

VARIATION IN PATTERN OF ATTACK BY *HYPSSIPYLA ROBUSTA* (MOORE) AND RECOVERY OF SEEDLINGS FOLLOWING SIMULATED *HYPSSIPYLA* DAMAGE ON *SWIETENIA MACROPHYLLA* (KING) GROWN UNDER DIFFERENT LIGHT CONDITIONS

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Short Running Title: Damage and recovery of *S. macrophylla*

ABSTRACT

Mahogany shoot-borer *Hypsipyla robusta* (Moore) is among the most economically important insect pest of forestry in Sri Lanka preventing cultivation of many Meliaceae. No viable methods of pest control are currently available. Shade has been repeatedly cited as a factor in reducing attack. In order to evaluate the relationship between attack by the shoot-borer and different shade conditions, field trials of *Swietenia macrophylla* (King) established under various light conditions provided by different canopy openings of two nurse crops, mature *S. macrophylla* and *Acacia curculiformis* (A. Cunn. Ex Benth). The recovery of seedlings after simulated damage of *H. robusta* was studied under an artificial shade trial. The incidence of shoot-borer attack after 54 weeks of planting in the low shade treatment was 76 % higher under mature mahogany and 31 % higher under *Acacia* than under high shade treatment. Similarly, the severity of attack in the low shade treatment was 69 times higher under mature mahogany and 112 times higher under *Acacia*. The number of new shoots produced 12 weeks after simulated damage in the artificial shade was significantly higher under low shade houses. These results indicate those plants grown under open conditions are more vulnerable to attack hence provision of high shade during early growing period may increase the ability of *S. macrophylla* to recover better after shoot-borer attack.

Key words

Swietenia macrophylla, *Hypsipyla robusta*, shade, attack, damage, recovery

INTRODUCTION

Swietenia macrophylla (Family: Meliaceae, Sub-family: Swietenioideae) is one of the premier cabinet wood in Sri Lanka with a long tradition of commercial use. Many Meliaceae grown in Sri Lanka including *S. macrophylla* are susceptible to an insect pest attack; mahogany shoot borer, *Hypsipyla robusta* Moore (Lepidoptera: Pyralidae), during the initial growing period (Beeson, 1941; Mahroof *et al.*, 1997 a).

Larvae of the shoot borer feed on young terminal shoots resulting in death of apical bud, leading to branching and forking of trees, which consequently reduces the yield of timber. Many control methods attempted failed, yet providing shade during early establishment period of *S. macrophylla* has acquired greater significance as a novel management system for shoot-borer.

Although, the effect of shade during the establishment of *S. macrophylla* has received a great deal of attention, the results of research undertaken do not always agree (Hauxwell *et al.*, 1997). The growth rate of *S. macrophylla* is influenced by the degree of shade (Grijpma, 1974; Whitmore, 1976). Factors, which promote vigorous apical growth, have been reported to increase incidence of attack by *Hypsipyla* spp. in Meliaceae such as *Khaya* spp. (Akanbi, 1973) and in *S. macrophylla* saplings (Yamazaki *et al.*, 1992). Faster-growing trees under higher light conditions produce increased numbers of susceptible sites by producing longer succulent shoots which the insects preferentially select for oviposition (Grijpma, 1974; Whitmore, 1976).

However, if plants suffer increased attack, relatively fast-growing plants may be consequently better able to recover form and height after attack by production of a vigorous apical shoot (Grijpma, 1975; Hauxwell *et al.*, 1996). Therefore, silvicultural techniques, which promote growth of the leading shoot and recovery of form succeeding damage, provide a means of enhancing tolerance to shoot-borer attack (Mahroof *et al.*, 1998 b; Hauxwell *et al.*, 1996).

An appropriate light environment for *S. macrophylla*, which reduces attack and promotes recovery after attack by production of a vigorous leader, has not been determined (Mahroof, 1999). In order to develop a practical silvicultural regime for the establishment of *S. macrophylla*, data are needed on how the severity and incidence of attack vary under different shade conditions. In this study, therefore, the effect of natural shade of two nurse crops matures mahogany and *Acacia auriculiformis* (A. Cunn. Ex. Benth.) on attack by shoot-borer and consequences of artificial shade on recovery of seedlings after simulated shoot-borer damage were determined.

MATERIALS AND METHODS

Site descriptions

The first site under mature mahogany was at Marukwathura plantation, Rambukkana and was planted with seedlings of mahogany in November 1997. The plantation was principally a mixture of mahogany and *Artocarpus integrifolia* (Linn.f.) established in 1926 (Sandom and Thayaparan, 1995). The area of plantation receives an average rainfall of between 1700 – 2300 mm and the mean relative humidity of the area is 78.1 %. The topography of the study site is one of undulating flat land with an altitude of 202 m.a.s.l. (Range Forest Office, Rambukkana, Sri Lanka). The second site 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'

Variation in pattern

The first and the second sites under *A. auriculiformis* were established in December, 1997 and April, 1998 respectively, at Nattiyapana, Mawanella at 116 m.a.s.l.. The mean annual rainfall of the location is 1700–2300 mm, average temperature ranges between 25–30° C and the topography of the study sites is of undulating hills with a slope of 30–35°. The two sites were located 1.5 km apart and were separated by a valley. The plantations had been established in 1989 by the Forest Department and the trees in the area were spaced 2.5 x 2.5 m apart (Range Forest Office, Rambukkana, Sri Lanka). The third site was established in February, 1998 at Mirigama, Gampaha at 60 m.a.s.l. under *A. auriculiformis* established in 1991 by the Forest Department. The mean annual rainfall, maximum and minimum temperatures of this location are 2650 mm, 35.7° C and 29° C respectively. The mean annual relative humidity of the area is 90%.

Shade houses for artificial shade experiment were located at the Faculty of Agriculture Farm site of the University of Peradeniya. Seedlings of *S. macrophylla* were established under different degrees of artificial shade in September 1997. The topography of site was level with an altitude of 487.6 m.a.s.l.. The region receives an average annual rainfall of 1850 mm with temperature variation that averages a minimum of 20.5 ° C to a maximum of 30.7 ° C. The mean relative humidity of the area is 70.2 % (Department of Agriculture, 1998).

Planting pattern

Six to eight month old seedlings of *S. macrophylla* originally raised under shade screens were obtained from Forest Research Nurseries at Kurunegala and Kegalle. Healthy, damage-free and un-branched seedlings of high vigour were selected for planting. Eighteen seedlings were planted in each plot under different shade regimes on a hexagonal grid exactly 1 m apart. Plant arrays were oriented by compass points and numbered individually using aluminium tags starting from the first plant in the northern corner in all cases.

Description of the natural shade treatments

Data on incidence and severity of attack by *H. robusta* were collected from seedlings planted under different canopy openings of mature mahogany plantations and under *A. auriculiformis* plantations. Seedlings were established in each of ten and six gaps of two sites under mature mahogany and in nine plots at three sites under *Acacia*. The natural shade regimes under mature mahogany comprised different degrees of canopy opening created either by using existing natural gaps or by felling trees. The canopy openings were classified to give a range of openings and each plot was classified as high, medium or low shade on the basis of visual assessment.

Similarly, treatments under *Acacia* were composed of three different canopy openings and they were categorised as high, medium and low shade. The different canopy pruning treatments were created as follows: (i) high shaded gap: by removing central *Acacia* tree within the 5 x 5 m plot area to ground level; (ii) medium shaded gap: by cutting the central tree within the plot to ground level, and pruning the six trees around the center of the plot to breast height; (iii) low shaded gap: by cutting the central

tree and the six trees around the center of plot to ground level and pruning the nine trees surrounding them to breast height.

Measurements of PAR under different shade plots

The canopy openings were initially classified by visual observation to give a range of openings and subsequently measured by a light sensor. 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). PAR of a shade opening was calculated as the ratio of PAR associated with a plot to an open area. The mean for each plot was calculated as a percentage mean over the eight-hour period of recording.

Attack by *H. robusta* under natural shade regimes

Attack by *H. robusta* on *S. macrophylla* seedlings was assessed 54 weeks after planting although damage was first observed 48 weeks after planting. Each individual tree was assessed for the presence of shoot-borer attack and subsequently the incidence (proportion of trees attacked in each treatment) of *H. robusta* attack was calculated. Assessments of attack were made by visual inspection of each plant, and counting the number of attack loci in each seedling (severity of attack) indicated by the presence of fresh frass. All attacks were assumed to be by *H. robusta*.

Description of shade houses

Data on recovery of form and height of *S. macrophylla* after simulated *H. robusta* damage were collected from the saplings planted in the shade houses. Nine shade houses, each 5 x 5 x 2.5 m were constructed and arranged in three blocks in an area of 45 x 45 m². The houses were constructed out of wooden frame treated with wood preservatives and each house covered with one of three thickness of shade cloth, giving light environments which ranged from 20–90 % full sun light. The three blocks were arranged in the experiment site, with each block having all three treatments (high, medium and low shade) randomly located within it. The high shade was provided by 1 cm² mesh coconut fibre and a layer of mosquito net covering whereas the medium shade was provided using 3 cm² mesh coconut fibre with a layer of mosquito net covering. Low shade houses were covered only with a single layer of mosquito netting, which was pale blue in colour. The roofs and sides of the shade houses were completely covered with netting.

Recovery of form and height under artificial shade

Two different methods were used to test the recovery of saplings. The first experiment between 1.4 - 1.6 m, of early flushing stage with un-expanded leaves and a single leading shoot, were cut 20 cm from ground using secateurs to simulate *H. robusta* damage. Particular care was taken to avoid splitting of bark during cutting. A total of 54 seedlings with six from each shade house were selected for the experiment. The plants were inspected once every three days for emergence of new shoots. Dominant shoot height and number of shoots produced were recorded 12 weeks after treatment.

Variation in pattern

A second experiment was carried out on 2nd of October 1998, 56 weeks after planting in the shade houses following the method of Rodgers *et al.* (1995). Saplings were selected within a height range of 1.5 - 2.3 m, root collar diameter between 3.0 - 4.0 cm, and a total number of leaves between 25- 30, with a single leading shoot. Twenty to thirty centimetre of the terminal-growing shoot including 4-6 leaves was removed using secateurs. A total of 27 saplings, including three from each shade house were selected for the study. Plants were inspected once every three days and the appearance of shoots was recorded. Eight weeks after cutting, the dominant shoot height and number of shoots produced were recorded.

Statistical analysis

Data were analysed by ANOVA to detect statistically significant differences in treatments and sites or blocks using SAS (1986). Because of some seedling mortality occurred over the extended period of the study, data on incidence and severity of damage were subjected to an unbalanced ANOVA, using the GLM procedure of SAS (Ray, 1982). Multiple comparisons among means of different light treatments were carried out using Duncan's multiple range test at $P \leq 0.05$. Graphs were plotted in Excel (V 7.0, 1997, Microsoft co-operation, USA). Data on proportion of attack were transferred into $\text{Arcsin } \sqrt{y}$ and severity of attack data were transformed into $\log(y+1)$ prior to analysis. Data on number of shoots after recovery were transformed to $\log(y+1)$ prior to analysis. Analyses used transformed data, where appropriate but the graphs were plotted with raw data.

RESULTS**PAR readings of plots under mature mahogany and *Acacia***

The PAR in the study plots under mature mahogany in sites 1 and 2 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 (d.f. = 2, $F = 129.1$, $P = 0.0001$).

Table 1

Mean percentage PAR under mature mahogany measured from 29/09/98 to 17/10/98 in site 1 and from 22/07/98 to 31/07/98 in site 2. Values are means \pm SE, n = 13; percentages were calculated in relation to PAR recorded in an open area nearby (Replicate is abbreviated as Rep).

Treatments	Site 1						Site 2	
	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 1	Rep 2
High shade	3.1 \pm 0.6	3.5 \pm 0.6	4.8 \pm 1.7	5.4 \pm 4.3	4.7 \pm 0.6	4.6 \pm 0.8	8.5 \pm 4.9	5.0 \pm 1.4
Medium shade	16.2 \pm 1.3	13.0 \pm 6.1	--	--	--	--	9.8 \pm 3.3	14.4 \pm 4
Low shade	41.0 \pm 9.8	37.1 \pm 29	--	--	--	--	78.4 \pm 11	51.5 \pm 11

Table 2 shows PAR in each shade treatment under *Acacia*. The mean percent PAR of high shade plots of the three sites ranged from 25.6 to 54.4, that in medium shade plots ranged from 42.3 to 56.0, and that under low shade ranged from 55.9 to 93.1 $\mu\text{mol m}^{-2}\text{s}^{-1}$. Significant effects of shade treatments were found on PAR (d.f. = 2, $F = 25.8$, $P = 0.005$; ANOVA).

Table 2
Mean percentage PAR of plots under *Acacia* measured from 22/07/98 to 27/08/98.
Values are means \pm SE, n = 12; percentages were calculated in relation to PAR recorded in an open area nearby.

Treatments	Site 1	Site 2	Site 3
High shade	25.6 \pm 2.9	21.6 \pm 1.1	54.4 \pm 12.1
Medium shade	43.4 \pm 3.8	42.3 \pm 0.6	56.0 \pm 7.0
Low shade	66.0 \pm 3.4	55.9 \pm 0.8	93.1 \pm 3.3

Incidence of damage

Attack by *H. robusta* under natural shade regimes was first observed when seedlings were 48 weeks old. Figures 1 and 2 show the mean incidence of attack under different shade treatments under mature mahogany and *Acacia*. The incidence of attack (proportion of trees attacked) in the low shade treatment was 76 % higher under mature mahogany and 31 % higher under *Acacia* than in high shade plots. Analysis of variance showed that the incidence of damage was significantly higher in the low shade treatments under mature mahogany (d.f. = 2, $F = 29.9$, $P < 0.0001$) and under *Acacia* (d.f. = 2, $F = 8.57$, $P = 0.0003$). The analyses also showed a significant difference in site effects of mature mahogany (d.f. = 1, $F = 35.72$, $P < 0.0001$) with overall attack higher in plots at site 2, but that at both sites attack under the low shade treatment was higher. No significant differences were observed between sites under *Acacia*.

Severity of damage

The severity of damage (number of attack entries per plant) in the low shade treatment was 69 times higher under mature mahogany and 112 times higher under *Acacia* than in high shade gaps. Figures 3 and 4 show the mean number of attack loci per plant under different shade treatments under mature mahogany and *Acacia*. Significant differences were observed between severity of attack between treatments under mature mahogany (d.f. = 2, $F = 28.46$, $P < 0.0001$) and under *Acacia* (d.f. = 2, $F = 12.54$, $P < 0.0001$). In addition, significant differences in site effects were recorded under mature mahogany (d.f. = 2, $F = 18.84$, $P < 0.0001$) with overall attack higher in plots at site 2, but at both sites severity of attack under the low shade treatment was higher. No significant differences were observed between sites under *Acacia*.

Variation in pattern

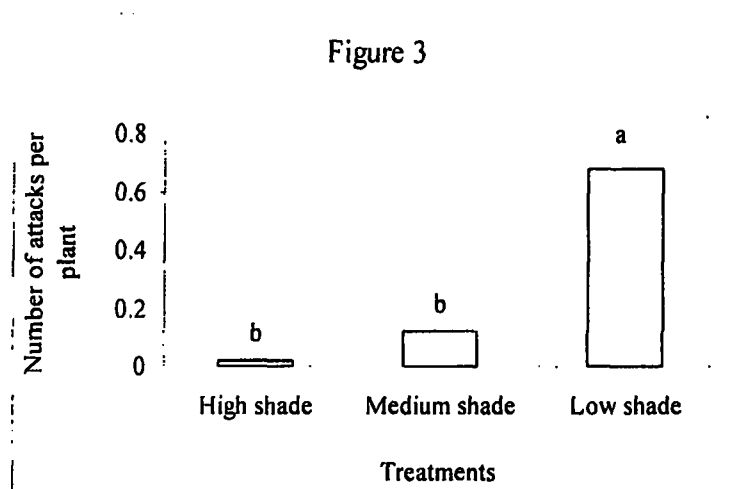


Figure 1. The effect of natural shade on proportion of attack by *H. robusta* on *S macrophylla* shoots at 2 sites under mature mahogany plantations. Measurements were taken 54 weeks after planting. Values presented are treatment means produced by ANOVA; DNMRT, $n=76$ (high shade), $n=52$ (medium shade) and $n=64$ (low shade). Analysis was done on Arcsin \sqrt{Y} transformed data. Treatments with the same letter are not significantly different from each other (at $P<0.05$).

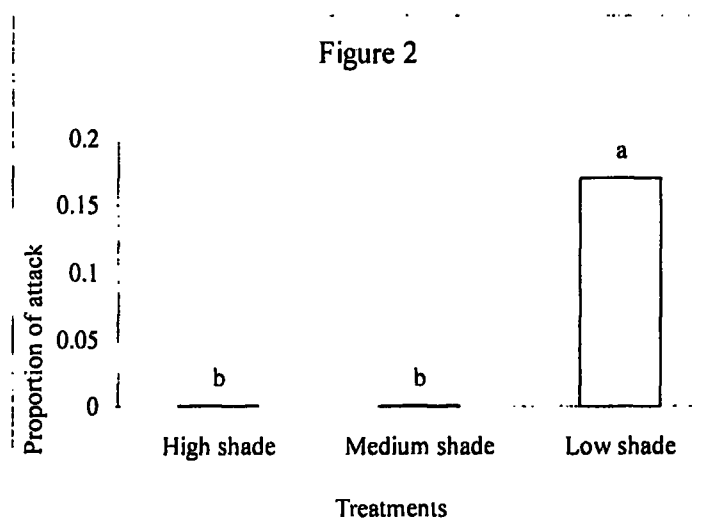


Figure 2. The effect of natural shade on proportion of attack by *H. robusta* on *S macrophylla* shoots at 3 sites under *Acacia auriculiformis* plantations. Measurements were taken 54 weeks after planting. Values presented are treatment means produced by ANOVA; DNMRT, $n=41$ (high shade), $n=48$ (medium shade) and $n=41$ (low shade). Analysis was done on Arcsin \sqrt{Y} transformed data. Treatments with the same letter are not significantly different from each other (at $P<0.05$).

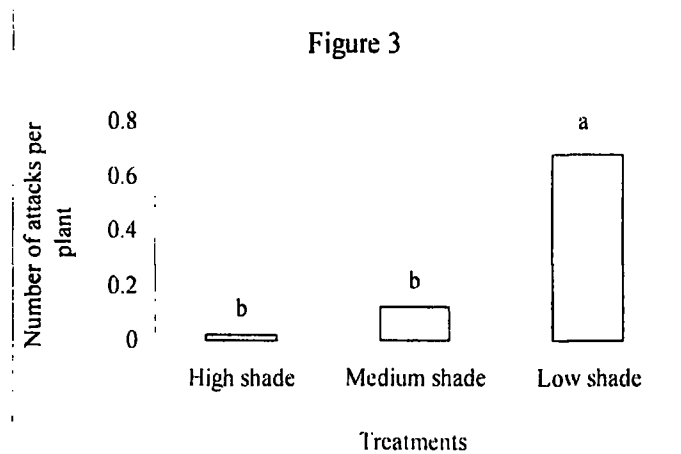


Figure 3. The effect of natural shade on number of attack per plant by *H. robusta* on *S macrophylla* shoots at 2 sites under mature mahogany plantations. Measurements were taken 54 weeks after planting. Values presented are treatment means produced by ANOVA; DNMRT, n=76 (high shade), n=52 (medium shade) and n=64 (low shade). Analysis was done on Log (Y+1) transformed data. Treatments with the same letter are not significantly different from each other (at P<0.05).

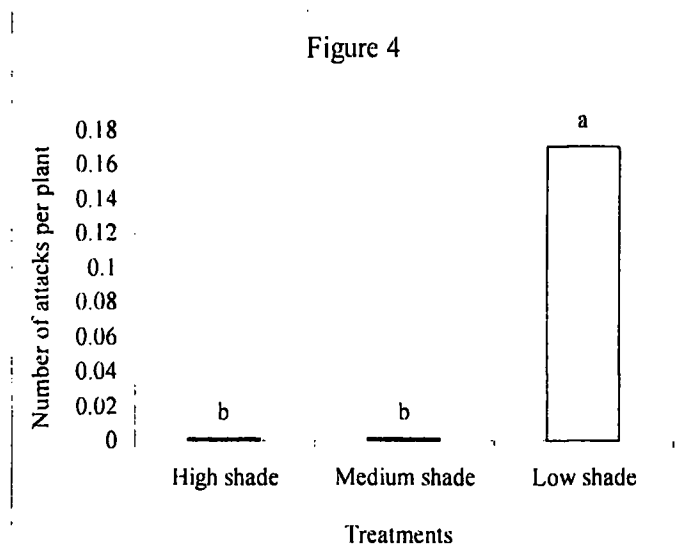


Figure 4. The effect of natural shade on number of attack per plant by *H. robusta* on *S macrophylla* shoots at 3 sites under *Acacia auriculiformis* plantations. Measurements were taken 54 weeks after planting. Values presented are treatment means produced by ANOVA; DNMRT, n=41 (high shade), n=48 (medium shade) and n=41 (low shade). Analysis was done on Log (Y+1) transformed data. Treatments with the same letter are not significantly different from each other (at P<0.05).

Number of shoots recovered

In the first experiment, when attack was simulated by cutting the stem 20 cm from ground, the plants started to re-flush 2-3 weeks after stem removal. Post-treatment mortality of seedlings was very low (1.8 %) four weeks after treatment. Analysis of variance showed significant differences in number of shoots produced under the different shade treatments (d.f. =2, $F = 4.51$, $P = 0.01$) with a higher number of shoots produced under the low shade treatment than the high shade and medium shade treatments (Figure 5). No significant block effects were observed (Table 3).

Table 3

The effect of artificial shade on mean number of new shoots \pm SE of *S. macrophylla* seedlings produced after simulated damage of *H. robusta* (cutting the stem 20 cm from ground) under artificial shade houses. Data were collected 12 weeks after treatment.

Treatments	Number of shoots produced \pm SE		
	Block 1	Block 2	Block 3
High shade	5.3 \pm 0.4	5.4 \pm 0.7	5.3 \pm 1.0
Medium shade	5.4 \pm 0.7	7.0 \pm 0.8	6.0 \pm 1.0
Low shade	8.3 \pm 2.2	7.5 \pm 1.2	12.2 \pm 3.4

In the second experiment where the top 20-30 cm of the stem was removed, saplings started to re-flush 3 weeks following simulated attack. However, no significant effects of shade treatments (d.f. =2, $F = 0.77$, $P > 0.05$; ANOVA) on number of shoots were observed (Figure 6), nor were any significant block effects observed.

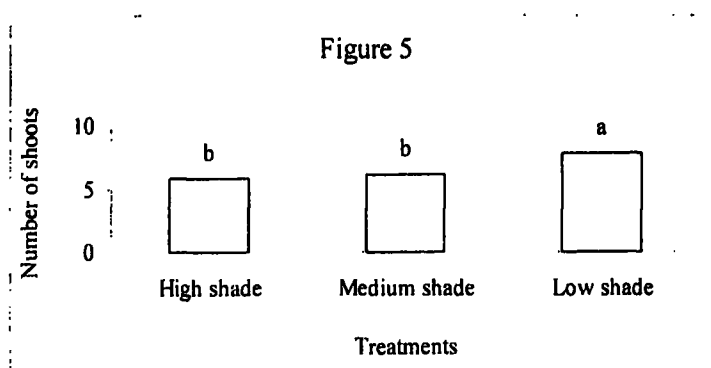


Figure 5. The effect of artificial shade on number of new shoots produced by *S. macrophylla* plants after simulated damage of *H. robusta* (cutting the seedling stem 20 cm from ground) in the shade houses. Data were collected 12 weeks after treatment. Values presented are treatment means produced by ANOVA; DNMRT, $n=18$. Analysis was done on Log ($Y+1$) transformed data. Treatments with the same letter are not significantly different from each other (at $P < 0.05$).

Figure 6

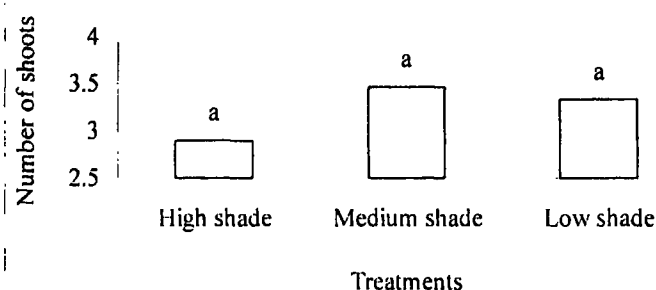


Figure 6. The effect of artificial shade on number of new shoots produced by *S macrophylla* plants after simulated damage of *H. robusta* (cutting the stem 20-30 cm from the tip of the shoot) in the shade houses. Data were collected 8 weeks after treatment. Values presented are treatment means produced by ANOVA; DNMRT, n=18. Analysis was done on Log (Y+1) transformed data. Treatments with the same letter are not significantly different from each other (at $P < 0.05$).

Dominant shoot height following recovery

The dominant shoot height in the first recovery experiment showed no significant difference between the shade treatments (d.f. = 2, $F = 1.62$, $P > 0.05$; ANOVA) or blocks. However, Duncan's multiple range test for mean separation indicated that significantly taller shoots were produced under the low shade treatment (Figure 7). In the second experiment, shade treatments (d.f. = 2, $F = 0.6$, $P > 0.05$, ANOVA; Figure 8) or blocks for dominant shoot height were not significantly different.

Figure 7

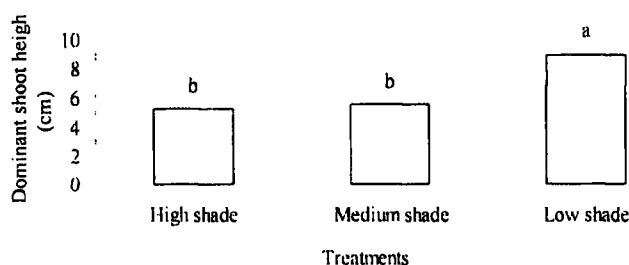


Figure 7. The effect of artificial shade on dominant shoot height produced by *S macrophylla* plants after simulated damage of *H. robusta* (cutting the seedling stem 20 cm from ground) in the shade houses. Data were collected 12 weeks after treatment. Values presented are treatment means produced by ANOVA; DNMRT, n=18. Treatments with the same letter are not significantly different from each other (at $P < 0.05$).

Variation in pattern

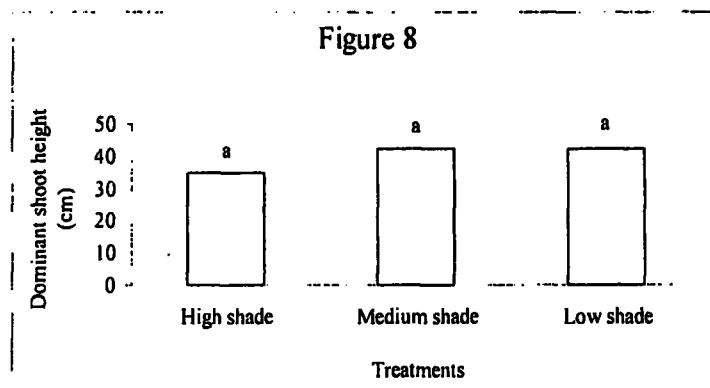


Figure 8. The effect of artificial shade on dominant shoot height produced by *S. macrophylla* plants after simulated damage of *H. robusta* (cutting the stem 20-30 cm from the tip of the shoot) in the shade houses. Data were collected 8 weeks after treatment. Values presented are treatment means produced by ANOVA; DNMRT, $n=18$. Treatments with the same letter are not significantly different from each other (at $P<0.05$).

DISCUSSION

Attack by *H. robusta* commenced at 48 weeks after planting when the mean height of plants was approximately 0.8 m for damaged seedlings under natural shade regimes. Other recorded information shows that attacks commence on seedlings of vigorous growth when they are as young as 12 weeks old and less than 0.3 m high (Beeson, 1941). However, the current results closely support those of Newton *et al.* (1998) who recorded first attack after 50 weeks in field-grown *S. macrophylla* at a height range of 1.1-1.3 m (Newton *et al.*, 1999).

Results in this study indicate that a higher incidence of attack was observed under the low shade treatment. Information gained from work described by other authors (Grijpma and Gara, 1970; Howard, 1991; Yamazaki *et al.*, 1992; Newton *et al.*, 1998) are also consistent with the observations of higher incidence of attack in seedlings with new shoots, fresh foliage and taller stems. This suggests those open-grown trees with new growth and longer shoots are more readily infested than shaded seedlings.

The distribution of number of attack entries per plant indicates clearly that saplings vary in the number of attacks received under shade treatments. The mean number of attacks per sapling varied from 0 (high shade) to 1.1 (low shade) and was significantly higher under the low shade treatment. The increased number of shoots produced under low shade may provide an increased number of susceptible sites for attack (Newton, *et al.*, 1998). In addition, variation in the number of attacks received may reflect variation in production of chemical attractants emitted in open-grown plants (Grijpma, 1975).

Many authors have suggested that light conditions, which promote attack also, may enable trees to recover from attack caused by *Hypsipyla* spp. (Grijpma, 1975; Vega, 1976; Mayhew and Newton, 1998). However, the influence of shade on this characteristic has not previously been investigated. Reserve carbohydrates in the lower boles and roots of many plants may serve as a resource, which is mobilised in order to support shoot re-growth after pruning and defoliation (Mika, 1986; Rodgers *et al.*, 1995) and re-sprouting after fire (Pate *et al.*, 1990). Rodgers *et al.* (1995) suggested that carbohydrate reserves in the roots of *Cedrela odorata* (L.) were mobilised in order to recover height increment following *Hypsipyla grandella* (Zeller) attack.

Branch formation in plants after decapitation or pruning is controlled by apical dominance, involving the regulation of axillary bud formation (Newton *et al.*, 1995). The expression of apical dominance has been found to be influenced by a range of environmental factors such as photoperiod, light and humidity (Ladipo *et al.*, 1992). McNaughton (1983) reported that re-growth in severely damaged trees was facilitated by improved environmental conditions around the tree following shoot removal, such as increased light and water availability. Jaremo *et al.* (1996) also suggested that under light-limited conditions, plants generally benefit from having fewer active primary shoots following artificial clipping. The current results suggest that the number of shoots produced 12 weeks after treatment (stem cut 20 cm from ground) was significantly higher under low shade. Under high light availability breakdown of apical dominance could be taking place, which may lead, to production of a higher number of shoots under low shade. In addition, the higher number of shoots under low shade may reflect a higher amount of carbohydrate reserves in the plant under the higher light environment.

In summary, these results indicate that plants grown under open conditions are more vulnerable to attack, which may result from increased suitability of light-grown plants for the growth and development of the insect. The results also suggest that light availability may influence the ability of *S. macrophylla* to recover after shoot-borer attack. Production of fewer shoots under high shade would provide fewer shoots for subsequent attack and also suggest the more rapid re-imposition of apical dominance, which would encourage strong vertical growth of the leading shoot.

ACKNOWLEDGEMENTS

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.

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