

Is shade important in rubber based cropping systems? Part 1. Effect of shade on growth, dry matter partitioning and adaptation of rubber and banana

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Abstract

*An on-station experiment to determine the effects of shade on growth and shade adaptation of rubber (*Hevea brasiliensis*) and banana (*Musa* sp.) was established using an existing mature rubber plantation to provide a natural shade canopy. Four treatments were imposed consisting of an unshaded control and three levels of shade with a 33, 55 and 77% reduction in incoming radiation. Plant girth, height and dry matter of both rubber and banana decreased with increasing shade. Both rubber and banana showed clear adaptations to shade with an increase in specific leaf area and/or decrease in leaf weight ratio, and partitioning of chlorophyll to the light harvesting complexes (as indicated by the decline in chlorophyll *a/b* ratio). These shade adaptations of both crops would account, in part, for the improved growth of banana and rubber when intercropped.*

Key words: dry matter partitioning, growth, intercropping, natural shade, shade adaptation

Introduction

Whilst rubber is normally grown in plantation monocultures on large estates, on smallholdings it is more common to find rubber interplanted with a range of cash, food and medicinal plants (Stirling *et al.*, 2001). In the traditional mixed cropping systems, component crops often experience some level of shading during their life cycles. One of the most common crops grown with immature rubber on smallholdings in Sri Lanka is banana (Rodrigo *et al.*, 2001a) and both crops experience a period of mutual shading (Rodrigo *et al.*, 1997; 2001b).

Previous studies have shown that intercropping enhances the growth of young rubber (Rodrigo *et al.*, 1997; 2001b) and it may be that plants benefit from the effects of shade, in part, shade adaptations. Results from earlier studies (Rodrigo *et al.*, 1997; 2001b) and discussions with rubber smallholders in Sri Lanka suggested that shade is an important factor for good early growth of component crops (Senevirathna, 2001). Based on their own observations, smallholders believe that the growth of young rubber is improved with intercropping, because of the effects of shade in reducing high radiation loads

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and maintaining favourable levels of soil moisture (Senevirathna, 2001).

Few, if any, studies have been done on shade effects on dry matter partitioning and shade adaptation of rubber and banana. None of the studies were reported under natural shade conditions, which provide sunfleck effect and reduced red/farred ratio to the understorey vegetation (Chazdon and Fetcher, 1984; Pearcy, 1987). The present study was designed to investigate the growth performance and shade adaptation of rubber and banana under natural shade and it is hypothesised that low level of natural shading benefits growth and development of rubber and banana during the establishment phase, in terms of shade adaptations.

Materials and methods

Experimental design

The experiment comprised four treatments designed to provide low, medium and high shade and an unshaded control of full sunlight. Natural shade treatments were applied by selecting existing mature rubber plantations to provide an average of 33%, 55% and 77% reduction in full sunlight. These different shade levels were achieved as a result of the age and inter-row spacing of rubber, and by selective pruning of branches of mature rubber (Senevirathna, 2001). Shade levels were monitored by a Ceptometer (Delta-T Devices, UK) and by installing two solarimeters per treatment plot fixed above the canopies of the experimental plants and connected to the data logger (21X, Campbell

Scientific Ltd., Leicestershire, UK) of the weather station (Campbell Scientific Ltd., Leicestershire, UK).

Plant material and establishment

Healthy plants of rubber (RRIC 100) that were *ca.* 8 months old and rhizomes of “embul” banana were used for planting (25 plants per treatment). Both rubber and banana were planted separately in single rows between the existing rows of mature rubber (used to provide shade), keeping an intra-row spacing of 3.0 m. To avoid competition with the roots of the mature rubber trees used to provide natural shade and to minimise variability in rooting conditions, all experimental plants were planted in soil-filled pits lined with a double layer of polythene film of gauge 500. Soil pits were excavated to a depth of 1.5 m and 1.0 m for rubber and banana respectively, and to a diameter of 1.8 m. All particles greater than 14 cm³ were removed from the excavated soil, and the pits were refilled according to the original soil profile.

Crop husbandry

Prior to planting, roots of the banana suckers were trimmed and treated with a solution of 2.5g/l of Carbofuran (Curaterr) and 2.5g/l of Captan for 10 minutes and kept for seven days to prevent insect infestation and fungal attack (Department of Agriculture, Sri Lanka, 1995). Chemical fertiliser for both rubber and banana were applied in accordance with recommendations given by the Rubber Research Institute (Samarappuli, 2001) and the Department of Agriculture

(1995) of Sri Lanka, respectively. As the plants were grown under the canopy of mature rubber, the new rubber plants were sprayed during the rainy season at weekly intervals with Dithane M45 (3 g in 1 litre of water) and Captan (4 g in 1 litre of water) to prevent leaf diseases (Jayasinghe, 2001).

Regular growth measurements

Regular growth measurements were confined to the stem diameter (at a height of 10 cm from the ground) and plant height of rubber at 4 monthly intervals, whilst for banana, stem basal girth (at a height of 10 cm from the ground) and plant height at 2 monthly intervals. In addition to the vegetative growth, time taken to flowering of mother crop of banana and bunch weight at maturity (excluding the stalk) and the number of fingers per bunch were recorded.

Destructive growth analysis

Both above- and below-ground dry matter was assessed at 7 and 14 MAP of rubber and 7 and 17 MAP of banana, using five plants randomly selected from each treatment. Selected plants were totally uprooted and the total fresh weight of the components; leaves, stem and roots were measured separately, immediately after harvest. A sub-sample of 40% of the total fresh weight from each component was dried at 80 °C in a forced draught oven to a constant weight and total dry matter was recorded (Rodrigo *et al.*, 1997). The leaf area of each leaf whorl of rubber was measured using the LI-3000 Leaf Area Meter (Li-Cor Inc., USA). Leaf area

ratio (LAR), specific leaf area (SLA) and leaf weight ratio (LWR) were calculated as described by Hunt (1978).

Analysis of leaf chlorophyll

Two leaflets from a plant of rubber and a lamina piece of banana (*ca.* 200 cm²) from five plants in each treatment were harvested early in the morning at *ca.* 12 MAP. In the laboratory, two and five grams of fresh rubber and banana leaf tissues were taken and cut into small pieces, ground with 80% aqueous acetone and the pigments were extracted. The extracts were then centrifuged at 2 000 rpm for 5 minutes and the resultant supernatant was separated from the precipitate by filtering through a Whatman No. 1 filter paper. Absorbance of the supernatant was measured using a spectrophotometer (M 330, Camspec, Cambridge, UK) at wavelengths 645 and 663 nm (Hipkins and Baker, 1986). Total chlorophyll and chlorophyll *a*, *b* were calculated according to Arnon (1949).

Data analysis

Regular growth measurements, plant dry weights, LAR, SLA and LWR were analysed using the Nested procedure and SAS statistical package (SAS Institute Inc., Cary, NC, USA). Whilst analysis of variance (ANOVA) and the General linear model (GLM) were used, respectively for balanced and unbalanced data. The mean separation of treatments was performed with Duncan's multiple range test (DMRT) for the comparison of the treatment effects.

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Results

At planting, height and stem diameter of rubber were similar across treatments (Fig. 1a,b). Treatment effects became more apparent over time, with both height and stem diameter decreased with increasing shade. After 8 months of planting, treatments differed significantly, with the highest values in the control ($p \leq 0.001$). Similarly, the stem basal girth and plant height of banana decreased with increasing shade, with

the exception of the medium shade treatment, which outperformed the low shade treatment from 11 months after planting (MAP) onwards (Fig. 1c,d). Data are shown for the mother crop of banana and because development was more advanced in the unshaded control treatment, plants had matured and started senescing before 13 MAP. From 13 MAP, girth and height of banana in the medium shade treatment was higher ($p \leq 0.01$) than the other two shade treatments.

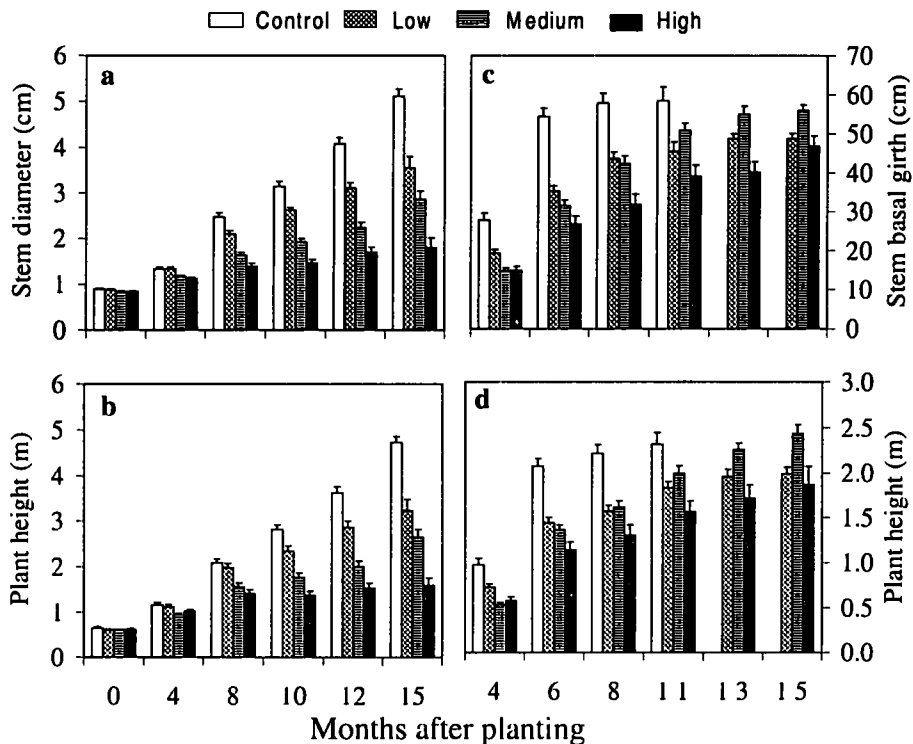


Fig. 1. Seasonal changes in (a) stem diameter and (b) plant height of rubber, (c) pseudostem basal girth and (d) plant height of banana in the unshaded control, low, medium and high shade treatments where the % reduction in incoming radiation was on average 0, 33, 55 and 77%, respectively. Data represent the mean \pm SE of an average of 19 measurements in each treatment. Stem diameter and girth were measured at a height of 10 cm from the ground.

Coinciding with growth, total dry matter (TDM) of rubber decreased with increasing shade at 7 and 14 MAP ($p \leq 0.001$; Fig. 2a). By 14 MAP, the unshaded control produced a TDM of 2.02 kg (± 0.27) per plant, which was sixfold greater ($p \leq 0.001$) than the high shade treatment. Total dry matter of banana at 7 MAP decreased with increasing shade (Fig. 2b). The first ratoon crop (17 MAP) showed a similar TDM production in the control and medium shade treatment, which were significantly higher ($p \leq 0.01$) than the TDM of the low and high shades. At 7 MAP, the unshaded control produced a dry matter of 3.58 (± 0.72) kg, which was threefold greater than the overall average of shade treatments (Fig. 2b).

Shade treatments had a marked effect on time to flowering for the mother crop of banana (Fig. 3a). The control produced flowers after 234 days

(± 6) of planting whilst flowering was delayed, on average, by 103% in the shaded treatments (Fig. 3a). However, the level of shading had no clear effect on flowering. Relatively larger bunches were produced in the unshaded control and the medium shade treatment than in the low and high shade treatments. The highest shade produced the lowest yield (Fig. 3b).

Shade significantly increased SLA of rubber ($p \leq 0.05$) at 7 MAP and by 14 MAP with SLA was on average 75% higher ($p \leq 0.001$) in the medium and high shade treatments than in the low shade and control (Fig. 4a). In contrast, LWR of rubber was higher in the control ($p \leq 0.01$) than in shade treatments at 7 MAP, whereas by 14 MAP there was no significant difference between treatments ($p > 0.05$; Fig. 4b).

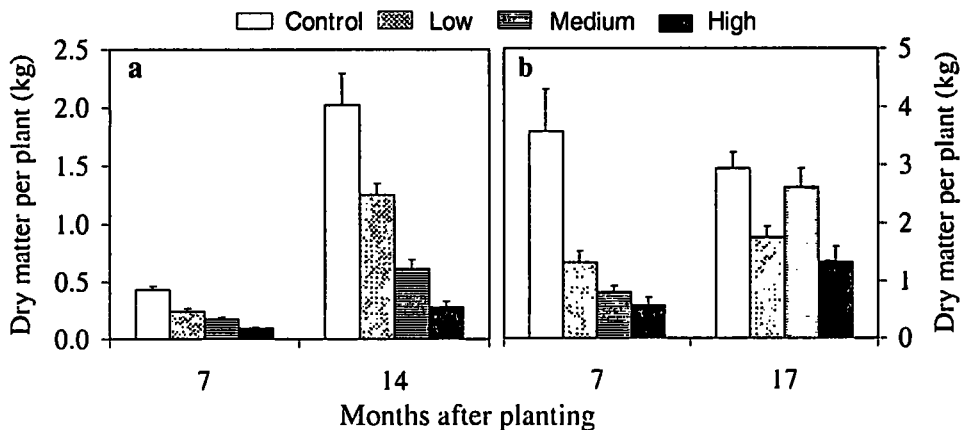


Fig. 2. Summary of the total dry matter production of (a) rubber and (b) banana in the unshaded control, low, medium and high shade treatments where the percentage reduction in incoming radiation was 0, 33, 55 and 77%, respectively. For banana, data at 7 and 17 months after planting are for mother crop and first ratoon crop, respectively. Each value is the mean of five replicates \pm SE.

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Shade had little effect on LAR of rubber at 7 MAP but at 14 MAP, LAR was higher in dense shade treatments. There was an ontogenic decrease in LAR in most of the treatments ($p \leq 0.001$; Fig. 4c). As was the case for rubber, SLA of banana increased ($p \leq 0.01$) with increasing shade at 7 MAP; at 17 MAP, the high shade treatment showed apparently a higher ($p \leq 0.01$) SLA over the other shade treatments (Fig. 4d). LWR of banana decreased from 7 to 17

MAP, but no significant treatment effect was observed (Fig. 4e). Similar to SLA, treatments effects on LAR were most prominent at 7 MAP when LAR increased significantly with shade ($p \leq 0.001$). Thereafter, no consistent difference between treatments was observed with the exception of the dense shade treatments where LAR was always significantly greater ($p \leq 0.01$; Fig. 4f).

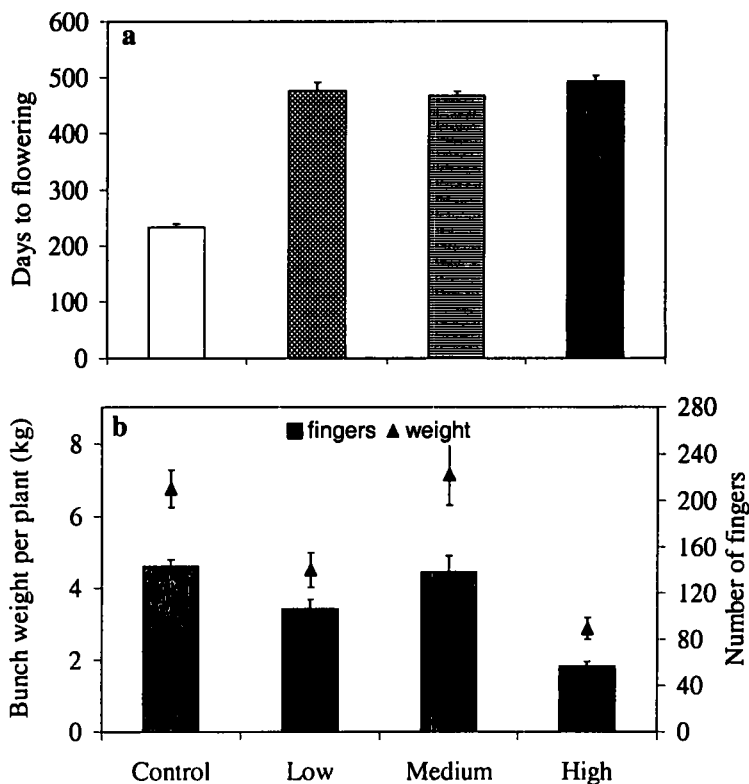


Fig. 3. Summary of the yield performance of banana for the mother crop where (a) is the time taken for flowering from planting and (b) is the bunch weight and number of fingers per bunch in the unshaded control, low, medium and high shade treatments where the % reduction in incoming radiation was 0, 33, 55 and 77%, respectively. Data represent the mean of average 8 replicates \pm SE.

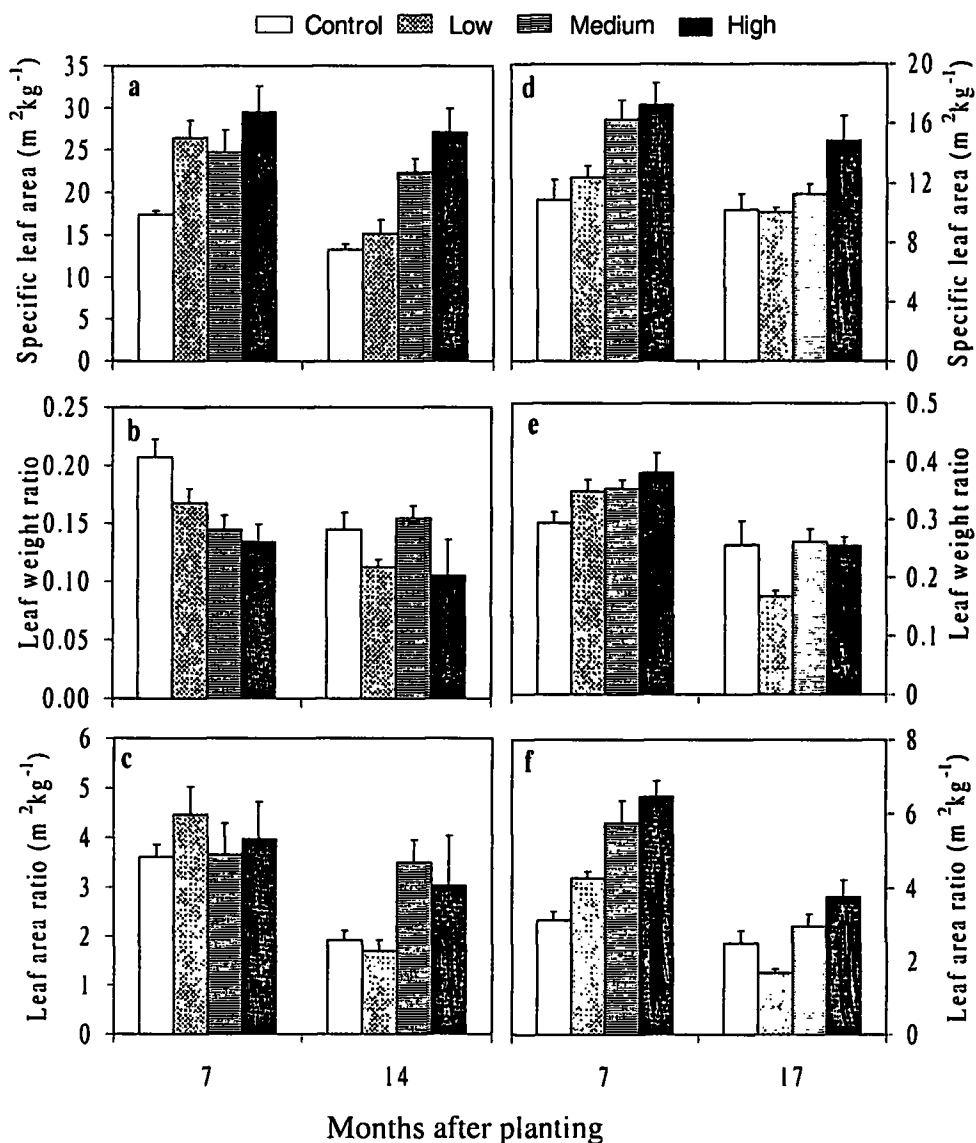


Fig. 4. Summary of the dry matter partitioning of rubber (a, b, c) and banana (d, e, f) in the unshaded control, low, medium and high shade treatments where the percentage reduction in incoming radiation was 0, 33, 55 and 77%, respectively. For banana, data at 7 and 17 months after planting are for mother crop and first ratoon crop, respectively. Each value is the mean of five replicates \pm SE

Figure 5 summarises the analysis of total chlorophyll content and chlorophyll *a:b* ratio measured at 12 MAP of rubber and banana. There was

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no clear treatment effect on total chlorophyll concentration of rubber (Fig. 5a) but chlorophyll *a* and *b* analysis indicated that the ratio decreased with increasing shade, with the highest value of 2.14 ± 0.03 in the unshaded control and the lowest value of 1.55 ± 0.05 in the high shade treatment (Fig. 5b). In the case of banana, total chlorophyll concentrations tended to be higher in the shaded treatments than that of the unshaded control but unexpectedly, chlorophyll concentration was low in the highest shade treatment compared to the low and medium shade treatments (Fig. 5c). However, the

chlorophyll *a/b* ratio declined with increasing shade from a maximum of $2.30 (\pm 0.19)$ in the control to $1.94 (\pm 0.02)$ in the high shade treatment (Fig. 5d).

Discussion

Growth and development of both rubber and banana decreased with increasing shade throughout (Figs. 1 and 2) indicating that the amount of light intercepted by shade plants was lower than that of plants grown under full sunlight. In support of this, it has been observed that growth is directly related to the amount of radiation

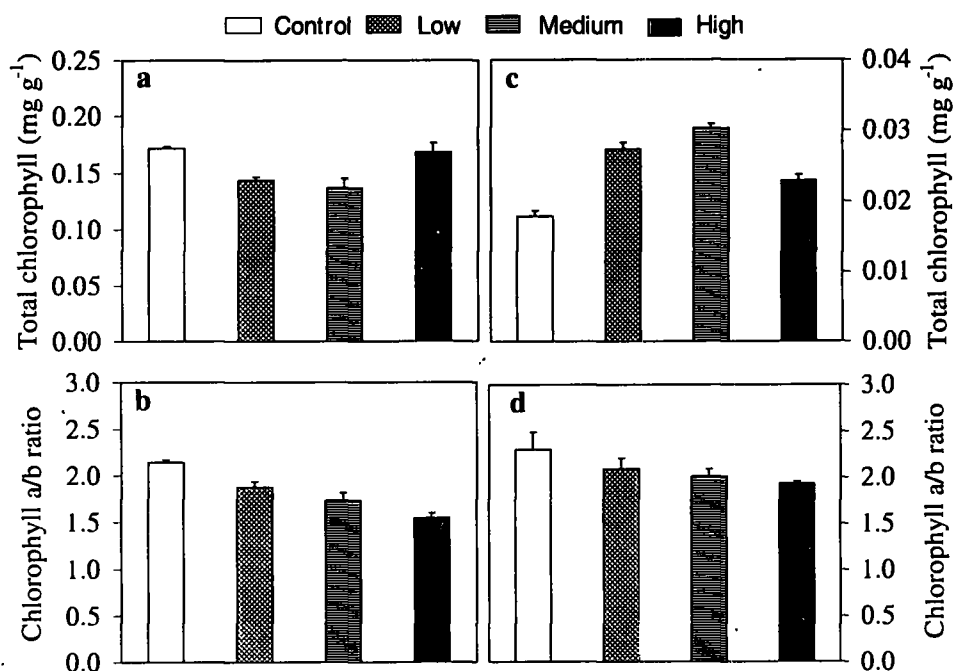


Fig. 5. Summary of the chlorophyll status (*i.e.* levels in terms of total and *a/b* ratio) of rubber (a, b) and banana (c, d) in the unshaded control, low, medium and high shade treatments where the percentage reduction in incoming radiation was 0, 33, 55 and 77%, respectively. Each value is the mean of five replicates \pm SE

intercepted by the canopy (Biscoe *et al.*, 1979; Matthews *et al.*, 1991; Monteith *et al.*, 1991). Reduced growth under shade is further evident by the slower rate of leaf development of both rubber and banana under shade conditions (Senevirathna, 2001). Surprisingly, banana in the medium shade treatment outperformed the low and high shade treatments after 11 months in terms of dry matter accumulation (Fig. 1c,d and 2b). This may have been associated with higher soil Mg and Ca in the medium shade treatment (Senevirathna, 2001). In support of this, Turner and Barkus (1980; 1983) reported an increase in dry matter production of banana with application of Mg. Corresponding to the slower development of banana under shade conditions, flowering was delayed (Fig. 3a), and the weight and size of bunches decreased with increasing shade except in the medium shade treatment where the yield was similar to the unshaded control (Fig.3b). Reduced growth, extended flowering and low yield of banana under shade conditions were also observed by Israeli *et al* (1995), Israeli *et al* (1996) and Eckstein *et al* (1997).

Although shade has reduced the growth of both rubber and banana, both crops showed adaptations to shade. In the case of rubber, SLA increased while decreasing the LWR with increasing shade (Fig. 4a,b). Banana showed a prominent increase of both SLA and LAR with increasing the intensity of shade (Fig. 4d,f). Although these shade adaptations of rubber and banana were not recorded earlier, these shade adaptations are common to many plant

species grown under shade (Tinoco-Ojanguren and Percy 1995; Landhausser and Lieffers, 2001; Poorter, 2001). Increased SLA and decreased LWR indicate the thinner leaves of lower mass were produced under shade, which enabled efficient utilisation of light energy under limited light conditions (Terashima and Hikosaka, 1995). In addition to the morphological adaptations in terms of dry matter partitioning, both rubber and banana showed a decreasing trend of chlorophyll *a,b* ratio (Fig. 5b,d) with increasing shade. Lower chlorophyll *a,b* ratio in the shaded plants reflects the greater association of chlorophyll with the light harvesting complexes, which have lower chlorophyll *a,b* ratios (Evans and Poorter, 2001), thereby increasing the efficiency of light harvesting in a light-limited environment.

From early studies of rubber/banana intercropping systems, improved radiation use and growth of both crops in systems with high populations of banana suggested that one of the factors for improved growth was enhanced mutual shading under high densities of banana (Rodrigo *et al.*, 1997; 2001b). However, the intensity of shade and duration of shading were not clearly defined in the rubber/banana intercrops. In the present study, plants were grown with overhead shading from the time of planting whereas, in rubber/banana intercrops, from establishment until *ca.* 4-6 MAP, plants experience full sunlight conditions most of the time. However, as canopy develops with plant growth, mutual shading increases. The lowest shade

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(33% reduction in incoming radiation) used in this study probably resulted in a greater reduction in incident PPFD than that would be experienced during mutual shading in the previous mixed rubber/banana systems. Also, the degree of shade experienced in such mixed cropping systems would fluctuate widely during the day and within the season. Therefore, the ultimate response observed is a compound effect of fluctuating shade over a period of growth, together with other microclimatic changes such as decrease in air temperature, increase in %RH, decrease in boundary layer thickness *etc.* under shade conditions (Guiselini *et al.*, 1999). Furthermore, mutual shading may not be experienced throughout the day unlike overhead shading and so even the lowest shade used in this study did not result in improved growth over the unshaded plants. Nevertheless, this study showed that both rubber and banana have clear abilities to adapt to shade, that could both supporting to early observations of improved growth of rubber and banana when intercropped.

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