

Shade In Tea: Is It Beneficial?

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ABSTRACT

Shade is considered as a necessary management practice in tea. However, there is still much debate on the necessity of shade in tea plantations. This paper deals with some physiological responses of tea due to shade in several experiments, two long term experiments carried out in St Coombs Estate, Talawakele (1,372 m amsl) and one experiment with pot grown young tea plants in a growth chamber.

In field grown tea, the maximum photosynthesis (A_{max}) of unshaded leaves was found to be nearly 40% less than shaded, indicating the increased capacity of shaded leaves for higher productivity. Under increased N input, the gap of A_{max} between shaded and unshaded leaves narrowed down. The total linear electron transport rate was found to be similar in both shaded and unshaded leaves. The allocation of electron transport products to CO_2 fixation was higher in shaded leaves, which was about 50% less in unshaded leaves than in shaded leaves. Conversely, allocation of electron transport products to photorespiration was significantly larger in unshaded leaves. The photosynthesis of field grown tea in several seasons with different climatic conditions showed that when there was high incident radiation intensity, the rates of photosynthesis were significantly low. F_v/F_m , which is a measure of photoinhibition was significantly lower in unshaded tea leaves. None of the other parameters, i.e. leaf temperature were significantly different between shaded and unshaded leaves, indicating the decrease in photosynthesis is due to photoinhibition. Interestingly in terms of the physiological responses, the best microclimate to the tea was provided under the shade of *Grevillea robusta* L.

In summary, shade can be considered as essential and beneficial for tea, in addition to the other known advantages such as nitrogen fixation, harbouring natural enemies of tea pests, moisture conservation and biodiversity aspects. Identification of alternate species of shade trees with favorable microclimate and low competition with tea for tea plantations will have to be carried out in order to sustain the long term stability.

Key words: Tea (*Camellia sinensis* L.), photosynthesis, fluorescence, shade

INTRODUCTION

Shade is considered as an important management practice in tea, but also subjected to much controversy. In its native habitats tea has been growing under the shade of forest trees (Eden, 1976). The history of the establishment of Shade in Tea Plantations dates back to 1800 (Dutta, 1961; Murthy, 1996). Masters (1863) claimed that the Assam tea does not appear to thrive well in the inferior soils when exposed to the full sunlight, hence recommended partial shade for tea. Following this, planting tea under the shade of trees, mainly *Albizia chinensis* became the practice in India (Barua, 1989). The practice of using shade trees spread from North East India to South India, Sri Lanka, Indonesia and Africa. Since then, shade has been a subject of much debate: Some authors claim that the yield increase under shade (Barua and Gogoi, 1979; Hadfield, 1962), some claim that there are decreasing yields under shade (Mc Culloch et al., 1965; Obaga and Othieno, 1987; Othieno, 1983) while others claim there are no yield responses.

In the mid 60's shade was removed from tea plantations in Sri Lanka, owing to the increase of the leaf disease 'blister blight' caused by the fungus *Exobasidium vexans*. However, by about 1970 it was realized that several problems occur as a result of shade removal, causing a yield drop as much as 25%. As a result, the shade trees were re-introduced (Sivapalan, 1993).

However, there is still much debate on the necessity of shade in tea plantations. This paper deals with some physiological responses of tea due to shade, in several experiments. Main focus was on tea photosynthesis and some of its partial processes as photosynthesis is regarded as the driving force of plant productivity.

MATERIALS AND METHODS

Two long term experiments were carried out in field number 8 at St Coombs Estate, Tea Research Institute, Talawakele, Sri Lanka (latitude 6° 55' N, longitude 80° 40'E and altitude 1,382 m amsl) and one experiment with pot grown young tea plants in a growth chamber.

Experiment 1

This experiment was carried out during July 1996 to June 1999. In this experiment, mature tea planted in 1964 of the cultivar TRI 2025 was used. This field experiment comprised of 3 shade levels, i.e. 70%, 35% and 0% shade and 3 N levels, i.e. 0, 360 and 700 kg ha⁻¹ yr⁻¹. The shade was provided with black nylon netting. These treatments (3 factor factorial) with 3 replicates were arranged in a completely randomized block design. On a clear day, the leaves on top of the canopy received about 1,750 μmol m⁻² s⁻¹ PAR during mid-day. The plots were approximately 16 m² area containing approximately 26

plants. In this paper only the results of the extreme treatments, i.e. High shade (70% shade), unshaded, high N (700 kg N ha⁻¹ yr⁻¹) and no N (0 kg N ha⁻¹ yr⁻¹) treatments will be discussed.

Experiment 2

This experiment was carried out from April 2001 onwards. In this experiment, mature tea planted in 1964 of the cultivar TRI 2025 was used. The experiment had 35% shade (provided by black nylon netting), 0% shade and the shade provided by *Grevillea robusta* L. as treatments with 3 replicates, arranged in a randomized block design. All other management practices were carried out as per TRI recommendations. On a clear day the leaves on top of the canopy received about 1,750 $\mu\text{mol m}^{-2} \text{s}^{-1}$ PAR during mid-day. In the shade tree plot the tree was in the middle of the plot. The plots were approximately 16 m² area containing approximately 26 plants.

The measurements were made in 2002-2003 on days with different climatic conditions. Four categories were selected to represent most common climatic conditions experienced in the region, based on the cloud cover and the light intensity. They were named as; A (bright, clear days with no clouds, receiving an average PAR about 1,750 $\mu\text{mol m}^{-2} \text{s}^{-1}$), B (morning bright and clear, but afternoon overcast sky with intermittent cloud cover), C (morning and evening overcast sky with a cloud cover, but mid-day bright) and D (overcast throughout the day, with no bright sunshine, with PAR ranging between 100-500 $\mu\text{mol m}^{-2} \text{s}^{-1}$ over the day). For day category A, measurements were taken on two seasons (season one in April 2001 and season two in March 2002): PAR and rate of photosynthesis (A) are presented for both seasons while other parameters of both seasons were merged for easiness of the discussion. Under each category, measurements were repeated at least on four similar, consecutive days, which were taken as replicates for statistical analysis.

Experiment 3

This experiment was carried out at IACR-Rothamsted, Harpenden, UK, in 1998. In this experiment, 1 year old tea plants of the cultivar TRI 2025 grown in peat based compost (pH=4.5) filled plastic pots (4 L volume), supplied with T65 nursery mixture as per recommendations, were used. The plants were grown in a growth chamber, acclimatized at different light intensities for 2 months (shaded, i.e. approximately 150-250 $\mu\text{mol m}^{-2} \text{s}^{-1}$ PAR and unshaded, i.e. 650-750 $\mu\text{mol m}^{-2} \text{s}^{-1}$ PAR) before measurements were taken.

Measurements

Photosynthesis and chlorophyll fluorescence Measurements

In all the experiments mature leaves with a swollen, active axillary bud was used for the measurements. Rate of photosynthesis and chlorophyll a fluorescence were measured on intact, healthy leaves.

In experiments 1 and 2, water vapour and CO₂ exchange of the leaves were measured at ambient CO₂ concentration (approximately 360 μmol mol⁻¹) and natural light intensities using a portable photosynthesis meter (model: LI-6200, Li-Cor inc., USA). Measurements were made from 5.30 a.m. to 7.30 p.m. at two hourly intervals. Two similar leaves on top of the canopy were used in each treatment. All the measurements were made when the leaves were enclosed in the chamber. Chlorophyll a fluorescence of photosystem II was measured using a portable modulated fluorescence meter (model OS-100, OSLOG-PP Systems, Hitchin, Herts, UK), soon after the photosynthesis measurements. F'_o was estimated using F_o, F_m, F_s, and F'_m (Oxborough and Baker, 1997). The F_o and F_m measurements were taken after completely darkening a set of similar leaves for a period of at least 45 minutes using dark adapted cuvettes provided by the manufacturer. When fluorescence reached a steady-state (F_s) in leaves exposed to actinic light, a saturating light pulse was applied to obtain the maximal fluorescence under actinic light (F'_m). Immediately after the photosynthesis and fluorescence measurements leaf disks of 10 cm³ were taken using a cork borer, dipped in cold MCW (60% methanol, 25% chloroform and 15% distilled water) and frozen in -20 °C and analyzed for the content of total sugars and starch.

In experiment 3, a six-chamber open-circuit gas exchange system with automatic data handling (ADC, model 225 MK3 IRGA, Hoddesden, Herts, UK) was used. Photon flux was provided with metal halide photo-flood lamps. The light was passed through a cold water filter to remove IR and UV radiations, to maintain temperature. The rates of total linear electron transport, the allocation of electron transport products to CO₂ fixation and photorespiration were calculated according to Ghashghaie and Cornic (1994) using the gas exchange and fluorescence measurements.

Total soluble sugar and hot water soluble starch

The samples mentioned in experiment 2, were homogenized using a homogenizer (kHa Labortechink model T8) and soluble and insoluble fractions were separated by centrifugation at 4 °C for 3 minutes. The pellet was kept for starch analysis. An equal volume of distilled water and chloroform (10 cm³) was added to the supernatant, shaken and separated into chloroform and aqueous methanol phases by centrifugation. The chloroform fraction was discarded and methanol -water fraction was removed and used for the total sugar content determination: to 50 μl of the sample, 0.9 cm³ of anthrone reagent containing 0.15% w/v anthrone in 75% sulphuric acid was added, mixed and incubated in 40 °C for 20 minutes in a water bath. Each sample was replicated twice. Optical density was read at 630 nm in a spectrophotometer (model GBC UV/VIS 911A, GBC Scientific Equipment Pvt Ltd., Victoria, Australia) in disposable plastic cuvettes, against a blank. A standard curve was prepared using sugars of known concentrations and absorbance, and the sugar concentration per unit leaf area was calculated per unit leaf area.

Starch content of leaves was estimated in the pellet as follows: First it was extracted with 10 cm³ 80% methanol to remove traces of sugar. The extract was then centrifuged at 5000 rpm for 30 minutes, and supernatant was discarded. To the residue, 10 cm³ distilled water was added, well mixed and heated in a water bath at 100 °C for 30 minutes. It was then centrifuged at 5000 rpm for 30 min, supernatant was collected in 10 cm³ volumetric flasks and made up to the volume. Two drops of a mixture of iodine (I₂) and potassium iodide (KI) was added to the solution and the absorbance measured at 660 nm wavelength against a blank. A standard curve was prepared using known concentrations of starch and absorbances, and starch concentration per unit leaf area was calculated.

Data were analyzed using SAS and Genstat statistical packages.

RESULTS

Fig. 1 represents the light response curves of field grown tea in experiment 1. Tea leaves attained light saturation around 800 $\mu\text{mol m}^{-2} \text{s}^{-1}$. The maximum photosynthesis (A_{max}) of unshaded leaves was found to be nearly 40% less than the shaded, indicating the increased photosynthetic capacity of shaded tea leaves. They also had relatively low apparent quantum yields and larger dark respiration values (Table 1). Under increased N input, the gap of A_{max} between shaded and unshaded leaves narrowed down.

Table 1. Mean photosynthetic parameters of the light response curves of field grown tea

	Apparent Quantum Yield (mol CO ₂ mol ⁻¹ photons)	A_{max} ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	Dark respiration ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
Unshaded, High N	0.026	9.70	-1.56
Unshaded, Low N	0.025	7.09	-1.38
High Shade, High N	0.028	10.19	-1.17
High Shade, Low N	0.029	9.88	-1.15

As measured in the Experiment 2, the total linear electron transport rate was found to be similar in both shaded and unshaded leaves (Fig. 2). However, the differences lay in the allocation of the electron transport products: the allocation of electron transport products to CO₂ fixation was higher in shaded leaves than in unshaded leaves (Fig. 3). This was about 50% less in unshaded leaves than in shaded leaves. Conversely, allocation of electron transport products to photorespiration was significantly larger in unshaded leaves (Fig. 4).

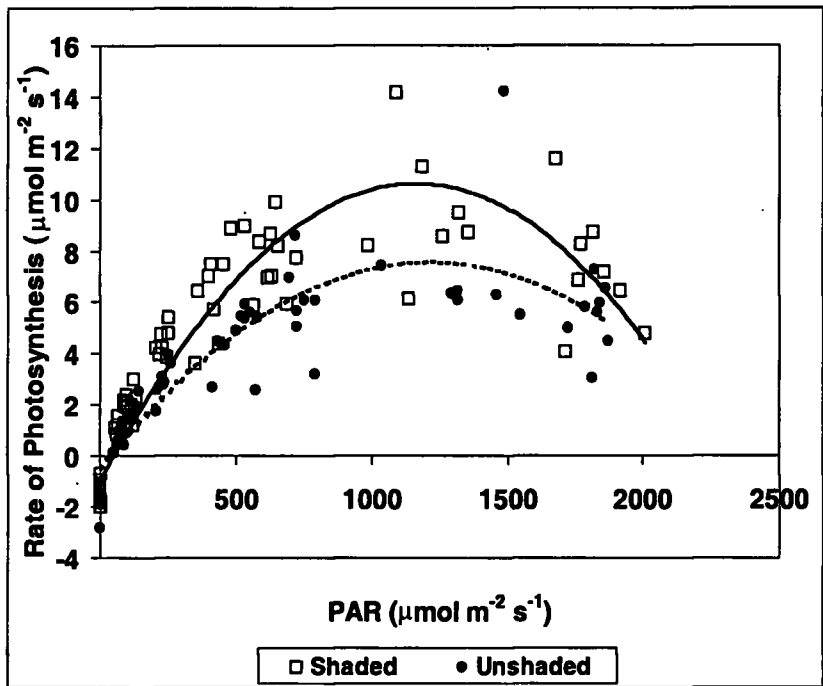


Figure 1. Light response curves of shaded and unshaded field grown tea leaves

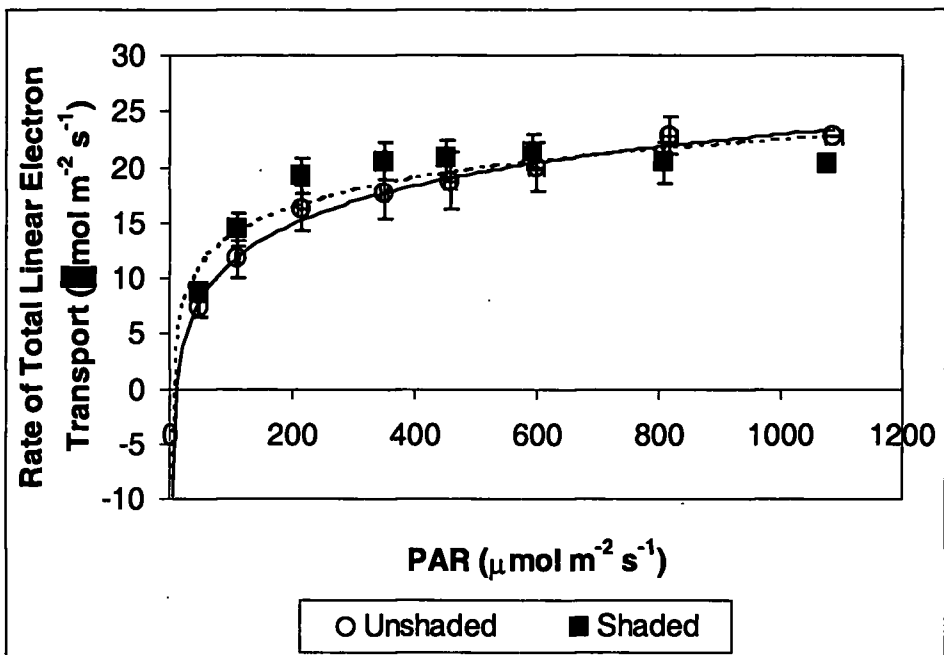


Figure 2. Rates of total linear electron transport of shaded and unshaded tea leaves

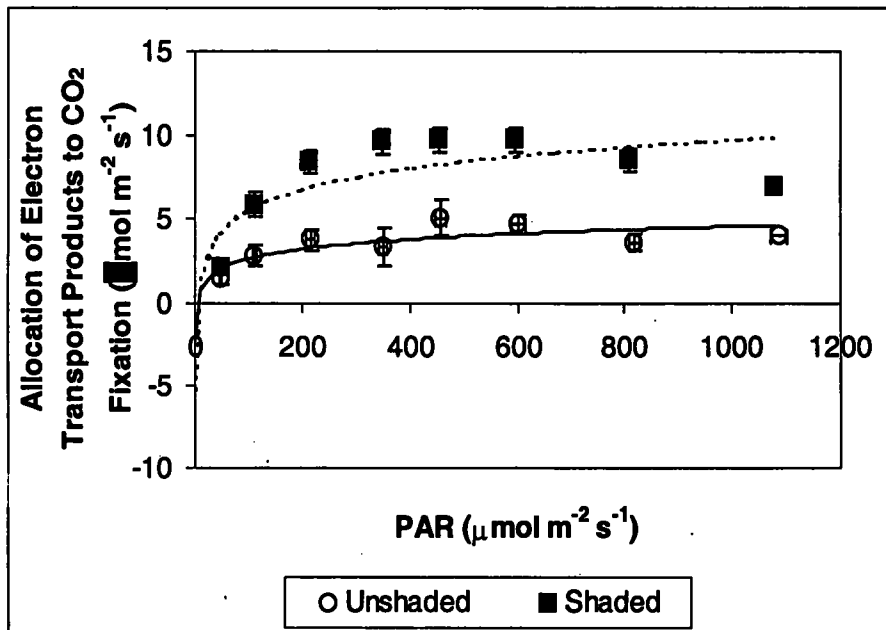


Figure 3. Allocation of electron transport products to CO_2 fixation in shaded and unshaded tea leaves

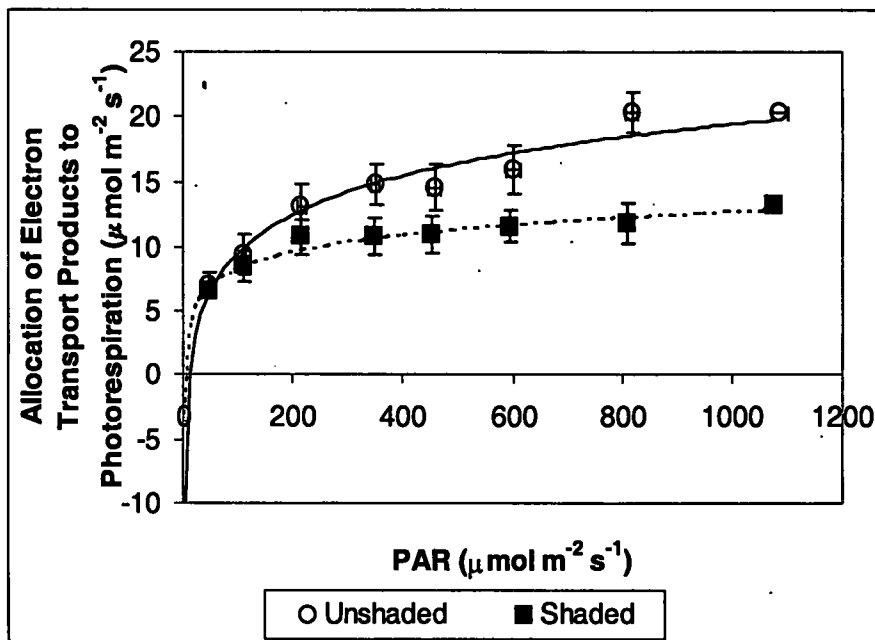


Figure 4. Allocation of electron transport products to photorespiration in shaded and unshaded tea leaves

The photosynthetically active radiation (PAR) was significantly low under the artificial shade than the other two treatments (Fig. 5). This was most prominent in the day categories A (bright, clear weather throughout the day) and B (morning and afternoon cloudy but bright mid-days). During cloudy weather throughout the day (category D), these differences between the treatments were not very prominent.

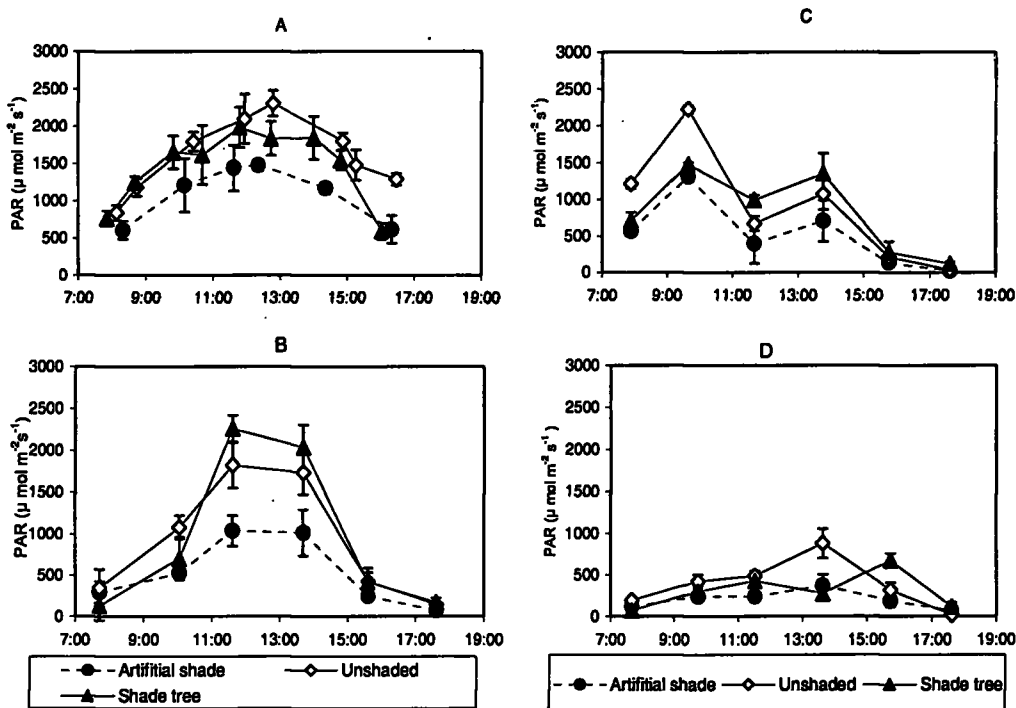


Figure 5. The PAR during the day in different seasons when the measurements were taken with field grown mature tea (Experiment 3): A: bright, clear weather throughout the day, B: Morning and afternoon cloudy but bright mid-days, C: Clear and bright mornings and cloudy afternoons, D: whole day cloudy.

Interesting results could be observed with the photosynthesis measurements taken under different conditions: During bright, clear weather (category A), when there was high incident radiation intensity around mid-day, the rates of photosynthesis of unshaded leaves were significantly lower than in the other two treatments, which behaved in a similar manner (Fig. 6). In day categories B and C the rates of photosynthesis were not significantly different between the treatments. In general, the rates of photosynthesis were largest under the shade tree in all the day categories. When cloudy weather prevailed throughout the day (day category D), the photosynthetic rates under the artificial shade was the lowest amongst the treatments as the PAR did not reach saturating light intensities.

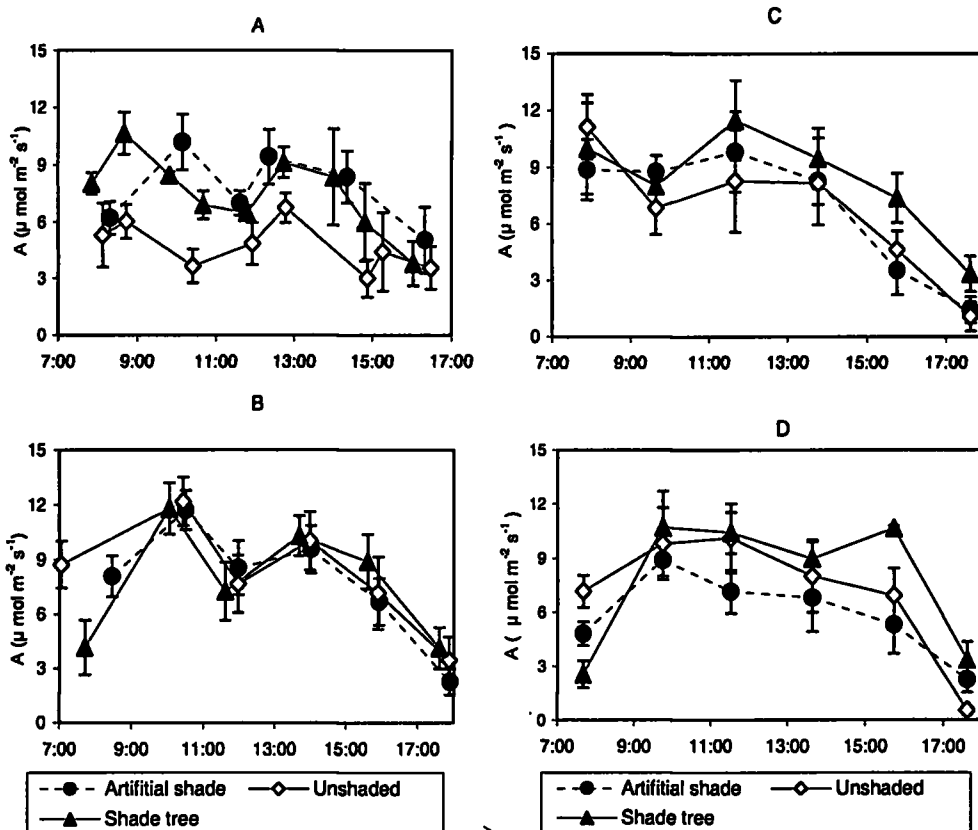


Figure 6. The diurnal variation of photosynthesis of tea leaves during different seasons when the measurements were taken with field grown mature tea (Experiment 3): A: bright, clear weather throughout the day, B: Morning and afternoon cloudy but bright mid-days, C: Clear and bright mornings and cloudy afternoons, D: whole day cloudy.

The changes in the leaf temperature did not show any significant differences between the treatments, during all the seasons (data not shown). In the day category A, when the rates of photosynthesis of unshaded leaves were significantly lower, the leaf water potential did not show any significant difference between the treatments (data not shown), indicating these differences were not due to any deficit of water in those plants. The total soluble sugar contents showed significantly lower contents in unshaded leaves than in the other two treatments (data not shown), indicating no end-product inhibition of photosynthesis in unshaded leaves.

DISCUSSION

As shown with the light response curves, photosynthesis of tea is light saturated around $\text{PAR } 800 \mu\text{mol m}^{-2} \text{s}^{-1}$. At light intensities above this value, photosynthesis drops as a result of photoinhibition (Fig. 1). Shade increased the capacity for increased photosynthetic efficiency in tea, and at the same time decreased the dark respiration

(Table 1). This was also evident with the photosynthetic measurements taken in the field, where unshaded tea leaves showed significantly low values than the values of shaded leaves. This increase could be observed both in day category A and mornings of day category C. The decreased rates of photosynthesis were also shown not to be due to any shortages of water or due to end-product inhibition. During consistently cloudy weather, only the plants in unshaded plots and under shade tree received light intensities adequate to drive light saturated photosynthesis. Increased rates of photosynthesis of tea under shade has been reported by several authors (Barman et al., 1993; Mohotti and Lawlor, 2002; Rajkumar et al., 2002). Many authors attribute these increases in photosynthesis to decreased leaf temperatures under shade (Barman et al., 1993; Hadfield, 1975). Shade is also reported to improve the bush health as measured by increased root starch and chlorophyll contents and increase soil water holding capacity and organic matter content than the unshaded tea (Rajkumar et al., 2002).

Photosynthetic CO₂ assimilation is the culmination of the sub-processes of photosynthesis and their interactions. As shown by the subsequent figures, some processes related to light reactions of photosynthesis showed differences in relation to shade, therefore the increased CO₂ assimilation in relation to shade is expected.

The F_v/F_m is a measure of the intrinsic efficiency of the photosynthetic system in capturing excitation energy when the photosystem II reaction centers are fully oxidized (Genty et al., 1989). In general, F_v/F_m in tea was lower than the classical value of 0.8 in healthy, unstressed leaves and was reached to a near figure only during the night period. The fact that tea has relatively lower value of F_v/F_m could mean that tea has less efficient primary photochemistry of photosystem II which could be due to the nature of the light harvesting complex-reaction center interactions with less efficient mechanisms for energy transfer. Shading increased the F_v/F_m and hence increased the efficiency of the primary photochemistry of photosystem II. This complies with some earlier work (Mohotti, 1998), where F_v/F_m of close to 0.75 has been reported in field grown tea, which was increased with shading.

Analysis of electron transport provided clear evidences of the beneficial effects of shade in tea. The rates of total linear electron transport were not significantly different between unshaded and shaded tea leaves. The differences lay in the allocation of electron transport products: Its allocation in CO₂ fixation was significantly greater in shaded tea leaves. The allocation of electron transport products to photorespiration was substantially greater in unshaded tea leaves. The greater rates of photosynthesis in shaded tea leaves could be a result of this allocation of electron transport products to CO₂ fixation.

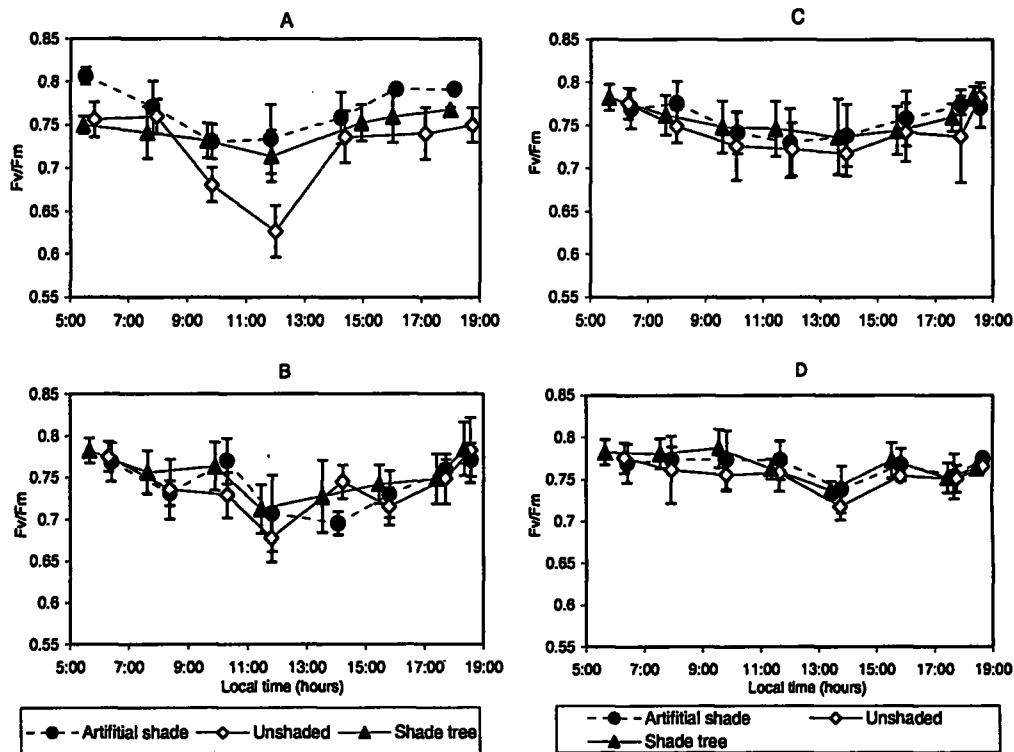


Figure 7. The diurnal variation in F_v/F_m of tea leaves during different seasons when the measurements were taken: A: bright, clear, weather throughout the day, B: Morning and afternoon cloudy but bright mid-days, C: Clear and bright mornings and cloudy afternoons, D: whole day cloudy.

At higher light intensities, photons are in excess of those that can be utilized in CO_2 assimilation (Percy, 1998). Also, if conditions restrict CO_2 assimilation and yet the leaves absorb the same number of photons the rate of photosynthetically generated energy equivalents is in excess of what is required by the dark reactions of photosynthesis. In such instances there may be an imbalance between photosynthetic processes, which can lead to an over-reduction of the photosynthetic electron transport chain, causing effects such as photoinhibition (Biehler and Fock, 1996). There has also been previous records of photoinhibition of field grown tea in Sri Lanka (Mohotti and Lawlor, 2002) and Tanzania (Smith et al., 1993). Mohotti and Lawlor (2002) have claimed that the recovery from photoinhibition was independent of shade or N nutrition of the tea bush, contrary to this experiment.

It was also evident that photoinhibition occurs in unshaded leaves, as measured by F_v/F_m (Figure 7): it is also considered as a measure of photoinhibition. The F_v/F_m was significantly lower in unshaded tea leaves than the other two treatments, between 9:00 – 15:00 hours. The decrease in F_v/F_m could also be due to adjustment of the mechanisms

to cope with intrinsically greater radiation loads experienced during bright sunny days. Except in the day category A, there was no difference in F_v/F_m between the treatments during other seasons indicating the decrease in photosynthesis of tea due to photoinhibition occurs only under bright and clear weather. During this type of days, differences in the morning values of photosynthesis and F_v/F_m between different treatments were not statistically significant, indicating the photoinhibition was removed during the night. However, the morning values of photosynthesis were smallest in unshaded leaves indicating that this recovery is slower when tea leaves were unshaded. In conclusion, shade was found to be having beneficial effects on the physiological measurements that were taken, which could have an impact on the productivity. Interestingly in terms of the physiological responses, the best microclimate to the tea was provided under the shade of *Grevillea robusta* L.

ACKNOWLEDGEMENTS

Dr D W Lawlor, IACR-Rothamsted, UK who has given valuable advice and guidance, post graduate and under graduate students of the University of Peradeniya, and staff of Physiology Division of the Tea Research Institute who contributed in collecting data are gratefully acknowledged.

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