissue of *S. macrophylla* seedlings under shade is greatly reduced.

## ACKNOWLEDGMENTS

This publication is part of a larger research project concerning influence of light on shoot borer damage, supervised by many investigators and funded by the Department for International Development of the United Kingdom. However, the Department for International Development can accept no responsibility for any information or views expressed. The experiments of this study were carried out at Forest Department Plantations, Sri Lanka.

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