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# Photosynthetic Efficiency of Sun and Shade Grown Tea Plants

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Bush health and metabolic aspects of tea plant in relation to varying degree of shade were studied under field conditions. The ultra violet spectrum varied with the structure, density and the depth of the shade. Light perception decreased from unshade condition to dense shade thereby influencing the microclimate at bush level. But under the prevailing agroclimatic regimes of Valparai, particularly during summer, regulated shade imparted favourable micro-climate at bush level. This favoured higher rate of carbon assimilation and amount of assimilates produced while reducing reassimilation. Variation in carbon metabolism was related to the levels of light harvesting pigments except chlorophyll-B and the ratio between chlorophyll-A and chlorophyll-B. Proline accumulation in tea leaves was more under unshaded conditions followed by regulated and densely shaded conditions. Tea plants grown under both full sun and shade possessed relatively lower carbohydrate content than that of the plants grown under regulated shade. Moisture of the soils of the area without shade rapidly evaporated. Enhancement in the soil organic matter content improved the water holding capacity of the tea soils possessed with shade trees.

## INTRODUCTION

Increasing the photosynthetic efficiency is important for achieving higher productivity targets. However, partitioning of assimilates to the economically important plant parts may not proportionately increase due to interacting biotic, cultural and environmental factors (Marimuthu et al., 1994). Plants which are adapted to shaded habitats perform more efficiently at low light intensities while at saturating light intensities they are incapable of assimilating more atmospheric carbon. Plants that grow under high light intensity have a high photosynthetic capacity but they fail to capitalise low light environment (Coombs *et al.*, 1987).

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The concept of shade as a thin unbroken cover of foliage with leguminous or non-leguminous shade over tea bushes is prevalent in N.E.India (Barua, 1989). Planting shade trees and their management is considered a routine cultural operation in south India [23](Hudson *et al.*, 1997). However, a much higher proportion of tea area in south India remains under inadequate shade. The present investigation was thus carried out with particular reference to the physiology of tea plants grown under different degrees of shade and their ecology.

## MATERIALS AND METHODS

Experiments were conducted in an estate in Valparai, India (~ 1000 m.a.s.l; 10°, 30' N, 77° 0' E) during 1998. Tea plants of clone UPASI-9 (*Camellia sinensis* (L.) O.Kuntze) selected for the investigation were grown under non-leguminous shade tree, *Grevillea robusta* A. Cunn. planted at 12 m x 6 m spacing and pollarded periodically at eight to nine m above ground level (regulated shade). Unpollared shade trees planted at 3 m x 1.5 m spacing was considered as dense shade. Tea plants grown without shade trees were selected as control for comparison. All the other cultural operations were executed as standard routine (Hudson *et al.*, 1997).

Non-replicated experimental plots were consisted of 500 bushes each. Spectral distribution of photon flux density (PFD) within the crop stand was measured with a LI-COR 1800 spectroradiometer (LI-COR instruments, Lincon, USA) on March 2, 1998 at bush level (top canopy). Measurements were taken with a cosine corrected sensor attached to a fibre optic cable and observations were completed within an hour of solar zenith with the sun unobscured. (Raj Kumar *et al.*, 1998).

Photosynthetic rate of recently matured tea leaves in different degrees of shade was monitored under given field conditions using an Infra-red gas analyser and an open type gas exchanger with the Parkinson leaf chamber (models LCA-3 and PLC-3, respectively. ADC, UK). A minimum of ten leaves of identical physiological maturity were scanned per treatment. Photosynthetic rate was monitored between 9.00 and 10.00 hours under given conditions during soil moisture stress at monthly intervals.

Mother leaves subtending the growing axillary buds were exposed to 25 µl of labelled sodium carbonate for an hour to fix carbon dioxide photosynthetically as demonstrated by Hale and Weaver (1962). Respiratory losses were estimated following the method suggested by Barbora and Barua (1988) with modifications (Raj Kumar *et al.*, 1998). Radioactivity counting was performed with liquid scintillation counter (LKB Rackbeta, model 1214, Finland, UK). Carbon dioxide liberated in the process of reassimilation was expressed as per cent C-14 evolved per unit area per hour while translocation was expressed in per cent (Marimuthu *et al.*, 1994).

Some biochemical constituents, i.e. proline, chlorophyll and carotenoid pigments in crop shoots, carbohydrate (starch + sugars) reserves in the roots and certain soil characteristics, i.e. soil moisture, water holding capacity and soil organic matter were also studied during soil moisture stress conditions adopting standard procedures. Biochemical analysis and soil characteristics were monitored twice with four random samplings from each treatment. The experiment has been repeated twice with four replicates. Data were subjected to statistical analysis (ANOVA).

## RESULTS AND DISCUSSION

The combination of filtered and unfiltered solar radiation in varying proportions depending on the structure, density and depth of the shade determined the spectrum of ultra violet rays (Figure 1). Under regulated and dense shade conditions, solar beam was filtered by the vegetation strands considerably and thereby the ultra violet radiation penetration had been reduced significantly. Both the incident photon flux density (PFD) and its quality changed significantly when it passed through the tree canopy (Figure 2). Under regulated shade condition, about 40% of light was reduced during April to June. However, at the end of one agricultural year this had been further reduced to 60%, due to the growth and development of shade trees (data not provided). Under dense shade, less than 20 % of light passed through the tree canopy even under hot sunny days.

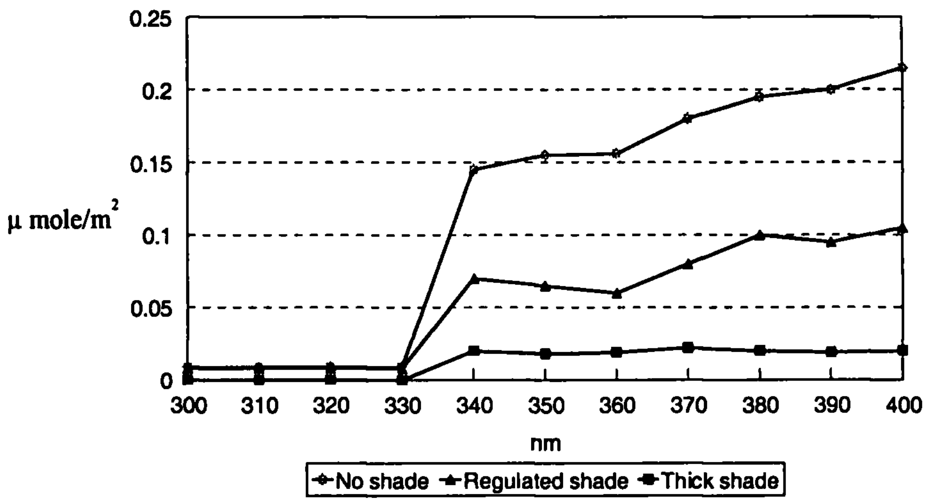


Figure 1: *Degree of shade on UV spectra*

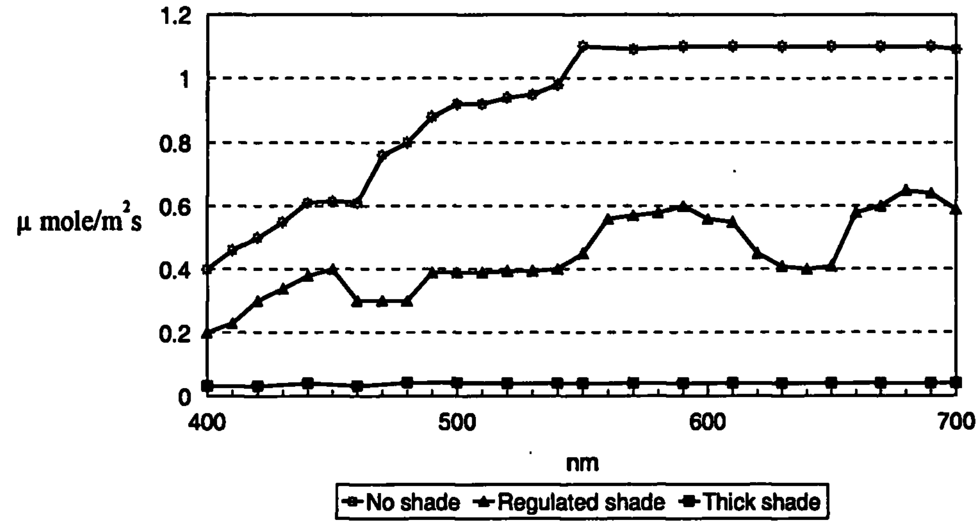


Figure 2: *Degree of shade on UV spectra*

Well trained *Grevillea robusta* trees having six to eight feet long branches in all four directions, provided full shade to 40 plants and it partially covered another 15 bushes at 10.00 hrs. However, it covered only 20 bushes fully or partially which imparted congenial microclimate at bush level during mid-day since the umbra is moving from west to east via north (Barua, 1989).

Eco-physiological behaviour of tea plants grown under varying degrees of shade are provided in Table 1. Tea plants under regulated shade exhibited significantly higher carbon dioxide assimilation followed by no shade and dense shade. Under no shade, incident light intensity and atmospheric temperature were significantly higher than under shaded conditions. It may be noted that IRGA monitoring was carried out between 9:30 to 10:30 hrs in no shade condition followed by other treatments. Even then, the atmospheric temperature increased significantly at bush level in the early hours of sunny dry weather conditions. Shade trees intercepted both infra red and visible radiation of sunlight thereby reducing the light energy besides heat (Barua, 1989). In the present investigation, around 50% of light had been intercepted by trees grown densely while 15% was prevented by regulated shade based on IRGA readings. The higher energy level under regulated shade may be due to the scattered light and the reflectance of the soil (table 1)

Table 1: Effect of shade on eco-physiological features of field grown tea plants

| Degree of shade | Photosyntheticaly[1] active radiation | Atmos temp.[2] | Evaporation rate[3] | Photosynthetic rate[4] | Stomatal conductance[5] | Water use efficiency[6] |
|---|---|---|---|---|---|---|
| **No shade** | 1214 | 33.6 | 5.8 | 7.91 | 0.29 | 1.37 |
| **Regulated shade** | 1024 | 32.8 | 6.1 | 11.93 | 0.39 | 1.97 |
| **Dense shade** | 642 | 30.8 | 5.7 | 5.61 | 0.49 | 0.98 |
| *C.D.P. = 0.05:* | 179 | 0.5 | 0.4 | 2.23 | 0.08 | 0.39 |

1: $\mu mole/m^2.s$; 2: degree centigrade; 3: $mmol/m^2.s$; 4: $\mu mole\ CO_2/m^2.s$; 5: $mol/m^2.s$; 6: a ratio between photosynthetic carbon assimilation and evaporation rate

There is a direct relationship between evaporation rate, stomatal conductance, photosynthetic carbon assimilation rate and water use efficiency. Photosynthetic rate and water use efficiency under moderate shade were significantly higher than in the other two treatments. Low partial pressure of carbon dioxide may cause the stomata to open, favouring free flow of gaseous exchange under regulated shade. Plants maintained under conditions favourable for photosynthesis at moderate PFD, did not suffer photoinhibition and intercepted PFD was transduced to drive carbon metabolism. In the present study, imposition of additive environmental limitations further exacerbated the inhibitory effect of high PFD on metabolic processes which supports the earlier findings (Powles, 1984).

Assimilation of photosynthetic carbon dioxide per unit area, amounts of assimilates and their reassimilation were greatly influenced by the pattern of shade (Table 2). Tea plants receiving higher light energy under no shade condition assimilated significantly higher radioactive carbon per unit area than those grown under dense shade. Similar trend was observed in the case of photosynthate translocation, as well. The results of the present study confirmed the findings of Barua (1989) that tea leaf photosynthesis under heavily shaded conditions exhibit lower quantum of carbon assimilation.

Table 2: Influence of shade on carbon assimilation and partitioning of assimilates

| Degree of shade | C-14 fixed/ unit area (CPM '000) | Assimilates translocated (per cent) | Respiration as % Photosynthetic rate | | Photo/ dark respiration |
|---|---|---|---|---|---|
| | | | Light | Dark | |
| No shade | 28.5 | 15.5 | 3.77 | 1.46 | 2.31 |
| Regulated shade | 39.2 | 19.8 | 2.95 | 1.57 | 1.82 |
| Dense shade | 11.4 | 10.5 | 3.33 | 1.67 | 1.99 |
| *C.D.P = 0.05:* | 8.6 | 4.1 | 0.46 | 0.24 | - |

Reassimilation under light conditions, both full sun and heavy shade was found to be similar and plants in both treatments exhausted significantly higher quantum of recently fixed photosynthates than the tea plants grown under regulated shade. It has been reported that out of total photosynthates synthesised, about 41% was reassimilated during day time and 23 % during night (Raj Kumar *et al.*, 1998).

The ratio under photo and dark respirations was high in plants under full sun followed by densely shaded tea plants (Table 2). Results of the present study were comparable with earlier findings, where the ratio was 1.78 under green house conditions. Reduced light intensity caused changes in photosynthetic and respiratory metabolism (Smith, 1982). As the amount of assimilated carbon dioxide under regulated light condition was large, retention of carbon was also high. However, partitioning of assimilates and reassimilation processes are regulated by shade to a great extent.

Total chlorophyll (Chl) and Chl - A level were significantly more in plants under regulated shade and dense shade, as compared to the plants grown under unshaded conditions (Table 3). Increase in Chl content might improve the light harvesting capability (Barman *et al.*, 1994). Significant variation in carotenoid composition was noticed between the treatments. Long term exposure of plants to strong light can result photodestruction of photosynthetic pigments, as it was noticed in the present study. Tea plants under dense shade invest a greater proportion of photosynthates for synthesis and maintenance of the light harvesting machinery than do sun plants (Boardman, 1977).

Table 3: Effect of shade on photosynthetic pigments and leaf proline content

| Degree of Shade | Chlorophyll mg/g fr.wt | | | | Carotenoids | Leaf proline |
|---|---|---|---|---|---|---|
| | A | B | a+b | A/B | | |
| **No shade** | 0.695 | 0.233 | 0.928 | 3.098 | 0.230 | 0.99 |
| **Regulated shade** | 0.828 | 0.253 | 1.083 | 3.348 | 0.303 | 0.90 |
| **Dense shade** | 0.808 | 0.255 | 1.063 | 3.145 | 0.263 | 0.82 |
| *C.D.P = 0.05:* | 0.097 | 0.043 | 0.135 | 0.435 | 0.033 | 0.13 |

* Leaf proline, µmole/g fresh weight

Proline content in tea leaves of "Chinery" clone is quite high when compared to the "Assam" cultivars (Rajkumar *et al.*, 1993). Proline accumulation was more in leaves of unshaded tea plants and this may be attributed to the soil moisture stress coupled with high temperature and high light intensity. Tea plants grown without shade might have diverted more photosynthates towards the synthesis of proline. The root carbohydrate levels were almost the same in plants grown without shade or under dense shade, but relatively lower than that of the plants with regulated shade (Table 4).

Table 4: Influence of shade on root carbohydrates and certain soil properties

| Degree of Shade | Root Carbohydrate (%) | Soil moisture (per cent) | Water holding capacity (%) | Soil OM (per cent) |
|---|---|---|---|---|
| **No shade** | 18.4 | 15.0 | 54.4 | 2.47 |
| **Regulated shade** | 21.7 | 17.1 | 64.1 | 2.60 |
| **Dense shade** | 18.7 | 18.5 | 63.6 | 2.79 |
| *C.D.P = 0.05:* | 3.9 | 2.0 | 8.7 | 0.29 |

The soil moisture depleted more rapidly from areas without shade than from areas under other treatments. Soil organic matter content improved markedly under dense shade followed by regulated shade conditions which inturn reflected on the water holding capacity of the soils (Venkataramani, 1961). Despite the differences in shade tree management and agroclimatic conditions in N.E.India and southern India, results of the present investigation substantiate the earlier findings of Barman *et al.* (1994).

It has been observed that full sun and dense shade inhibited metabolic activities of tea plants. High light intensity can be reduced substantially by raising the recommended shade trees while dense shade should be thinned out to get adequate light intensity, which inturn will sustain higher metabolic activity even under conditions of soil moisture stress.


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