EFFECTS OF TWO DIFFERENT GROWTH REGULATORS ON THE GROWTH AND WATER RELATIONS OF *ACACIA MANGIUM* SEEDLINGS

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SHEIKH ALI ABOD & YAP, S.W. 1994. Effects of two different growth regulators on the growth and water relations of *Acacia mangium* seedlings. *Acacia mangium* seedlings overgrow in size when the timing between plant production and field planting cannot be synchronized. Survival and growth of these overgrown seedlings are reported to be poor because of unfavourable root to shoot ratio resulting in desiccation during post-transplanting. This study compares the effectiveness of two different growth regulators, namely, paclobutrazol and daminozide, for controlling the growth and water relations of *A. mangium* seedlings with the objective of improving their post-transplanting establishment. Fourteen-week-old potted *A. mangium* seedlings were foliar sprayed with paclobutrazol or daminozide at concentrations of 0, 25, 50, 75, 100, 150 and 200 $mg\,l^{-1}$. Plants were measured for height and leaf area increments, transpiration and stomatal conductance at weekly intervals. They were harvested after 12 weeks for measurements of height, leaf area, number of branches, total root length, root and shoot dry weights and the ratios of total root length to leaf area and root to shoot dry weight. Both paclobutrazol and daminozide reduced root and shoot growth, root to shoot ratio, transpiration and stomatal conductance of *A. mangium* seedlings. The effects of the chemicals increased with increasing concentration from 25 to 200$mg\,l^{-1}$. Weekly measurements of height and leaf area increments, transpiration and stomatal conductance revealed that the differences in values of treated plants compared to the control generally increased with time. Paclobutrazol was more potent than daminozide in affecting seedling growth and water relations, and the two chemicals differed in their effects. The results are discussed with implications for practical application.

Key words: *Acacia mangium* - planting stock - transpiration - growth control

SHEIKH ALI ABOD & YAP, S.W. 1994. Kesan dua pengatur tumbesaran yang berlainan ke atas tumbesaran dan kaitan air anak benih *Acacia mangium*. Anak benih *Acacia mangium* membesar berlebihan apabila pengaturan masa antara pengeluaran pokok dan penanaman di ladang tidak boleh diselaraskan. Survival dan pertumbuhan anakbenih yang telah membesar berlebihan dilaporkan tidak baik kerana pengeringan semasa pengalihan akibat daripada nisbah akar dengan pucuk yang tidak elok. Kajian ini membandingkan keberkesanan dua pengatur tumbesaran yang berlainan iaitu paklobutrazol dan daminozid untuk mengatur tumbesaran dan kaitan air anak benih *A. mangium* dengan objektif untuk memperbaiki kehidupan anak-anak benih tersebut selepas pengalihan. Anak benih *A. mangium* yang ditanam di dalam tabung dan berumur 14 minggu diberikan semburan daun dengan

paklobutrazol atau daminozid pada kepekatan 0,25,50,75,100,150 dan 200 *mg* l^{-1}. Pertambahan dalam ketinggian dan luas daun serta transpirasi dan konduksian stomata diukur setiap minggu. Pokok-pokok dituai selepas 12 minggu untuk pengukuran ketinggian, keluasan daun, bilangan cabang, jumlah panjang akar, berat kering akar dan pucuk serta nisbah jumlah panjang akar dengan keluasan daun dan nisbah berat kering akar dengan nisbah berat kering pucuk. Kedua-dua paklobutrazol dan daminozid mengurangkan tumbesaran akar dan pucuk, nisbah akar dengan pucuk, transpirasi dan konduksian stomata anak-anak benih *A. mangium*. Kesan kimia-kimia tersebut bertambah dari kepekatan 25 ke 200*mg* l^{-1}. Pengukuran pertambahan ketinggian dan keluasan daun, transpirasi dan konduksian stomata yang dibuat setiap minggu menunjukkan bahawa perbezaan pada nilai pokok-pokok yang dirawat berbanding dengan kawalan, pada amnya, meningkat dengan masa. Paklobutrazol lebih berkesan daripada daminozid dalam mempengaruhi tumbesaran dan kaitan air anak benih dan kesan kedua-dua kimia itu berbeza. Keputusan-keputusan yang dibincangkan mengambilkira implikasi-implikasi untuk kegunaan praktikal.

Introduction

Acacia mangium Willd. is the principal species planted by the Departments of Forestry for plantation establishment in Malaysia. This is mainly because of its rapid growth rate which has been recorded to have a mean annual increment exceeding 30 m^3 ha^{-1} (Johari & Chin 1986). In the nursery, however, excessive growth of *A. mangium* is a liability if transplanting in the field is delayed. Overgrown seedlings have poor survival because of unfavourable root to shoot ratio, resulting in desiccation during post-transplanting (Abod & Abun 1991).

Researchers have sought reliable, effective and safe methods of controlling shoot growth of tree species using chemical growth retardants. Paclobutrazol (cultar) and daminozide (alar) are two common growth regulators which inhibit endogenous gibberelin biosynthesis and thereby control excessive growth of plants. Daminozide was introduced as a plant growth retardant by Riddell *et al.* (1962) and has since been used extensively for controlling excessive tree size in the nursery (Stahly & Williams 1967). Paclobutrazol is relatively new but was found to be very effective in retarding the height growth of *A. mangium* seedlings when applied as foliar sprays (Abod & Jeng 1993) at concentrations greater than 250 $mg\,l^{-1}$ (Abod & Leong 1993). There was, however, no complete recovery in growth of the *A. mangium* seedlings even at the lowest concentration of 250 $mg\,l^{-1}$ tested 12 weeks after treatment (Abod & Leong 1993).

The present study is a continuation of the earlier works of Abod and co-workers (Abod & Abun 1991, Abod & Jeng 1993, Abod & Leong 1993) to develop guidelines for treatment chemicals and concentrations to control the growth of *A. mangium* seedlings.

Materials and methods

Three hundred and twenty-five uniform-sized *A. mangium* seedlings, 14 weeks old and averaging 45 *cm* high were supplied by the Negri Sembilan Department of

Forestry nursery at Mantin for the experiment. The seeds originated from seed stands near Jalan Sikamat, Negri Sembilan. Plants were grown in a mixture of 7:3:2 soil, sand and peat mixed with triple superphosphate fertilizer.

Paclobutrazol (PP333) was supplied by Imperial Chemical Industries (ICI) in a aqueous suspension at a concentration of 250 $g\ l^{-1}$ with an active ingredient of 22.0% ww^{-1}. Its trade name is cultar and chemical formula (2 RS, 3 RS)-l-(4-chlorophenyl)-4, 4-dimethyl-2 (1H-1, 2, 4 triazol-l-yl) pentan-3-ol).

Daminozide (B-9) was supplied in a powder form with an active ingredient of 85.0 % ww^{-1}. It is manufactured by Uniroyal Chemical Inc. Middlebury, CT 067 49, USA. Its trade name is alar and chemical formula N-dimethylamino succinamic acid (IUPAC) butanedioic acid mono (2, 2-dimethyl-hydrazide) (CA) succinic acid 2, 2-dimethylhydrazide.

The chemicals were diluted in distilled water to give concentrations of 25, 50, 75, 100, 150 and 200 $mg\ l^{-1}$. A surfactant was added at a concentration of 2.0 $ml\ l^{-1}$. The aerial parts of plants were sprayed to runoff using a hand-held pressure sprayer. Some of the chemicals were inevitably also deposited in the potting medium.

There were 25 replicates per treatment totaling 325 plants, *i.e.*, control and six concentrations of paclobutrazol and daminozide respectively. Increments in height (*i.e.*, length of the main stem from the soil surface to the shoot apex), leaf area and measurements of transpiration and stomatal conductance were observed at weekly intervals until harvest 12 weeks after treatment. Five plants were selected randomly from each treatment for measurements of transpiration and stomatal conductance in the open by a Li-Cor steady state porometer. The porometer is similar to that described by Jones and Norton (1979) which measures the difference in relative humidity between inlet (maintained at zero) and outlet air flowing at a constant rate (2.5 $ml\ s^{-1}$) through a chamber enclosing a 1.76 cm^2 of leaf surface.

Transpiration ($\mu g\ cm^{-2}\ s^{-1}$) and stomatal conductance ($cm\ s^{-1}$, on the abaxial side of leaf) were measured on one fully matured leaf, unshaded and at the mid-position of the main stem between 1200 and 1400 *h* with the plant's soil moisture condition at field capacity.

Plants were harvested 12 weeks after treatment and measurements taken of height, root collar diameter and leaf area, number of new branches, total root length and root and shoot oven dry weights. Roots were washed over a sieve of mesh pore size less than 1.0 *mm* square using pressurized water supply. Total root length was measured by a Comair root length scanner (Abod & Webster 1989). Leaf area was measured by a Li-Cor 3100 portable leaf area meter.

The experiment followed a completely randomized design. All data were subjected to analysis of variance to determine differences between treatment means.

Results

Effects on growth

Results in Table 1 showed that *Acacia mangium* seedlings foliar sprayed with either paclobutrazol or daminozide had lower height, diameter and leaf area increments, total root length, total root dry weight and the ratio of root length to leaf area 12 weeks after treatment. The effects of the chemicals increased with increasing concentrations. Total shoot dry weight and the ratio of root to shoot dry weights were not significantly affected. Branching was decreased by paclobutrazol at all chemical concentrations compared to control plants. On the other hand, daminozide reduced branching at concentrations of 25 to 100 $mg\ l^{-1}$ but increased it to nearly three times more branches at 150 and 200 $mg\ l^{-1}$.

Daminozide appeared more potent than paclobutrazol in retarding the height and diameter increments. The converse was true for total root length and total root dry weight. Plants treated with daminozide generally had greater root length to leaf area ratio compared to similar concentrations of paclobutrazol.

Plants treated with either paclobutrazol or daminozide displayed similar patterns of response for increments in height (Figures 1a & 1b) and leaf area (Figures 2a & 2b). All concentrations of paclobutrazol were effective in significantly reducing the height increment from weeks 1 to 10 (Figure 1a). However, plants treated with the lowest concentration at 25 $mg\ l^{-1}$ had fully recovered by the 11th week. In contrast, low concentrations of daminozide, *i.e.*, less than 100 $mg\ l^{-1}$ did not appear to be effective in significantly reducing the height increment of *A. mangium* (Figure 1b).

The effect of paclobutrazol on leaf area increment was not statistically significant until the 11th and 12th weeks where values of treated plants were less than the control at concentrations of 100, 150 and 200 $mg\ l^{-1}$ (Figure 2a). A similar pattern of response to chemical spray was also displayed for daminozide. Differences between the leaf area increment of daminozide treated plants were, however, significantly less than for the control beginning on the 10th week after treatment at concentrations of 150 and 200 mg l^{-1} (Figure 2b). At 12 weeks after treatment, differences between the control and treated were also statistically significant for daminozide concentration of 100 $mg\ l^{-1}$ (Table 1 & Figure 2b).

Paclobutrazol significantly reduced total root length of treated plants by 15.2, 25.5, 34.5, 44.3, 49.6 and 60.7% at the concentrations of 25, 50, 75, 100, 150 and 200 $mg\ l^{-1}$ respectively 12 weeks after treatment. Differences between treatment means were statistically significant at all levels of concentration (Table 1).

Similarly daminozide reduced total root length by 12.0, 14.9, 17.9, 26.9, 35.1 and 46.3% at concentrations of 25, 50, 75, 100, 150 and 200 $mg\ l^{-1}$ respectively 12 weeks after treatment (Table 1). Paclobutrazol caused a greater reduction in root length than daminozide at equivalent concentrations of chemicals.

Increasing the concentrations of paclobutrazol from 25 to 200 $mg\ l^{-1}$ caused a corresponding increase in root length: leaf area ratio. Differences with control plants were statistically significant at paclobutrazol concentration of 50 $mg\ l^{-1}$ or greater. There was no clear pattern for daminozide.

Table 1. Effects of paclobutrazol or daminozide on the growth of *Acacia mangium* seedling 12 weeks after treatment

Treatment	Concentration ($mg\ l^{-1}$)	Height increment (cm)	Diameter increment (cm)	Number of new branches	Leaf area increment (cm^2)	Total root length (m)	Total root dry weight (g)	Total shoot dry weight (g)	ln Total root length (cm) / Total leaf area (cm^2)	ln Total root dry weight (g) / Total shoot dry weight (g)
Control	0	24.2	0.27	4.7	433.2	75.0	6.5	28.72	2.85 (17.32)	-1.48 (0.22)
Paclobutrazol	25	25.5	0.25	4.6	403.9	63.6	6.21	27.77	2.75 (15.75)	-1.49 (0.22)
	50	22.1	0.24	4.6	403.1	55.9	6.17	27.41	2.63 (13.87)	-1.49 (0.22)
	75	19.8	0.25	4.4	390.8	49.1	6.12	26.19	2.53 (12.57)	-1.45 (0.23)
	100	19.6	0.23	3.9	319.7	41.8	6.06	25.40	2.57 (13.07)	-1.43 (0.23)
	150	18.7	0.23	3.6	301.2	37.8	6.02	23.59	2.53 (12.57)	-1.36 (0.25)
	200	18.2	0.22	3.0	283.8	29.5	5.96	22.63	2.34 (10.40)	-1.33 (0.26)
Daminozide	25	22.1	0.27	2.9	423.7	66.0	7.04	27.84	2.74 (15.58)	-1.37 (0.25)
	50	20.1	0.22	2.9	413.4	63.8	7.00	27.43	2.73 (15.45)	-1.36 (0.25)
	75	19.7	0.21	2.7	399.6	61.6	6.93	27.24	2.73 (15.42)	-1.36 (0.25)
	100	18.9	0.20	2.7	338.6	54.8	6.61	26.64	2.78 (16.21)	-1.39 (0.24)
	150	12.2	0.19	7.2	305.9	48.7	6.34	25.14	2.76 (15.91)	-1.37 (0.25)
	200	9.9	0.16	7.3	288.4	40.3	5.64	23.82	2.63 (13.99)	-1.44 (0.23)
sed		0.24	0.004	0.09	16.23	2.45	0.446	0.462	0.070	0.062
		***	***	**	***	***	*	ns	***	ns

Error df = 32; *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; ns = not significant;
Bracketed means are retransformed values; sed is standard error difference.

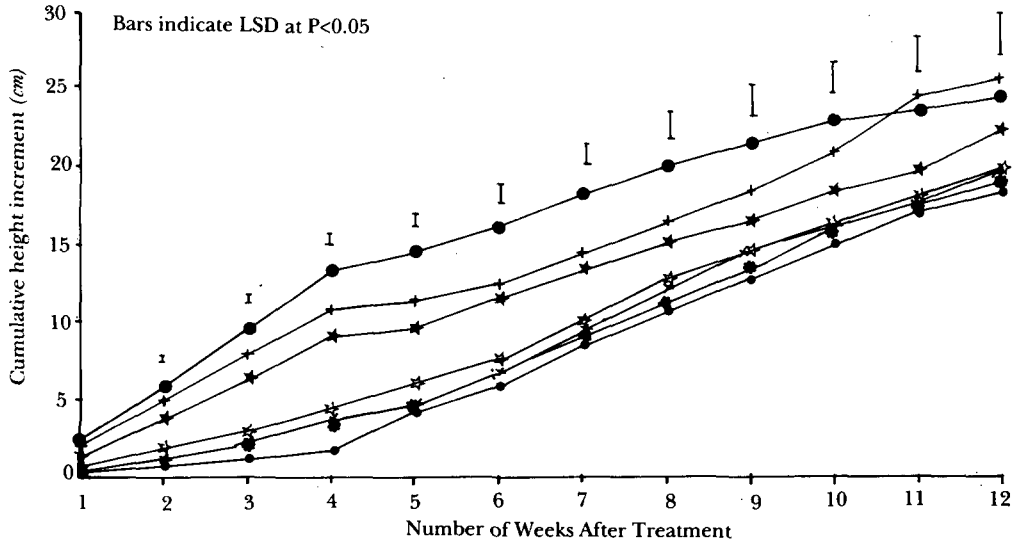
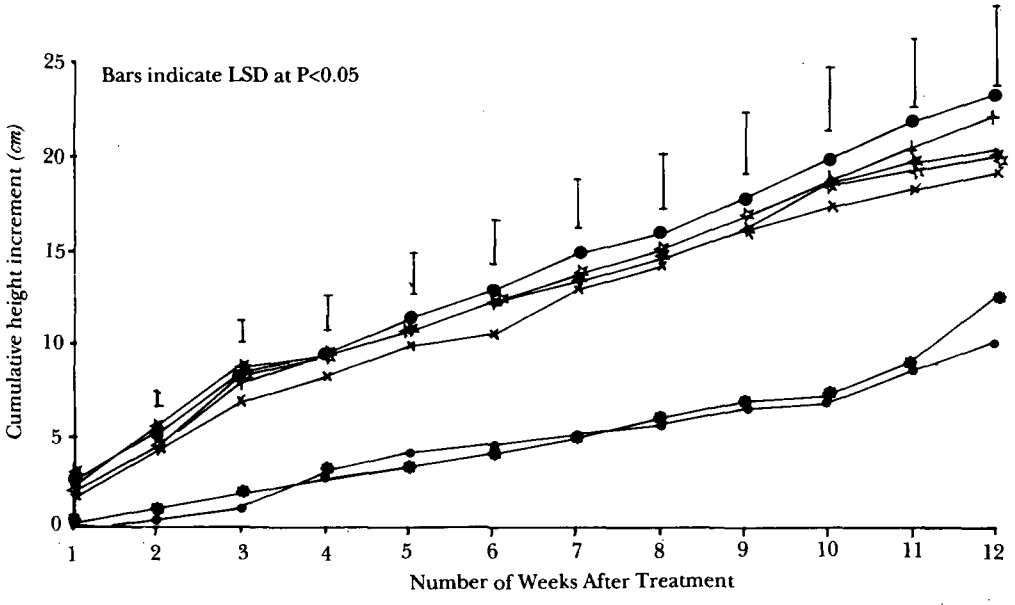


Figure 1a. Effect of paclobutrazol on the height increment of *Acacia mangium* seedlings



• 0 $mg\ l^{-1}$ + 25 $mg\ l^{-1}$ * 50 $mg\ l^{-1}$
x 100 $mg\ l^{-1}$ * 150 $mg\ l^{-1}$. 200 $mg\ l^{-1}$

Figure 1b. Effect of daminozide on the height increment of *Acacia mangium* seedlings

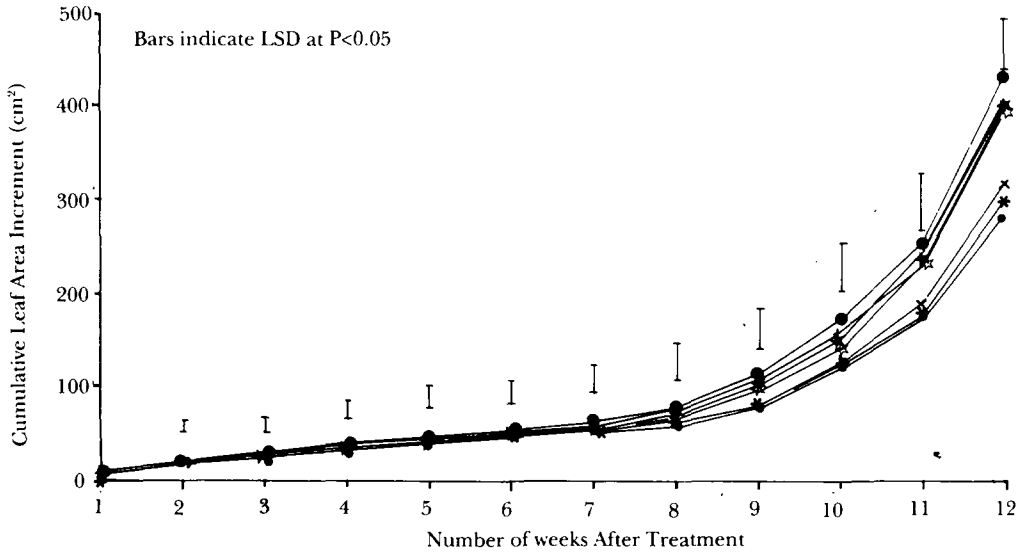


Figure 2a. Effect of paclobutrazol on the leaf area increment of *Acacia mangium* seedlings

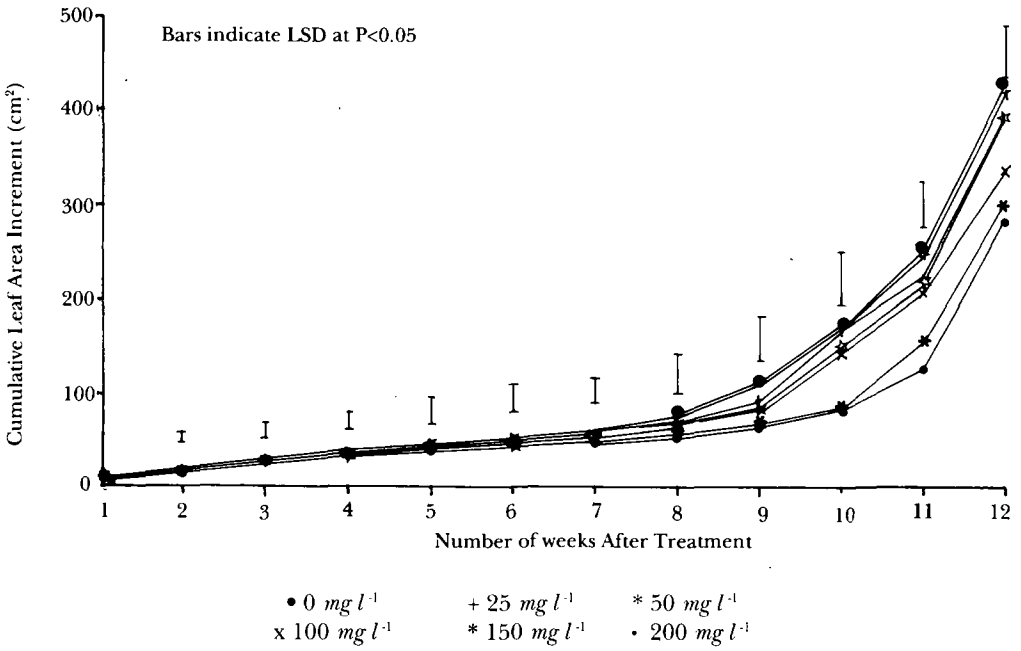


Figure 2b. Effect of daminozide on the leaf area increment of *Acacia mangium* seedlings

Effects on water relations

In general control plants had higher rates of transpiration than those treated with either paclobutrazol or daminozide at all times of measurement (Figures 3a & 3b). Paclobutrazol was generally more effective than daminozide in reducing transpiration. For example, compared to the control, the reductions on transpiration by paclobutrazol 12 weeks after treatment were 23.0, 36.9, 45.4, 45.4 and 47.5% at concentrations 50, 75, 100, 150 and 200 $mg\,l^{-1}$ chemical. Reductions by daminozide were 10.5, 13.9, 13.9, 14.2, 19.3 and 20.6% at concentrations of 25, 50, 75, 100, 150 and 200 $mg\,l^{-1}$ respectively.

No recovery in transpiration was evident at any of the daminozide concentrations tested 12 weeks after treatment (Figure 3b). Differences with the control plants were statistically significant even at the lowest daminozide concentration of 25 $mg\,l^{-1}$. In contrast, the transpiration of plants treated with 25 $mg\,l^{-1}$ of paclobutrazol was higher than the control at week 10 onwards indicating a full recovery (Figure 3a).

The patterns of response for transpiration (Figures 3a & 3b) are well correlated with stomatal conductance (Figures 4a & 4b). Like transpiration, control plants generally had greater stomatal conductance than when treated with either paclobutrazol (Figure 4a) or daminozide (Figure 4b) at all times of measurement. Paclobutrazol reduced stomatal conductance more than daminozide at equivalent concentration of chemicals. Twelve weeks after treatment, paclobutrazol reduced stomatal conductance by 10.1, 17.1, 24.8, 40.3 and 58.9% at concentrations of 50, 75, 100, 150 and 200 $mg\,l^{-1}$ respectively. Reductions by daminozide were 10.2, 13.6, 30.5, 31.1, 37.9 and 40.1% at concentrations of 25, 50, 75, 100, 150 and 200 $mg\,l^{-1}$ respectively. Differences with the control were statistically significant even at the lowest daminozide concentration of 25 $mg\,l^{-1}$, 12 weeks after treatment (Figure 4b). In contrast, the stomatal conductance of plants treated with 25 $mg\,l^{-1}$ of paclobutrazol had recovered to higher levels than the control on the 10th week after treatment (Figure 4a).

Discussion

Both paclobutrazol and daminozide reduced root and shoot growth, transpiration and stomatal conductance of *A. mangium* seedlings. The effect of the chemicals increased from 25 to 200 $mg\,l^{-1}$ concentrations tested. Weekly measurements of height and leaf area increments, transpiration and stomatal conductance revealed that differences in values of treated plants compared to the control generally increased with time.

In general, paclobutrazol was more potent than daminozide in affecting the growth and water relation of *A. mangium* seedlings. However, the two chemicals differed in their modifications of growth and water relations. Plants sprayed with

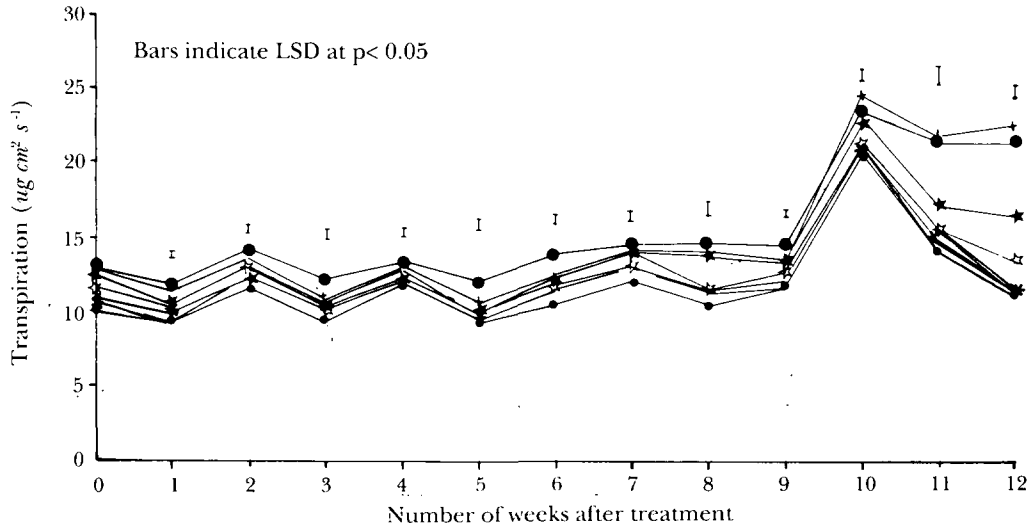


Figure 3a. Effect of paclobutrazol on the transpiration of *Acacia mangium* seedlings

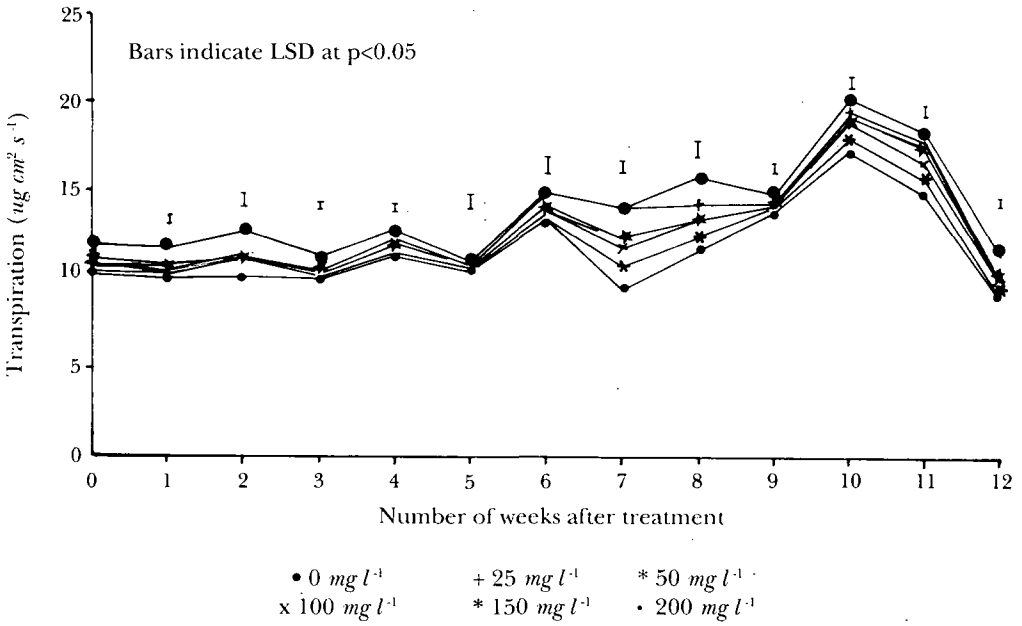


Figure 3b. Effect of daminozide on the transpiration of *Acacia mangium* seedlings

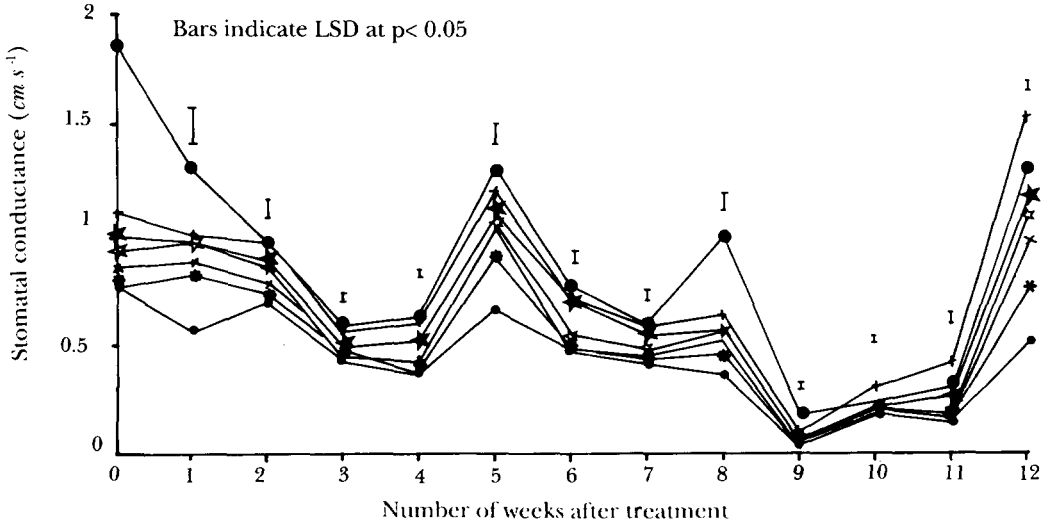


Figure 4a. Effect of paclobutrazol on the stomatal conductance of *Acacia mangium* seedlings

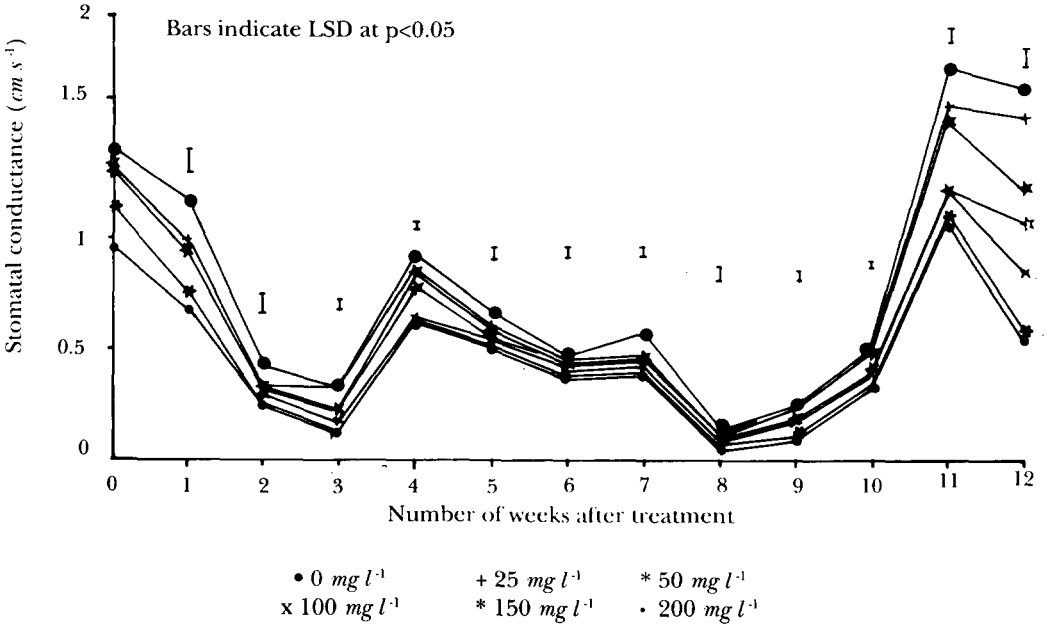


Figure 4b. Effect of daminozide on the stomatal conductance of *Acacia mangium* seedlings

paclobutrazol at 25 *mg* l^{-1} reduced height growth significantly in the first week after treatment and recovered on the eleventh week (Figure 1a). Low concentrations of daminozide, *i.e.*, 25 to 100 *mg* l^{-1} were not effective in significantly reducing the height growth (Figure 1b). Nickell (1983) recommended concentrations greater than 500 *mg* l^{-1} daminozide to achieve effective growth retardation of plants. Batjer *et al.* (1964) found daminozide to require two weeks after treatment before its effect on shoot growth of fruit trees became apparent.

Paclobutrazol but not daminozide consistently reduced branching . Daminozide reduced branching at concentrations of 25 to 100 *mg* l^{-1} but increased it to nearly three times more at 150 and 200 *mg* l^{-1}. The chemical was also reported to increase branching at higher concentrations when tested on pears (Brooks 1964), apples (Williams 1972) and a flowering plant *Meliotus parvifolia* (Mohan & Yadava 1985). Paclobutrazol was not found to induce branching of *A. mangium* even at a high concentration of 12000 *mg* l^{-1} (Abod & Jeng 1993).

Plants treated with either paclobutrazol or daminozide displayed similar patterns of response in leaf area increment. Reduction in growth was gradual and minimal until the tenth week (Figures 2a & 2b). This may explain why differences in the total shoot dry weight were not statically significant between treatments at harvest, 12 weeks after the foliar-spray of either chemicals.

Both paclobutrazol and daminozide reduced the total root length of *A. mangium*. The root tips of paclobutrazol treated plants were observed to be thicker than those of plants treated with daminozide. Roots of daminozide treated plants were more fibrous and the total root length was generally longer than those treated with similar concentrations of paclobutrazol.

Increases in root: shoot ratios stimulated by plant growth retardant treatment should, in theory, also improve plant water relations and increase tolerance to drought (Turner & Begg 1981). Abod and Webster (1989) claimed that plants with a high root length to leaf area ratio have a greater chance to survive following transplanting. The ratio of total root length to leaf area ratio of *A. mangium* seedlings in the present study was, however, lower than the control at the range of concentrations tested for either chemicals. Higher concentrations of paclobutrazol (*i.e.*, > 250 *mg* l^{-1}) were found to increase the ratio significantly in *A. mangium* (Abod & Jeng 1992, Abod & Leong 1993).

The ratio of root to shoot dry weight was, however, not significantly affected by either chemicals indicating that dry matter partitioning was not significantly affected at harvest, 12 weeks after treatment.

Both chemicals reduced the seedlings rate of transpiration. The reduction correlated well with reduced stomatal activity and to a lesser extent with leaf area. Paclobutrazol (Atkinson & Chauhan, 1987, Abod & Webster 1991a,b) and daminozide (Cathy 1964, Martin & Williams, 1966) generally reduce water use in plants. Paclobutrazol appeared to be more effective, however, as evidenced by the lower rates of transpiration recorded in the present study.

Paclobutrazol was relatively more effective than daminozide in controlling the growth and water relations of *A. mangium* seedlings. Although the cost of foliar spraying one seedling to runoff at a concentration of 25 *mg* l^{-1} was calculated to

be 0.032 cents for paclobutrazol compared to 0.016 cents for daminozide, the former chemical is relatively cheaper at the effective rate. It is imperative that very low concentration (< 25 $mg\,l^{-1}$) of paclobutrazol is used in the nursery to retard growth to ensure a fast post-transplanting recovery. Further research is warranted to develop guidelines for paclobutrazol concentration, frequency of application and implications to the production and establishment of *A. mangium* seedlings.

Conclusion

Paclobutrazol was found to be relatively more effective than daminozide in controlling the growth and water relations of *Acacia mangium* seedlings. The chemical is also cheaper at the effective rate. The lowest concentration tested at 25 $mg\,l^{-1}$ paclobutrazol appeared to be the most suitable since it also ensures an earlier recovery. However, further research is recommended for practical application.

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