Impact of photosynthetic active radiation on performance of tea crop under agro forestry eco system in eastern India

*Asis Mukherjee**, *S. Sarkar*

Abstract: *A study was carried out in the* University tea garden *to screen suitable shade tree in terms of tea yield and Photosynthetic Active Radiation (PAR) use efficiency. Seven shade tree species viz.* Acacia auriculiformis, Casuarina equisetifolia, Dalbergia sissoo, Glyricidia sepium, Albizia lebbek, Gmelina arborea and Eucalyptus hybrid *were considered in this study as main plot treatment. In this study tea leaves were plucked on four occasions (3rd Oct, 13th Nov, 27th Feb and 13th March). Growing periods in between two consecutive pluckings were termed as Phases, which were considered as sub-plot treatment. On the basis of incidental and absorbed PAR, growth rate and dry weight of tea leaves, the shade trees were grouped into: high (*Acacia, Casuarina *and* Dalbergia*), medium (*Eucalyptus*) and low (*Glyricidia, Albizia *and* Gmelina*) categories. Considering all aspects* Acacia auriculiformis *can be recommended as the most suitable shade tree for growing tea crop in eastern India.*
Keywords: *tea, Photosynthetically active radiation (PAR), shade tree, leaf yield.*

Riassunto: *Uno studio è stato condotto nel* University tea garden *per lo* screening *di piante di tè adatte alle condizioni ombreggiate, in termini di resa e di efficienza nell'uso della radiazione. Sette specie di alberi ombra sono state considerate in questo studio:* Acacia auriculiformis, Casuarina equisetifolia, Dalbergia sissoo, Glyricidia sepium, Albizia lebbek, Gmelina arborea and Eucalyptus hybrid. *Nel corso dello studio le foglie di tè sono state raccolte in quattro epoche (3 Ottobre, 13 Novembre, 27 Febbraio e il 13 marzo). I periodi di crescita compresi fra due raccolte consecutive sono state definite "fasi" e sono state considerate come trattamento sub-plot. Sulla base della radiazione incidente e assorbita, il tasso di crescita e il peso secco delle foglie di tè, gli alberi ombra sono stati raggruppati in: alto (*Acacia, Casuarina *and* Dalbergia*), medio (*Eucalyptus*) e basso (*Glyricidia, Albizia *and* Gmelina*). Considerando tutti gli aspetti* Acacia auriculiformis *può essere raccomandato come la specie più adatta alla coltivazione del tè in ombra nell'India orientale.*
Parole chiave: *tè, Radiazione Fotosinteticamente Attiva (PAR), alberi da ombra, produzione di foglie.*

1. INTRODUCTION

Tea is one of the major commercial crops in India and contributs 5.8 per cent of the total agricultural export. India occupies around 18.4 per cent (600000 ha) land area of the global tea cultivation and shares 21 per cent (966600 MT) of world production (FAO, 2014). Traditionally tea is grown at large patches in the hilly areas of south, eastern and north-eastern states of India. However, since the beginning of this century farmers in plains also grows tea under agro-forestry eco-system (Boriah 2002). Dry matter production of vegetation under non-limiting water and nutrient condition is a function of intercepted PAR (Mariscal 2000, Monteith 1994) and the final biomass of the crop responds linearly to the accumulated intercepted PAR during the entire cropping period up to a certain limit (400 MJ m^{-2}), above which a curvilinear relationship exists (Purcell *et al.*, 2002). Variation of dry matter production could rise from differences in the amount of cumulative intercepted radiation (Hamzei and Soltani 2012). Productivity of any crop depends on the total net accumulation of assimilated carbon, in general, and on photosynthetic rate per unit leaf area, in particular (Mohotii and Lawlor 2002). Although photosynthetic active radiation (PAR) spectrum represents a small fraction of the total solar radiation energy, it plays a major role on biological system through regulating canopy photosynthetic rate (Shulski *et al.*, 2004). Linear relationship between above ground biomass and absorbed or intercepted PAR under non-stress condition, supports this hypothesis (Mukherjee *et al.*, 2014, Will *et al.*, 2005, Carnell *et al.*, 1987, Dalla-Tea and Jokela 1991).

Tea is a shade loving crop, adapted to the understorey of forests in its native habitat (Obaga 1984, Carr and Stephens 1992). Shades from overstorey crops, may ameliorate microclimatic conditions for understorey crops (Gregory and Ingram, 2000) and such microclimatic variation has a major impact on crop

* Corresponding author's e-mail: asismukherjee@gmail.com
Department of Agricultural Meteorology and Physics, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, India.
Received 19 April- 2015, accepted 22 July 2015

DOI:10.19199/2016.1.2038-5625.037

performance, growth, development and yield (Singh *et al.*, 2012, Slingo *et al.*, 2005). There are optimal level of temperature, radiation and other meteorological parameters, above or below which physiological and deve-lopmental processes as well as yield reduce significantly (Challinor *et al.*, 2005, Porter and Semonov 2005). Thus, shade trees increase understorey productivity by providing favourable microclimatic conditions to the understorey crop and redistributing water from relatively wet to drier soil horizon by the process of hydraulic lift. In this case, water moves from relatively wet to dry soil layers through plant roots, mainly during the night time when leaf stomata are closed and the highest potential gradient existes in between the deep (wet soil) roots and the drier (top soil) roots (Ludwig *et al.*, 2003).

The intensity of radiation is an important factor because it influences the status of photo inhibition (Smith *et al.*, 1993). Coffee, which physiology is similar like tea, also responds similarly to radiation and shade (Ramalho *et al.*, 1997, Nunes *et al.*, 1993). Exposure of tea crop to strong radiation reduces the activity of photosynthetic components (Baker and Bowyer 1994). It has been reported that in the north-eastern plains of India, productivity of tea declines even up to 50 per cent of its potential level when it grows under open environment condition (Banerjee 1993).

Agroforestry may provide an economically viable way of protecting the understory crop when microclimatic elements exceed the optimal values (Lin 2007). Nowadays in plain land of India, area of tea cultivation is increasing under agro forestry system and it is converting to the system that is more profitable. Impact of trees on microclimate of the understorey crop on their physiological responses and on yield is not well-documented (Ong *et al.*, 2006, 2007). In addition to that, there is very little information available regarding the selection of shade trees based on the criteria of understorey crop yield and PAR utilisation. With this background, the present study was performed to describe the influence of different shade trees on understorey microclimate, focusing on PAR and to identify suitable shade trees for tea cultivation in the lower Indo- Gangetic plain of eastern India.

2. MATERIALS AND METHODS

2.1 Study site

The study was carried out since September 2010 to March 2011 in the tea garden of the Central Research Farm of the University (Latitude $22^0 58'$ N, Longitude $88^0 31'$ E, altitude 9.75 m amsl), Gayeshpur, West Bengal, India. The soil was sandy loam Aeric Haplaquept. Climatologically, the area falls under sub humid tropical zone. Long period average annual rainfall of this site is around 1700 mm, of which 1234 mm occurs during rainy (June-September) season and the rest of the amount occurs during non-rainy season. Monthly variation of long period maximum and minimum temperature is presented in Fig. 2. Phase wise variation of rainfall and temperature values are illustrated in Fig. 3.

2.2 Experimentation

The experiment was set up in a split - plot design with seven shade tree species as main plot treatments and four growing periods in between two plucking (Phases) as subplot treatments.

The size of the each shade treatment plot was 20m x 12m. The sapling of the each tree species were planted 5 m x 4 m apart within respective shade (Fig. 1).

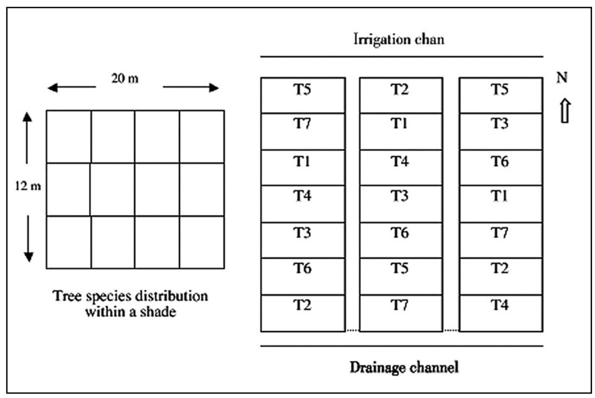

Fig. 1 - Schematic diagram of experimental layout.
Fig. 1 - Diagramma schematico dell'impianto sperimentale.

The seven shade tree species were: T1: *Acacia auriculiformis,* T2*: Casuarina equisetifolia,* T3*: Dalbergia sissoo,* T4*: Glyricidia sepium,* T5: *Albizia lebbek,* T6: *Gmelina arborea and* T7: *Eucalyptus hybrid*. Four Phases were: Phase I – 7th September to 3rd October; Phase II – 4th October to 13th November; Phase III – 14th November to 27th February; Phase IV – 28th February to 13th March.

3. OBSERVATIONS

3.1 Photosynthetic active radiation

Four components of PAR like Incident PAR (IPAR) above tea canopy (passes through shade trees), transmitted PAR (TPAR) through tea canopy, reflected PAR from tea crop (RPARc) and soil (RPARs) were recorded once a week (every Friday) at 9 a.m. and 1 p.m. At these two times incoming radiation was measured inside the shade trees and

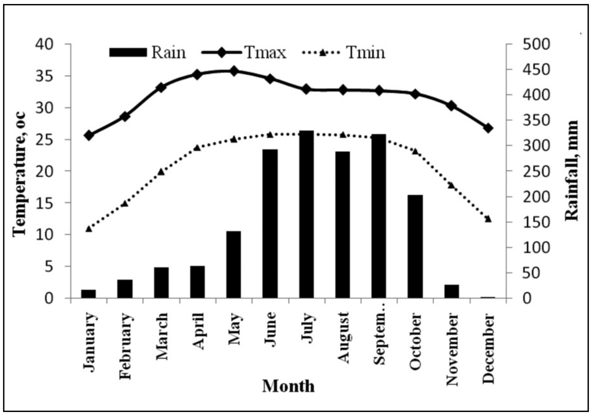

Fig. 2 - Variation of long period monthly rainfall, maximum and minimum temperature of the experimental location.
Fig. 2 - Variazione di lungo periodo delle precipitazioni mensili e della temperatura massima e minima nell'area di studio.

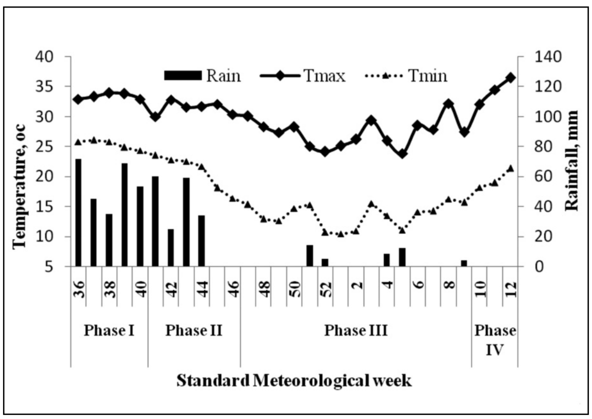

Fig. 3 - Phase wise variation of rainfall, maximum and minimum temperature during the experimental period.
Fig. 3 - Fasi di variazione delle precipitazioni e della temperatura massima e minima durante il periodo di sperimentazione.

within the tea canopy as well as in the open area (un-shaded). Diurnal parabolic graph of the previously recorded incoming radiation data shows that, the morning time steepness of the incoming radiation starts around at 9 a.m. hr and the maximum value of the day occurs at 1 p.m. (Yuan *et al.*, 2004). The data were taken from four different points underneath a particular shade tree and the values were averaged for presentation. Hourly incoming radiation data were collected from a nearby (500 m) automatic weather station. The PAR photon flux density (m mol m^{-2} s^{-1}) was measured with a point quantum sensor (Model LI- 185 B, Li – Cor, Lincoln, NE) and subsequently converted to irradiance (W m^{-2}) using a conversion factor of 4.6 m mol quanta J^{-1} (Li – Cor 1991).

Fresh leaves and buds were plucked at each plucking date from 4 X 5 m^2 area and subsequently dried in plant drier to get the dry leaf weight.

Leaf area index of shade trees was measured by using Plant canopy analyser instrument (LI COR, inc, LAI-2050, PCH-2416, Made in USA).

Absorbed PAR (APAR) by tea crop was calculated using the equation proposed by Gallo and Daughtry 1986.

$$APAR = (IPAR + RPAR_S) - (TPAR - RPAR_C) \quad (1)$$

Hourly incident PAR data inside the shade trees were extrapolated from the hourly incident automatic weather station data; by comparing relative percentage of recorded data, in each shade tree and open condition. Then the day to day APAR under different shade tree species was accumulated for all the Phases.

Thereafter, the APAR use efficiency (APARUE) was calculated as:

$$APARUE = \frac{\text{Total dry yield of tea leaves}}{\sum APAR} \quad (2)$$

3.2 Statistical analysis

The statistical differences among shade tree species and Phases and their interaction on LAI and leaf yield were tested with Fisher's least significant difference test ($P \leq 0.05$) using analysis of variance as mentioned in Panse and Sukhatme (1967). The statistical measurements of coefficient of determination (R^2) of the equations were determined to indicate the degree of association between two variables.

4. RESULTS AND DISCUSSION

4.1 Incident photosynthetically active radiation (IPAR) above tea canopy

Incident PAR above tea crop surface depends on the canopy architecture and leaf area index (LAI) of the above storey shade tree. IPAR showed an inverse and significant linear relationship with LAI value (Fig. 4). At 9 a.m., irrespective of Phases, mean IPAR value was at the highest level under *Dalbergia* sissoo (Tab. 1). Because of the elliptical shape of the leaves and branching pattern more amount of PAR passes through the *Dalbergia sissoo* tree (Bose *et al.*, 1998). In contrast, the minimum amount of IPAR, in general, reached tea crops in all the four Phases under *Albizia lebbek*. Leaf angle distribution of shade trees influenced the magnitude of IPAR passes through the trees (Singh *et al.*, 2012, Grant 1991, Grant 1999). In general, highest LAI of *Albizia lebbeck* largely restricted the penetration of PAR. On

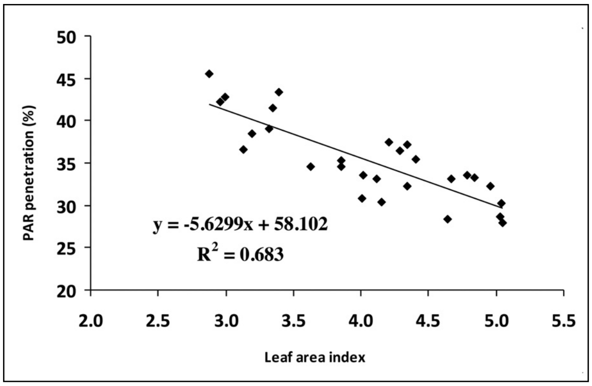

Fig. 4 - Relationship between PAR penetration and leaf area index of shade trees.
Fig. 4 - Relazione tra la penetrazione del PAR e il LAI in alberi ombra.

the other hand, lower LAI of *Dalbergia sisoo* (Tab. 2) caused greater penetration through its canopy. Because of amount of IPAR, penetrated through shade trees at 9 a.m., the seven shade trees were grouped into three categories as high, medium and low. *Acacia, Casuarina and Dalbergia* falls under high (45.3 to 47.8 W m^{-2}), Eucalyptus (41.6 W m^{-2}) and *Glyricidia*, *Albizia* and *Gmelina*, under low (36.8 to 37.6 W m^{-2}). So far, when the IPAR data at 1 p.m. are considered, *Dalbergia* falls under moderate shade group and *Eucalyptus* under light shade group (Tab. 1). Except these two, IPAR passes through different shade tree species and Phases followed similar trend at both 1 p.m. and 9 a.m. It is a well-known fact that angle of sun playes a crucial role on intensity of solar radiation. Thus, both season (Phase) as well as tree species playes crucial role in monitoring IPAR status underneath shades (Feldhake and Belesky 2009). This is well pointed out by the IPAR data obtained through the shade tree at different time of the year. During Phase – I, IPAR value attain the second highest value (46.9 W m^{-2}). With the advancement of time at Phase - II the IPAR values decreased if compared to Phase - I. Phase - III, which comprises the typical winter months, the IPAR values were at their lowest level (30.5 W m^{-2}). During the spring season Phase- IV, IPAR value attained its highest level (50.1 W m^{-2}). During this period, due to greater leaf senescence,

Shade tree species	Observation time							
	9 hours				1 3 hours			
	P - 1	P - II	P - III	P - IV	P - 1	P - II	P - III	P - IV
Acacia	50.8	40.9	30 .9	58.4	120.4	82.6	62.8	110.8
Casuarina	50.3	42.5	32.3	56.3	129.5	72.5	65.6	110.6
Glyricidia	43.0	38.1	28.9	40.3	111.6	64.0	52.4	81.2
Eucalyptus	47.3	37.9	32.4	48.8	94.4	49.9	48.4	90.8
Albizia	42.2	32.3	27.6	45.7	90.5	53.6	48.1	65.0
Dalbergia	55.8	43. 9	31.2	60.2	119.2	83.6	61.4	93.9
Gmelina	38.9	36.9	30.3	41.1	92	56.0	48.3	77.2
Open	127.7	103.1	81	150.3	267	203.7	186.4	244.7
	Statistical analysis							
	9 hours				13 hours			
Factor	SEm (±)		LSD (P = 0.05)		SEm (±)		LSD (P = 0.05)	
Shade Tree species (S)	2.73		8.3 9		13.76		42.51	
Phase (P)	3.01		8.58		12.59		35.93	
S x P	7.96		NS		33.31		NS	

 values presented in the table are average of weekly reading during the entire phase (P)
Phase I – 7th September to 3rd October; Phase II – 4th October to 13th November;
Phase III – 14th November to 27th February; Phase IV – 28th February to 13th March

Tab. 1 - Photosynthetic active radiation (W m^{-2}) penetrated through shade trees at different growing periods.
Tab. 1 - Radiazione fotosinteticamente attiva (W m^{-2}) penetrata attraverso la chioma degli alberi in diversi periodi di crescita.

Shade tree species	Phases				Mean
	P - 1	P - II	P - III	P - IV	
Acacia	3.39	4.34	3 .19	2.99	3.48
Casuarina	2.88	4.21	3.13	2.96	3.30
Glyricidia	4.28	4.84	4.15	4.01	4.32
Eucalyptus	4.96	5.03	4.02	3.85	4.47
Albizia	4.78	5.05	4.64	4.12	4.65
Dalbergia	3.35	4.41	3.63	3.32	3.68
Gmelina	4.67	5.04	4.34	3.85	4.48
Mean	4.04	4.70	3.87	3.59	
	Statistical analysis				
	S Em ±	LSD (P = 0.05)			
Shade tree species (S)	0.095	0.293			
Phases (P)	0.121	0.345			
S X P	0.216	0.617			

Tab. 2 - Variation of leaf area index of shade trees during different seasons.
Tab. 2 - Variazione del LAI di alberi ombra durante stagioni diverse.

leaf area index value remained at the lowest level (Tab. 2) under all the shade trees as well as the incoming solar radiation was at the highest level during this phase (Tab. 1). Thus, lower LAI of shade trees allowed higher magnitude of incoming radiation during Phase IV.

4.2 Absorbed photosynthetic active radiation by the tea crop

Canopy status of a shade tree also influenced the magnitude of absorbed photosynthetically active radiation (APAR) of tea crop, grown under it. At 9 a.m. magnitude of APAR was at the highest level under *Dalbergia* (44.0 W m^{-2}). It was at the lowest level (33.6 W m^{-2}) under *Gmelina* (Tab. 3). Generally higher magnitude (41.7 to 44 W m^{-2}) of PAR was absorbed under *Acacia, Casuarina* and *Dalbergia* shades. Thus, these tree species are grouped into high category while as *Eucalyptus* falls under medium group for intermediate APAR value (37.9 W m^{-2}) and *Albizia*, *Gmelina* and *Glyricidia,* in general, falls under low category (33.6 to 34.1 W m^{-2}). Notable variation in magnitude of APAR was also noticed among the Phases (Tab. 3). During Phase - I magnitude of PAR absorbed by tea crop touched the peak value (44 W m^{-2}) because just after the rainy season the profuse new leaves came out, which are more potential for radiation absorption. Thereafter it declined continuously up to Phase - III followed by moderately increasing trend Phase - IV. Mean value of APAR during Phase - IV was 43.8 W m^{-2}. Recorded data on absorbed PAR at 1 p.m. shows that *Eucalyptus* comes under low group and *Glyricidia* comes into moderate group. Except these two cases, APAR values under different shades and Phases, followed similar pattern like 9 a.m.

4.3 Growth rate of tea leaves

In the present study, irrespective of Phases, growth rate of tea leaves under *Acacia* and *Dalbergia* were was at higher (2.53 to 2.89 kg $ha^{-1}day^{-1}$) category, where, under *Eucalyptus*, *Gmelina* and *Albizia* it falls in the middle group (2.41 to 2.46 kg $ha^{-1}day^{-1}$). In general growth rate was at the lowest level (1.95 to 2.18 kg $ha^{-1}day^{-1}$) under *Glyricidia* and *Casuarina* (Tab. 4). Photosynthesis, respiration and other physiolo-gical activities, which ultimately regulate the growth rate, are usually influenced by different environmental factors like radiation, temperature, precipitation etc.

Due to the positive influence of monsoonal rain, Phase – I showed higher magnitude (3.55 kg ha^{-1} day^{-1}) of tea growth rate. Low incident radiation (Tab. 1) and lowering of temperature (Fig. 3) to the tune of 10-16 °C may be responsible for a sharp decrease in growth rate from Phase - I to Phase - III. The optimum temperature range for tea cultivation is 28-32 °C and drastic reduction in growth rate has been observed when temperature goes below 13°C (TOKLAI, 2015).

Shade tree species	Observation time							
	9 hours				13 hours			
	P - 1	P - II	P - III	P - IV	P - 1	P - II	P - III	P - IV
Acacia	47.5	38.8	28.2	52.1	112.7	77.9	58.9	104.2
Casuarina	46.9	39.9	30.0	50.1	121.9	67.8	62.0	103.9
Glyricidia	40.3	36.2	26.0	33.7	104.8	60. 2	48.8	75.8
Eucalyptus	44.3	35.9	29.9	41.6	87.1	46.2	45.4	85.1
Albizia	39.9	30.5	25.1	40.5	85.5	50.4	44.6	60.4
Dalbergia	52.5	41.4	28.4	53.5	113.2	79.3	57.4	88.6
Gmelina	36.3	35.1	27.8	35.0	86.9	52.8	45.3	72.6

Statistical analysis

Factor	9 hours SEm ±	9 hours LSD (P = 0.05)	13 hours SEm (±)	13 hours LSD (P = 0.05)
Shade Tree species (S)	2.08	6.39	8.90	27.42
Phase (P)	1.47	4.20	5.76	16.43
S x P	3.89	11.11	15.23	43.47

Tab. 3 - Role of shade trees on absorbed photosynthetic active radiation (W m^{-2}) at different growing periods.
Tab. 3 - Ruolo di alberi ombra sull'assorbimento di radiazione fotosinteticamente attiva (W m^{-2}) in diversi periodi di crescita.

After attaining the lowest growth rate (0.92 kg ha^{-1} day^{-1}) at Phase – III an increasing trend (3.85 kg ha^{-1} day^{-1}) of the same was recorded at Phase – IV. Increase in atmospheric temperature as well as values of incident PAR were responsible for highest growth rate at Phase - IV. The relationship between growth rates of tea leaf and mean APAR was constructed using all 28 sets (7 tree species x 4 Phases) of data. The linear regression between growth rate and mean APAR showed that about 62 per cent of variation in growth rate could be attributed to variations in APAR (Fig. 4). In general,

Shade tree species	Phases				Mean
	P - 1	P - II	P - III	P - IV	
Acacia	4.36	1.39	0.80	5.00	2.89
Casuarina	4.28	0.79	0.93	2.71	2.18
Glyricidia	2.40	0.95	0.65	3.80	1.95
Eucalyptus	3.66	1.23	0.94	3.83	2.41
Albizia	2.72	1.78	0. 81	4.54	2.46
Dalbergia	3.79	1.81	1.24	3.26	2.53
Gmelina	3.60	1.11	1.08	3.83	2.41
Mean	3.55	1.29	0.92	3.85	

Statistical analysis

	SEm ±	LSD (P = 0.05)
Shade tree species (S)	0.006	0.017
Phases (P)	0.026	0.076
S X P	0.069	0.199

Tab. 4 - Role of shade trees on Growth rate (kg ha^{-1} day^{-1}) of dry tea leaves at different growing periods.
Tab. 4 - Ruolo di alberi ombra sul tasso di crescita (kg ha^{-1} $giorno^{-1}$) di foglie di tè in diversi periodi di crescita.

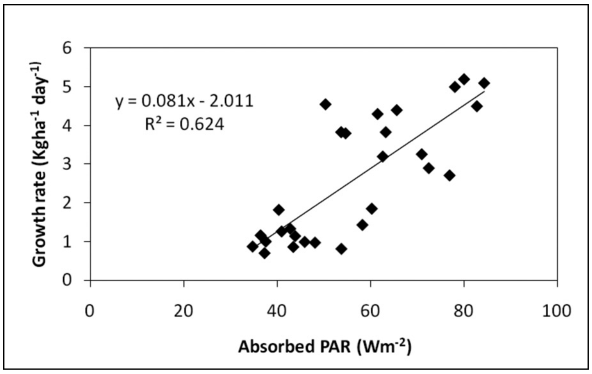

Fig. 5 - Relationship between absorbed PAR and growth rate of tea leaves.
Fig. 5 - Relazione tra PAR assorbita e tasso di crescita di foglie di tè.

photosynthetic activity of most of the crops increased with an increase in availability of per cent sunlight fallen on the crop. However, tea crop prefers up to a certain limit of sunlight vis-à-vis total solar radiation for its optimum growth and development. That is also supported by Banerjee (1993), who observed a decreasing trend in net assimilation rate of tea when the amount of daylight crosses the 50 per cent limit of its actual value.

4.4 Dry leaf yield

Irrespective of Phases, in general, dry leaf yield attained higher values (90.5 to 99.5 kg ha^{-1}) under *Acacia*, *Gmelina* and *Dalbergia* (Tab. 5), whereas the same under *Eucalyptus*, *Casuarina* and *Albizia* falls in the medium group (81.8 to 88.2 Kg ha^{-1}). Dry leaf yield under *Glyricidia* falls under low category (67.9 Kg ha^{-1}). The nature and properties of sun flecks varied due to different shade tree species. The spectral properties of leaves of different shade tree species have also a profound effect on solar radiation absorbed by the tea canopy. The shade tree leaves strongly absorbed solar radiation in the visible range and emitted radiation effectively in the far infrared. Therefore, the tea canopy under the shade receives different kinds of radiant energy under different kind of shade trees. *Glyricidia* tree intercepts more than 90 % of incoming radiation, thus lower amount of radiation is available inside the shade (Chirwa *et al.*, 2003). Thus, variation in status of PAR influenced the magnitude of dry leaf weight of tea crop. Plant leaf area has an important influence on light interception and dry matter production (Kar and Kumar 2014, Panda *et al.*, 2003). Acacia trees enhanced the understorey vegetation by reducing incident solar radiation, air and soil temperature (Belsky *et al.*, 1989) and allelopathic effect of *Eucalyptus* may be one of the causes of reduction of tea leaf yield. In the present study unlike growth rate, incident and absorbed PAR, the phasic variation of dry leaf yield showed quite different pattern. Marked variation on total duration of a particular phase (PI-31 days, PII-39 days, PIII-106

Shade tree species	Phases				Mean
	P - 1	P - II	P - III	P - IV	
Acacia	135.3	54.2	85.3	120.1	98.7
Casuarina	132.7	30.8	98.5	65.0	81.8
Glyricidia	074 .3	36.9	69.4	91.1	67.9
Eucalyptus	113.6	47.8	99.6	91.8	88.2
Albizia	084.3	69.3	85.9	108.9	87.1
Dalbergia	117.5	70.4	131.9	78.3	99.5
Gmelina	111.6	43.4	114.8	92.0	90.5
Mean	109.9	50.4	97.9	92.5	
	Statistical analysis				
	SEm ±	LSD (P = 0.05)			
Shade tree species (S)	5.82	17.34			
P hases (P)	3.22	9.18			
S X P	8.51	24.29			

Tab. 5 - Impact of shade trees on dry leaf weight (kg ha^{-1}) of tea at different growing periods.
Tab. 5 - Impatto di alberi in ombra sul secco di foglie (kg ha^{-1}) di tè in diversi periodi di crescita.

Shade tree species	Phases				Mean
	P - 1	P - II	P - III	P - IV	
Acacia	0.767	0.135	0.197	0.458	0.389
Casuarina	0.565	0.086	0.122	0.395	0.292
Glyricidia	0.423	0.131	0.199	0.414	0.292
Eucalyptus	0.550	0.203	0.178	0.452	0.346
Albizia	0.573	0.351	0.221	0.45	0.399
Dalbergia	0.486	0.215	0.093	0.475	0.317
Gmelina	0.867	0.182	0.175	0.527	0.438
Mean	0.604	0.186	0.169	0.453	
		Statistical analysis			
	SEm ±	LSD (P = 0.05)			
Shade tree species (S)	0.0245	0.0755			
Phases (P)	0.0189	0.0540			
S X P	0.0500	0.1428			

Tab. 6 - Role of shade trees on PAR use efficiency (g MJ^{-1}) of dry tea leaves at different growing periods.
Tab. 6 - Ruolo di alberi ombra sull'efficienza d'uso del PAR (g MJ^{-1}) di foglie di tè in diversi periodi di crescita.

days and PIV-24 days) and average growth rate of tea leaves (Tab. 4) were the probable reason for such trend in dry leaf production. On an average, highest dry leaf yield (109.9 kg ha^{-1}) was produced during Phase I (Tab. 5), which is due to highest growth rate of tea leaves (3.55 kg ha^{-1} day^{-1}) after rainy season. Decrease in average growth rate (1.29 kg ha^{-1} day^{-1}) due to lowering temperature during Phase II resulted the lowest (50.4) dry leaf yield. Though the growth rate remained at the lowest level (0.92 kg ha^{-1} day^{-1}) during Phase III, however longer duration (106 days) of this phase was responsible for achieving almost double (97.9 kg ha^{-1}) leaf dry matter compared to Phase II. During Phase IV increasing incident radiation and temperature (Fig. 2) accelerated the growth rate and produced 92.5 kg ha^{-1} dry leaf yield within a span of only 24 days. Photosynthetic rate is determined by the characteristics of photosynthetic apparate, which is governed by meteorological conditions near the crop during the growth period. As the governing meteorological parameters change with seasons (Fig. 2) there is a seasonal variation in the productivity level of tea crop (Lawlor 2001).

4.5 Use efficiency of absorbed photosynthetic active radiation

Statistically significant variation in APAR use efficiency (APARUE) was observed among different shade trees as well as among the Phases. Irrespective of Phases, the highest (0.44 gMJ^{-1}) APARUE was obtained under *Gmelina* closely followed by *Albizia* and *Acacia*. The rest of the shade trees remained statistically at par. However, the lowest magnitude (0.292) of PARUE was recorded combinely under *Casuarina* and *Glyricidia*. The magnitude of APARUE at different Phases (average over shade tree) followed similar trend like that of leaf yield. On an average APARUE was at the highest (0.604 g MJ^{-1}) level at Phase – I; it was significantly lower at Phase II (0.186 g MJ^{-1}) and Phase III (0.169 g MJ^{-1}); then therewas a sharp increase (0.453 g MJ^{-1}) at Phase IV (Tab. 6).

5. CONCLUSIONS

In the tropical sub-humid condition of eastern India, *Acacia auriculiformis, Casuarina equisetifolia, Dalbergia sissoo* species can be preferred for plantation as shade trees in the tea gardens for better utilisation of photosynthetic active radiation and productivity of tea leaves. In this region, pre and post rainy seasons are most suitable times for higher productivity of tea leaves. Variation in absorbed photosynthetic active radiation was responsible for fifty per cent variation in growth rate of tea leaf under the given experimental condition.

REFERENCES

Baker N.R., Bowyer J.R., 1994. Photo inhibition of photosynthesis, from molecular mechanism to the field. Oxford, UK.

Banerjee B., 1993. Tea production and processing (1st edition).Mohan Primlani for Oxford and IBH, New Delhi. pp. 336.

Belsky A.J., Amundson R.G., Duxbury J.M., Riha S., Mwonga S.M., (1989). The effects of trees on their physical, chemical and biological environments in semi-arid savanna in Kenya. J Appl Ecol, 26: 143-155.

Boriah B., 2002. India, world's largest tea consumer. The Hindu Survey of Indian Agric. 2002, pp. 125-128.

Bose T.K., Das P., Maiti R.G., 1998. Trees of the world – vol. 1 Regional Plant Resource Cen. Bhubaneswar. Orissa, India, pp. 506.

Carnell M.G.R., Milne R., Shepard L.I., Unsworth M.H., 1987. Radiation interception and productivity of willow. J of Appl Eco, 24: 261-278.

Carr M.K.V., Stephens W., 1992. Climate, weather and the yield of tea. In: Wilson K.C., Clifford, M.N., (Eds.) Tea-cultivation to consumption. London: Chapman and Hall, 87-135.

Challinor A.J., Wheeler T.R., Slingo T.M., Hemming D., 2005. Quantification of physical and biological uncertainty in the simulation of yield of a tropical crop using present-day and doubled CO2 climates. Philos Trans R Soc B 360: 2085-2094.

Chirwa P.W., Black C.R., Ong C.R., Maghembe J.A., 2003. Tree and crop productivity in gliricidia/maize/pigeonpea cropping systems in southern Malawi. Agroforestry Systems 59 (3): 265-277.

Dalla-Tea F., Jokela E.J., 1991. Needlefall, canopy light interception, and productivity of young intensively managed slash and lobbolly-pine stand. Forest Science, 37:1298-1313.

FAO, 2014. Online statistical database of Food and Agricultural Organization of United Nations. http:/ www.faostat.fao.org.

Feldhake C.M., Belesky D.P., 2009. Photosynthetically active radiation use efficiency of Dactylis glomerata and Schedonrus phoenix along a hardwood tree-induced light gradient. Agroforestry System, 75: 189-196.

Gallo K.P., Daughtry C.S.T., 1986. Techniques for measuring intercepted and absorbed photosynthetically active radiation in corn canopies. Agron J, 78: 752 -756.

Grant R.H., 1991. Ultra violet and photosynthetically active bands: plane surface irradiance at corn canopy base. Agron J, 83: 391-396.

Grant R.H., 1999. Ultraviolet –b and photosynthetically active radiation environment of inclined leaf surfaces in a maize canopy and implications for modelling. Agric For Meteor, 95: 187-201.

Gregory P.J., Ingram J.S.I., 2000. Global change and food and forest production: future scientific challenges. Agric Ecosyst Environ, 82: 3-14.

Hamzei J., Soltani J., 2012. Deficit irrigation of rapeseed for water-saving: Effects on biomass accumulation, light and radiation use efficiency under different N rates. Agric Ecosys and Environ, 155: 153-160.

Kar G., Kumar A., 2014. Forecasting rainfed rice yield with biomass of early phenophases, peak intercepted PAR and ground based remotely sensed vegetation indices. J. of Agrometeorology, 16: 94-103.

Lawlor D.W., 2001. Photosynthesis: molecular, physiological and environment processes, 3rd edn. Oxford, UK: Bios Scientific Publishers.

Li – Cor, 1991. Radiation measurement instruments. Li – Cor, Lincoln, NE., USA.

Lin B.B., 2007. Agroforestry management as an adaptive strategy against potential microclimate extremes in coffee agriculture. Agric For Met, 144: 85-94.

Ludwig F., Dawson T.E., Kroon H., Berendse F., Prins H.H.T., 2003. Hydraulic lift in Acacia tortilis trees on an East African savanna. Oecology, 134: 293-300.

Mariscal M., Orgaz F., Villalobos F., 2000. Modelling and measurement of radiation interception by olive canopies. Agric For Meteorol, 100:183-197. doi:10.1016/S0168-1923(99)00137-9.

Mohotti A.J., Lawlor D.W., 2002. Diurnal variation of photosynthesis and photoinhibition in tea: effects of irradiance and nitrogen supply during growth in the field. J Expt Botany, 53: 313-322.

Monteith J.L., 1994. Validity of the correlation between intercepted radiation and biomass. Agric For Met, 68:213-220.

Mukherjee J., Singh G., Bal S.K., 2014. Radiation use efficiency and instantaneous photosynthesis at different growth stages of wheat (*Triticum aestivum* L.) in semi arid ecosystem of Central Punjab. India. J of Agrometeorology 16: 69-77.

Nunes M.A., Ramalho J.D.C., Dias M.A., 1993. Effect of nitrogen supply on the photosynthetic performance of leaves from coffee plants exposed to bright light. J of Expt Botany, 44: 893-899.

Obaga S.O., 1984. Shade trees in tea: a review. Tea, 5: 39-47.

Ong C.K., Anyango S., Muthuri C.W., Black C.R.,

2007. Water use and water productivity of agroforestry systems in the semi-arid tropics. Ann Arid Zone, 46: 255-284.
Ong C.K., Black C.R., Muthuri C.W., 2006. Modifying forests and agroforestry for improved water productivity in the semi-arid tropics. CAB Reviews: Perspectives in Agriculture, Veterinary Science. Nutr Nat Resour, 65: 1-19.
Panda R.K., Behera S.K., Kashyap P.S., 2003. Effective management of irrigation water for wheat under stressed conditions. Agric Water Manage, 63: 37-56.
Panse V.G., Sukhatme P.V., 1967. Statistical methods for agricultural workers. Published by I.C.A.R., New Delhi. pp. 38.
Porter J.R., Semenov M.S., 2005. Crop responses to climatic variation. Philos Trans R Soc B, 360: 2021-2035.
Purcell L.C., Ball R.A., Reaper J.D., Vories E.D., 2002. Radiation use efficiency and biomass production in soyabean at different plant population densities. Crop Science, 42(1): 172-177.
Ramalho J.C., Pons T.L., Groenveld H.W., Nunes M.A., 1997. Photosynthetic responses of *Coffeaarabica* leaves to a short-term high light exposure in relation to N availability. Physiologia Plantarum,101: 229-239.
Shulski M.D., Elizabeth A., Shea W., Hubbard K.G., Yuen G.Y., Horst G., 2004. Penetration of photosynthetically active and ultraviolet radiation into alfalfa and tall fescue canopies. Agron J, 96: 1562-1571.
Singh A.K., Kumar P., Singh R., Rathore N., 2012. Dynamics of tree crop interface in relation to their influence on microclimate change- A review. Hort Flora Research Spectrum, 1: 193-198.
Slingo J.M., Challinor A.J., Hoskins B.J., Wheeler T.R., 2005. Introduction: food crop in a changing climate. Philos Trans R Soc B, 360: 1983-1989.
Smith B.G., Stephens W., Burgess P.J., Carr M.K.V., 1993. Effects of light, temperature, irrigation and fertilizer on photosynthetic rate in tea (*Camellia sinensis* L.). Expt Agric, 29: 291-306.
Tanton T.W., 1992. Tea crop physiology. In: Wilson, K.C., Clifford, M.N., (Eds.) Tea-cultivation to consumption. London: Chapman and Hall, 173-199.
TOKLAI, 2015. Tea Research Association. URL: www. Tocklai.net/activities/tea-cultivation. Viewed on 25.06.2015.
Will R.E., Narahari N.V., Shiver B.D., Teskey R.O., 2005. Effects of planting density on canopy dynamics and stem growth for intensively managed loblolly pine stands. Forest Ecology and Management, 205: 29-41.
Yuan G., Luo Y., Sun X., Tang D., 2004. Evaluation of crop water stress index for detecting water stress in winter wheat in the North China Plain. Agric Water Manage, 64: 29-40.