Journal Crop and Weed, 11(Special Issue):71-79(2015)

Studies on effect of altitude and environment on physiological activities and yield of Darjeeling tea (*Camellia sinensis* L.) plantation

R. KUMAR, J. S. BISEN, M. CHOUBEY, M. SINGH AND [1]B. BERA

Darjeeling Tea Research and Development Centre, Tea Board of India, Kurseong, Darjeeling, (WB), – 734203,

[1]Tea Board of India, 14, B. T. M. Sarani, Kolkata – 700001, India

Received:15-10-2014; Revised:30-12-2014; Accepted:05-01-2015

ABSTRACT

An investigation was conducted at DTRDC experimental farm (mid elevation) and Sungma Tea Estate (High elevation), Darjeeling during 2012 to 2013 to study the effect of photosynthetic activities on Darjeeling tea clonal cultivars of hybrids' China'- type and old china tea bush. Net photosynthetic rate (Pn) of clone T78, AV2, B157 and Old china cultivation was 11.23, 11.07, 10.26 and 9.63 μ molm^{-2}s^{-1} at mid elevation (DTRDC, experimental farm) and clone T78, AV2, B157 and Old china cultivation was 10.57, 10.13, 9.41 and 8.41 μ molm^{-2}s^{-1} respectively at high elevation from the top of canopy (0- 10 cm). Among the clones, T78 and B157 showed lower rate of transpiration (E) than clone, AV2 and old china cultivation at both elevation of Darjeeling hill. Water use efficiency (WUE) of clone T78 was higher as compared to clone, B157, AV2 and old china cultivation. Among the clones, AV2 and Old china bush showed lower rate of leaf water potential (ψ_L) than clone, T78 and B157 at both elevation of Darjeeling hill. Maximum Leaf area Index (LAI) was recorded in from the mid elevation than high elevation in the canopy depth 0-10cm. Clone AV2 was recorded lowest leaf area index in mid elevation than high elevation. Leaf area index (LAI) has a positive correlation with yield. In all treatments, vapour pressure deficit (VPD) was highest in the canopy depth 0-10cm. Highest annual tea yield was 729.26 Kg ha^{-1} recorded in T78 clone at mid elevation than high elevation and varied with clone.

Keywords: Leaf area index, leaf water potential, net photosynthetic rate, stomatal conductance, tea clone, transpiration

Tea plants are often mentioned as belonging to three distinctive types, *viz*. Assam, China, and Cambod. According to a recent classification, there are three taxa of cultivated tea, corresponding to the three geographical regions of South East Asia, namely Assam, China and Indo-China. The first two are distinct varieties, *assamica* and *sinensis*, while the third form is known as southern or Cambod form. They are "light leaf" and "dark leaf" Assam varieties. The commercially grown tea plant, as we know it today, is highly heterogeneous. It is not uncommon to find tea plants with varying leaf angles, leaf pose, leaf size, pubescence, and colouration. Two main varieties (subspecies) of *Camellia sinensis* are used for tea production. Within these main varieties, there are thousands of cultivars and clones. Assam variety (*Camellia sinensis var*. *assamica*, also known as *Camellia assamica*) (J. Masters) Kitam, and Chinese variety (*Camellia sinensis var*. *sinensis*). Tea is mainly cultivated in tropical and subtropical climates, but commercial cultivation can also be found in more temperate areas, such as Portugal (Azores Islands), the U.S. mainland (South Carolina, Washington, Georgia, and California), and even the United Kingdom (UK) (Yorkshire and Cornwall). Tea grows best under high and evenly distributed rainfall. In the tropics, it needs at least 1,500 mm rain per year with a dry season of less than 3 months. Young transplants may require supplemental irrigation. The upper limit to the amount of rainfall appears to be around 3,000 mm. In Sri Lanka, however, tea grows well in certain areas that annually receive more than 5,000 mm of rain. The ideal temperature for growth is 18–30°C. Growth is limited by temperatures above 32–35°C and below 12–13°C. The ideal day length for vegetative growth is 11Ó hours. This means that tea can be harvested year round within 15–18° of the Equator. Outside this area, dormancy will occur at a rate of 30 days for every additional 3–5° from the Equator. Tea can be grown from the lowlands to 1500–2000 m elevation above sea level. Many high quality teas are grown at high elevations, where rainfall less than 2,000 mm. In these areas the plants generally grow more slowly which results in a better flavor.

Since it is the young vegetative shoots that are harvested from the tea bush, it has been presumed that the economic yield of tea is more directly linked to photosynthetic rate than in other perennial crops (Roberts and Keys, 1978). Net photosynthetic rate (P_N) of tea leaves is influenced by the photosynthetic photon flux density (PPFD), temperature, day length, carbon dioxide concentration, genetic potential of given cultivar, physiological maturity, and management practices (Raj Kumar *et al*. 1993, Ghosh Hajra and Kumar, 1999). Therefore, study the impact of climatic variables on Pn in tea is necessary to obtain a complete

Email: rk.jayantdtrdc@yahoo.com

picture. Further, analysis of gas exchange pattern may be useful in constructing models of plant growth every day. Therefore, study of the impact of climatic variables and photosynthetic activity on physiology in Darjeeling tea cultivation is necessary to obtain a complete picture. The aim of this paper was to investigate (1) the influence of the climatic variables (Internal and External) on physiological characteristics of released tea clones and old china bush planted in Darjeeling.

MATERIALS AND METHODS

The study was conducted at the Darjeeling Tea Research & Development Centre, Kurseong (Lat. $26^0$52'09 SN, Long.$88^0$15'45 SE, altitude 1347 MSL) and Sungma Tea Estate, Darjeeling (Lat. $26^0$52'94 SN, Long.$88^0$15'49 SE, altitude 1510 MSL) during 2012 to 2013. The topography comprised of moderate slopes (25-30%). The topsoil is about 45 cm in depth and the sub soil is stony. The soil is an Umbric Dystrochrept, moderately permeable and moderately well drained. Infiltration rate is 4 –6 cm h^{-1} measured by water hydrograph method in the field (unsaturated) conditions. The soil texture is sandy loam.

Three (3) quality and contrasting tea clones, *viz*.T78, B-157, AV2 and old China plantation were selected in high elevation and mid elevation of Darjeeling hill for this study. Spacing for clones planting was 90 cm x 60 cm x 60 cm and the distance from hedge to hedge was 90 cm, row to row 60 cm, and plant to plant 60 cm and spacing for old china plantation was 100 cm x 60 cm. There were three replications per treatment. Each replication consists of 30 plants. The plants were not irrigated as this is the general practice in this region.

The Darjeeling Tea Research & Development Centre Kurseong and Sungma Tea Estate Darjeeling are both located in the lower Himalayas. Owing to the Sub-tropical situation, the year comprises a summer season (March to mid. May), rain (Mid. May to August) and winter season (November to February). The winter is divided into two portions. The first, at the end of the rains, is mild and generally free from mist and cloud (September and October). This is the autumn. Towards the beginning of December frost can occur and sometimes in January the ground becomes extremely cold and the temperature goes down to 5 ^{0}C. Although there can be occasional falls of snow in January and February and air temperatures fall below freezing point, No snowfall was experienced during the study.

During 2012 to 2013, Net photosynthetic rate (P_N), stomatal conductance (g_s) and transpiration (E), water use efficiency (WUE) and vapour pressure deficit (VPD) were monitored three times in a month at the beginning, middle and end of April, July, October and January, using a portable photosynthetic system (Li 6200, Li -cor, Nebraska, USA) with a well mixed 390 cm^3 chamber as described (Li-Cor Inc., 1987). This portable instrument has internal programmes to calculate physiological quantities from measurements of air and leaf temperatures, humidity and CO_2 concentrations. Assimilation rates are computed in this instrument by assuming linear rates of change in water vapour and CO_2 concentrations within the leaf chamber. All data points during a measurement period were fitted using linear regression techniques. The humidity within the chamber was kept constant during the measurement period in order to get satisfactory results as observed by Leuning and Sands (1989). Dark-green healthy looking mature leaves at the surface of the canopy and fully exposed to incident sunlight were used for the observations. Such leaves are often referred to as 'maintenance' foliage. Three plants randomly selected from each replicated plot were assessed on every recording (540 reading). Efforts were made to ensure that measurements were taken only when there was no cloud cover. All measurements were made between 10 00 and 12 00 hours when the maximum values of P_N and other physiological parameters were recorded in the diurnal study (Ghosh Hajra and Kumar, 2002). Photosynthetic photon flux density (PPFD) and VPD were measured concurrently using the photosynthesis system three times in a month at the beginning, middle and end of the months. The intercellular CO_2 concentration (Ci) was computed in the Li-6200 using initial values of P_N, E, ambient CO_2 concentration, and leaf resistance. The water use efficiency (WUE) was calculated as the ratio of CO_2 assimilated to water transpired. Leaves were not brought into horizontal position during the measurement to avoid sudden change in incident quantum flux. The infrared gas analyzer had been recalibrated using compressed CO_2 gas immediately before the experimental work.

Leaf water potential (ψ_L) was measured simultaneously with P_N using a dew point hygrometer (model C-52 sample chamber connected to an HR 33T microvoltmeter, Wescor Inc., Logan, USA) as described by Wescor Inc. (1988). Small circular leaf discs from the leaves on the opposite branches to those for P_N measurement were used and ψ_L values were expressed as megapascals (-Mpa).

From each plot, leaf samples were collected for measuring Leaf Area Index (LAI). Sample size was 1 square meter. Leaf area was measured from the field using a portable area meter (Li-3000A, Li – cor, Nebraska, USA) as described (Li - Cor Inc., 1987). Leaf area index (LAI) is the total leaf area divided by the sample surface area. Following equation was used to calculate LAI.

Shoots (two leaves and a terminal bud) were harvested at weekly intervals between March and October (Twenty-six cycles per year) from all the plots between fourth and sixth year after field planting. Harvesting was carried out throughout the season by the same pluckers. The total fresh mass of the shoots from each plot was weighed at each harvest and converted to the made tea equivalent using a constant value of 0.22 (Anonymous, 1988). In the Darjeeling Hills, flushing of the tea crop starts at the end of March and after a sequence of production of normal leaves in April the shoot goes dormant for a short period during May. Thereafter, harvesting of the tea crop continues until September, declines considerably towards the end of October and then ceases during November till flushing starts again at the end of March.

RESULTS AND DISCUSSION

Climate

Mean maximum air temperature ranges from around 16 ^{0}C in February to 24 ^{0}C in July; a mean minimum temperature of 4.5 ^{0}C was recorded in January (Table 1). A rapid increase of temperature takes place during March and April owing to the warmer air from the plains. In May, the southerly winds reach the hills and causes increased precipitation which is at times are very high. November to February are almost rainless and the light showers which fall in December and March occur when shallow depressions are passing eastward over the plaint. In October, northerly winds begin, cloud is much less than the previous months and rainfall occurs, mainly owing to cyclonic storms that generally re-curve towards North Bengal at the end of the season. Based on the agro-climatic conditions, the month of April is considered as pre-monsoon, June to August as monsoon, October to December as post monsoon and January to February as winter. Further, December to April could be considered as a moisture-stress period. The daily maximum net photosynthetic rate (Pn) was recorded in clones T78 and minimum in old china bush in canopy depth (from the top of bush) 0-10 cm during autumn (September) when humidity was (85%), air temperature (24^{o}C) and photosynthetic photon flux density (PPFD) (1270 μ molm^{-2}s^{-1}) were moderate. Similar findings about P_n was also reported by Kumar and Bera, 2013. In Darjeeling, the extension in growth stops at monthly mean maximum and minimum temperature of 18^{0}C and 10^{0}C respectively in November and it start flushing at the meddle of March when maximum and minimum temperature exceed 20^{0}C and 12^{0}C respectively. In Kenya, the monthly mean maximum and minimum temperatures rarely exceed 24^{0}C and 11^{0}C respectively at any time of the year, but the tea plants flush throughout the year and produce annual yields of the same order as plants in many warmer regions.

The data depicted in Fig. 15 revealed that the upper most canopy (0-10 cm) received the full sunlight and recorded highest (1400-1500 μ mol m^{-2}s^{-1}) photosynthetic photon flux density (PPFD) followed by 10-20, 20-30 and >30 cm depth of canopy during all seasons. It was almost negligible below the 30 cm depth of canopy (50-60 μ mol m^{-2}s^{-1}). Among seasons, highest PPFD was recorded in summer followed by autumn, winter and rain. These findings are in conformity with the finding made by Okano *et al*. (1995), that 85% of canopy photosynthesis (Pc) of tea growing in autumn, in Japan was carried out by the top 5 cm leaf layer of the canopy and the maximum canopy depth effective for photosynthesis was only 10 cm. The light saturation points for assimilation of maximum CO2 in tea leaf were 1100-1500 μ mol m^{-2}s^{-1} in Kenya (smith *et al*., 1993), 900-1200 μ mol m^{-2}s^{-1} in South India (Raj Kumar *et al*., 1998), 1340 μ mol m^{-2}s^{-1} in Darjeeling (Ghosh Hajra and Kumar, 1999), 500-800 μ mol m^{-2}s^{-1} in Sri Lanka (Mohotti and Lawlor, 2002).

The concept of thermal duration (degrees-days) helps tea growers to determine important plucking policies such as plucking rounds for different periods of the year based on their temperature variation. Accuracy of such predictions depends to a large extent on the precision of the estimation of base (threshold) temperature (Tb) and the absence of other limiting factors for growth such as soil water and VPD. Carr (2000) also reported that small differences in Tb can have relatively large effects on rate of shoot development and extension at high altitudes where ambient temperature (Ta) is low. The other practical implication limiting the use of the thermal duration concept for deciding plucking rounds is the presence of a mixture of genotypes in a given tea plantation as Tb may vary between genotypes

Photosynthetic activities and yield

Highest value of Pn, E, gs were recorded in canopy depth 0 -10cm and lowest in <30cm. Among the clones, T78 showed the highest value of Pn in all canopy depth at both elevations (Fig. 1 & 2). Low temperature accompanied with low soil moisture reduced photosynthetic rate in winter than autumn. Pn was recorded lowest in rainy season when humidity (87%) and soil moisture (32%) were highest, and PPFD and sunshine hours were very low (3.16 h d^{-1}). A positive correlation between Pn and PPFD was observed. The maximum value of transpiration rate (E- 5.908 m mol $m^{-2}s^{-1}$) and stomatal conductance (gs- 0.499 mol $m^{-2}s^{-1}$) were recorded in old china bush and minimum in clones in canopy depth 0-10cm to 10-20 cm in DTRDC plantation (Fig. 3, 4, 5 and 6). Maximum water use efficiency (WUE) was found in the canopy depth 0-10 cm in high elevation at Sungma tea estate, Darjeeling than DTRDC experimental farm (Fig. 7 & 8). The photosynthesis (Pn) is the sum of the product between Pn and surface area of all individual leaves of the canopy.

However, there was a positive correlation was observed between all the parameters with depth of canopy and it is due to distribution of radiation incident within the canopy through light penetration along with Pn as determined by the internal and external factors and also determine the magnitude of Pn. Similar observation has been reported in tea by Okano *et al*. (1995). However, Okano *et al*. (1996) concluded that in spring, at the plucking stage, nearly 90% of Pc was conducted by developing new leaves and the contribution by overwintering mature leaves was only 10%. Smith *et al*. (1993) computed Pc by dividing the canopy in to five types of leaves (depending on their maturity) and summing the product between Pn and fraction of radiation interception of each layer. The rate of Pn was highest in the fully-expanded, dark-green, mature leaves on the plucking table, with both the younger leaves above them and the older leaves below them showing lower Pn. However, there was no significant variation in *g*s between different types of maintenance foliage. The fully-expanded, dark-green, mature leaves also showed the highest fraction of radiation interception and therefore made the highest contribution towards Pc. These leaves also had the highest Pn/gs ratio indicating that their instantaneous transpiration efficiency was also highest.

Response of Pn to variation of the atmospheric CO2 concentration (*C*a) is important not only to determine spatial and temporal variations of leaf Pn, but also to determine how the productivity of tea would respond to long-term climate change with increasing *C*a. Smith *et al*. (1993) observed a positive, linear correlation between instantaneous Pn and CO2 concentration of their measurement chamber (which varied between 351 to 490 μ mol mol^{-1}). The rate of increase of Pn per 1 μ mol CO2 mol^{-1} was 8.16 x 10-3 μ mol m^{-2} s^{-1}.

Water use efficiency (WUE) of clone T78 was highest (2.618 μmol $mmol^{-1}$) as compared to clone, B157, AV2 and old china cultivation at high elevation than mid elevation from the top of canopy (0-10 cm) (Fig. 7 & 8)). Leaf water potential (ψ_L) of clone T78, B157, AV2 and Old china cultivation was -2.05, -2.21, -2.45 and -2.54 (-Mpa) at mid elevation (DTRDC, experimental farm) and clone T78, B157, AV2 and Old china cultivation was -1.94, -2.01, -2.33 and -2.44 (-Mpa) respectively at high elevation from the top of canopy 0- 10 cm (Fig. 11 & 12) . Among the clones, AV2 and Old china bush showed lower rate of ψ_L than clone, T78 and B157 at both elevation of Darjeeling hill (Fig. 11 & 12)). Stomatal conductance is a key internal factor affecting Pn of tea. Because of the sensitivity of stomatal opening to several stimuli from the external environment (i.e. light intensity, water availability, TL, VPD etc.), very often, gs mediates the response of Pn to external factors as well. Generally, there is a positive relationship between Pn and *g*s because increased stomatal opening (i.e. higher gs) allows a greater flux of CO2 for photosynthesis and *vice versa*. However, when the internal photosynthetic capacity is reduced due to environmental stresses such as drought or internal factors such as shade adaptation or leaf ageing, gs may be lower because of the lower photosynthetic capacity. Smith *et al*. (1993) observed a highly significant positive correlation between gs and Pn. In addition to affecting Pn, *g*s also influences transpiration and play a pivotal role in determining the water status of tea leaves. Stomatal conductance is, in turn, influenced by the water status in leaf and soil.

There have been some conflicting opinions on how important the photosynthetic rate is in determining the productivity of tea. Based on evidence compiled from several studies, Squire and Callander (1981) concluded that the current rate of Pn is not directly linked to leaf yield of tea. The basis of their argument was that leaf yield of tea is controlled more by the rates of shoot initiation and extension rather than by the supply of assimilates from current Pn. Rates of shoot initiation and extension are primarily controlled by Ta and VPD and shoot turgor (Squire, 1979) whereas Pn is primarily controlled by light intensity. Moreover, the weight of harvested shoots of tea (*i.e*. 2-3 leaves and a bud) is only a small fraction (0.05- 0.15) of its total biomass production (Tanton, 1979). Stomata normally close in response to increasing VPD. Maximum VPD was recorded in canopy depth from 0-10 cm (2.34 kPa) and minimum in depth from >30 cm (1.72 kPa) (Fig. 9 & 10). In general, a reduction in g_s with higher VPD values was observed in the present study which is in conformity with the findings of Squire and Callander (1981). Squire and Callander (1981) also cite the frequent observation of higher Pn even during periods of low shoot growth rates due to higher VPD or cooler Ta (Squire, 1979) or higher soil water deficits (Stephens and Carr, 1991) as evidence for the independence of tea yield from Pn. However, Smith *et al*. (1993) argues that assimilates produced during periods of slow shoot growth is subsequently used during periods of higher shoot growth. Hence, although tea yield may not be correlated with current Pn, over a longer-time period, time-integrated tea yield and Pn should be positively correlated.

Tea is one of the plant species which has been shown to be highly sensitive to atmospheric VPD of the growing environment. During the dry periods of many tea growing regions of the world, VPD could rise to levels which would influence *g*s, shoot ψ_L and the rates of shoot initiation and extension (Squire and Callander, 1981). In addition, VPD influences these key processes of yield formation of tea even during periods when the soil is wet. Furthermore, the linear relationship between shoot extension rate and temperature breaks down at higher VPD (Squire and Callander, 1981). During wet periods with frequent rain, shoot ψ_L of tea has an inverse, linear relationship with VPD (Williams, 1971; Squire, 1976, 1979). This probably operates through the influence of VPD on transpiration, which increases with increasing VPD causing a decrease in shoot ψ_L. During these wet periods, VPD did not exceed 2 kPa and shoot ψ_L did not fall below –1 MPa. Furthermore, during wet periods, this relationship did not show hysteresis.

Tea has highly sensitive stomata, which show partial closure during midday even when the plants are growing on a wet soil (Williams, 1971; Carr, 1977). Stomatal closure was slightly preceded by reduced shoot xylem ψ_L, indicating that stomatal closure occurred as a response to an internal water deficit in the shoot. This indicates that the rate of root water absorption and its subsequent transfer through the xylem is not very efficient in tea even under conditions of moderate atmospheric demand (*i.e.* > 5 mm d^{-1}). This could be due to specific characteristics in the absorbing region of the root system and/or the xylem vessels.

Maximum leaf area index (LAI) was recorded in clone T78 and minimum in old china tea bush at both elevation in all canopy depth (from the top of bush) 0-10 cm to >30 cm (Fig. 13 & 14). Among the clones, AV2 showed lowest leaf area index while T78 recorded highest in all depth of canopy in mid elevation (Fig. 13). Leaf area index has a positive correlation with yield. Higher the LAI more is the total carbon uptake for carbohydrate production (Barman *et al*, 1992). Further, all the clones clearly showed their superiority in respect of yield at comparatively lower elevation (DTRDC) as compared to higher elevation (Sungma T.E.). However the upper most of the canopies (0-10 cm) is contributes about 75 % of total productivity due higher rate of photosynthesis. Similar finding made by Manivel and Hussain, (1992), that the leaves below than 20 cm of canopy and shaded conditions fix a very low amount of CO_2, so that they do not parasite upon other organs.

Productivity and yield components of tea

In Darjeeling hills, flushing of tea crop starts at the end of March when maximum and minimum temperatures exceed 21 ^{0}C and 14 ^{0}C respectively (Ghosh Hajra and Kumar, 1999) and after a sequence of production of normal leaves in April the shoot goes dormant for a short period during May. Thereafter, harvesting of tea crop continues until September, declines considerably towards the end of October, and then ceases when monthly mean maximum and minimum temperature of 18.5 ^{0}C and 12.5 ^{0}C respectively observed in November indicate that low temperature is one of the major climatic variables limiting yield. In the present study, the mean annual yield of made tea was recorded 714 Kg ha^{-1} and varied with clone. The yield from clone AV2 was lower (699.85 kg ha^{-1} at DTRDC and 675 kg ha^{-1} at Sungma Tea Estate, Darjeeling) than those from T78 and B157 (729 and 715 kg ha^{-1} at DTRDC; & 710 Kg ha^{-1} and 706 kg ha^{-1} at Sungma Tea Estate, Darjeeling respectively) (Fig. 16). Maximum plucking round was recorded at mid elevation than high elevation due slow growth (Fig. 16). The productivity of tea is quantified in terms of the weight of 'made tea' per unit land area per year. 'Made tea' refers to the form of tea obtained after the harvested (or 'plucked') shoot has gone through the manufacturing process (*i.e.* withering, fermenting and drying). Weight of made tea is directly related to the fresh weight of plucked shoot (2-3 leaves and a bud) by a factor of 0.2. Therefore, yield components of tea are the number of plucked shoots per unit land area (Number of shoot) and the mean weight per shoot (shoot weight). Out of these two yield components, it is the variation of number of shoot that has the stronger correlation with yield variation. The number of plucked shoots per unit land area is determined by the rate of shoot initiation whereas weight of shoot is determined by the rate of shoot expansion. Although number of shoot has been identified as being the main factor responsible for the observed variation in tea yields between different genotypes, variation in the rate of shoot growth is the main parameter that causes season-to-season yield variation in a given genotype (Squire and Callander, 1981). In addition, both yield components are influenced by the duration between two successive harvests (known as the plucking round). Furthermore, weight of shoot is also determined by the plucking standard adopted, *i.e.* whether two leaves and a bud or three leaves and a bud are plucked.

Therefore, both Tanton (1979) and Squire and Callander (1981) argued that assimilate supply cannot be a limiting factor in yield determination, when harvested yield is such a small fraction of total biomass production. Instead, tea leaf yield per unit land area is strongly correlated with number of shoot (Nsh). Hence, Tanton (1979) concluded that tea yield is sinking limited rather than source-limited. Based on the results of a simulation model, Matthews and Stephens (1998) also suggest that assimilate supply is unlikely to limit shoot growth under most conditions. However, it should be borne in mind that photoinhibition could reduce source capacity and thereby could impose a source-limitation as well on tea yield (Mohotti *et al.*, 2000; Mohotti and Lawlor, 2002).

The results indicate that the highest photosynthetic activities were recorded in the mid elevation at DTRDC, Kurseong. The rising ambient temperature (Ta) triggers a variety of changes in the atmosphere leading to modified rainfall patterns, evapo-transpiration rates and VPD. Because of the close relationships between tea yield and these atmospheric variables, long-term climate change is likely to cause significant impacts on the key physiological and developmental processes that determine the yield and yield components of tea. Responses to different aspects of climate change can be both positive and negative. The yield increases due to increasing atmospheric CO_2 concentration (*C*a) were augmented by increasing Ta at high altitudes. However, at low altitudes, yield gains of higher *C*a were pulled back because the rising Ta pushed the already high Ta in to the DTRDC, Kurseong for most of the key physiological processes that determine yield. The climate change scenarios specified by different Global Circulation Models also showed increased yields at higher altitudes, but reduced yields at lower altitudes in future.

Table 1: Meteorological parameters recorded during the year 2012 to 2013.

Months	DTRDC experimental Farm, Kurseong				Sungma Tea Estate, Darjeeling			
	Air Temp		Rainfall (mm)	R.H (%)	Air Temp		Rainfall (mm)	R. H. (%)
	Max. (^{0}C)	Min (^{0}C)			Max. (^{0}C)	Min.(^{0}C)		
April	26.70 (22)	12.81(16)	85.50	86 (75)	24.30 (21)	12.10 (16)	67.50	87 (75)
May	27.20 (25)	13.10 (18)	60.00	87 (76)	22.70 (19)	12.21(15)	81.50	86 (75)
Jun	26.80 (23)	18.20 (20)	489.00	88 (85)	25.00 (22)	2.81(20)	281.50	88 (86)
July	24.00 (23)	18.90 (16)	1555.00	88 (86)	24.00 (22)	18.00 (21)	483.75	90 (88)
Aug	27.70 (25)	19.20 (20)	478.50	88 (85)	26.00 (22)	18.00 (20)	127.50	88 (86)
Sep	27.60 (23)	18.20(19)	157.50	88 (86)	25.10 (22)	17.81(18)	399.00	88 (86)
Oct	23.60 (22)	13.10 (16)	26.50	88 (79)	22.00 (21)	14.50 (15)	17.00	88 (86)
Nov	21.70 (19)	9.90 (12)	0.00	82 (73)	21.50 (18)	8.80 (13)	0.00	84 (76)
Dec	16.80 (15)	7.20 (9)	0.00	86 (72)	15.00 (14)	8.00 (9)	0.00	86 (73)
Jan	17.90 (15)	4.60 (8)	13.50	80 (66)	16.20 (16)	4.00 (9)	7.50	82 (70)
Feb	22.30 (18)	7.80 (16)	10.50	86 (62)	21.00 (22)	6.50 (12)	39.00	86 (68)
Mar	23.70 (21)	10.90 (14)	9.00	85 (65)	23.00 (20)	10.00 (15)	22.00	86 (68)

Note: Figures in the parenthesis is average.

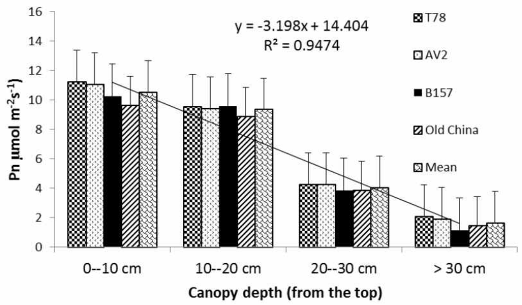

Fig. 1. Net photosynthetic rate (Pn) in different layer s of Darjeeling tea clones and old china plantation at DTRDC, Kurseong. Vertical bar indicate standard error of means.

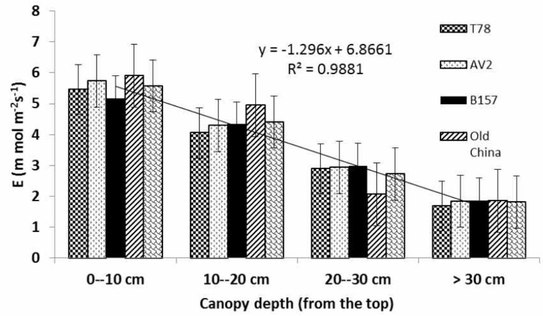

Fig. 3: Net transpiration rate (E) in different layer s of Darjeeling tea clones and old china plantation at DTRDC, Kurseong. Vertical bar indicate standard error of means

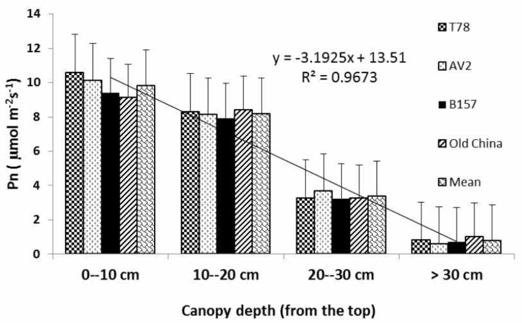

Fig. 2. Net photosynthetic rate (Pn) in different layer s of Darjeeling tea clones and old china plantation at Sungma Tea Estate, Darjeeling. Vertcal bar indicate standard error of means.

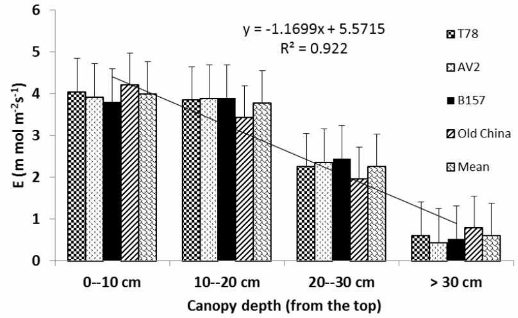

Fig. 4: Net transpiration rate (E) in different layer s of Darjeeling tea clones and old china plantation at Sungma Tea Estate, Darjeeling . Vertical bar indicate standard error of means

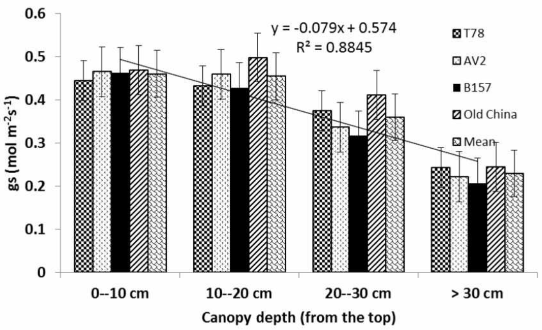

Fig. 5: Stomatal conductance (gs) in different layer s of Darjeeling tea clones and old china plantation at DTRDC, Kurseong. Vertical bar indicate standard error of means.

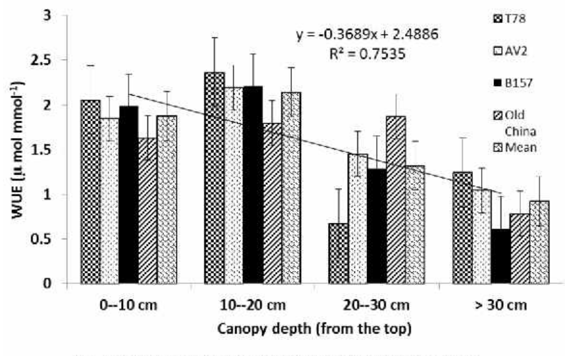

Fig. 7: Water use effeiciency (WUE) in different layer s of Darjeeling tea clones and old china plantation at DTRDC, Kurseong . vertical bar indicate standard error of means.

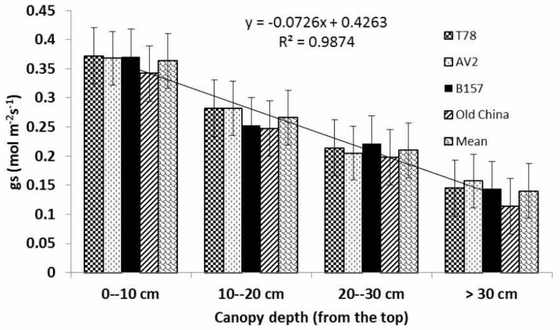

Fig. 6: Stomatal conductance (gs) in different layer s of Darjeeling tea clones and old china plantation at Sungma Tea Estate, Darjeeling. Vertical bar indicate standard error of means.

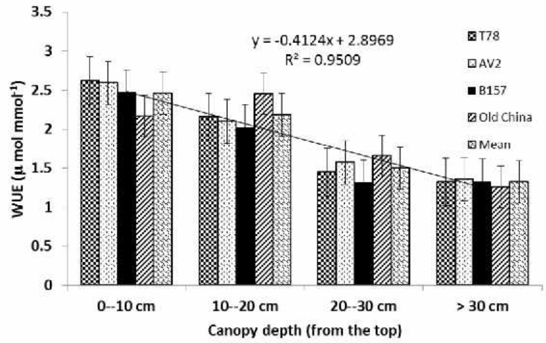

Fig. 8: Water use effeiciency (WUE) in different layer s of Darjeeling tea clones and old china plantation at Sungma Tea Estate, Darjeeling. Vertical bar indicate standard error of means.

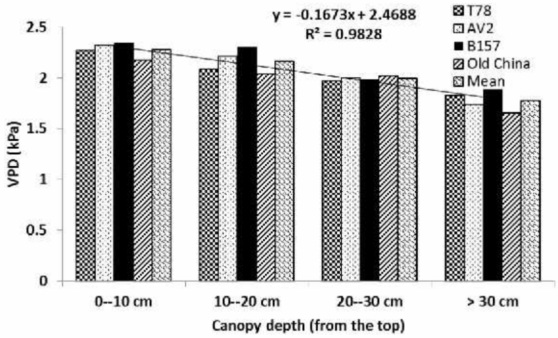

Fig. 9: Vapour pressure deficit (VPD) in different layer s of Darjeeling tea clones and old china plantation at DTRDC, Kurseong.Vertical bar indicate standard error of means.

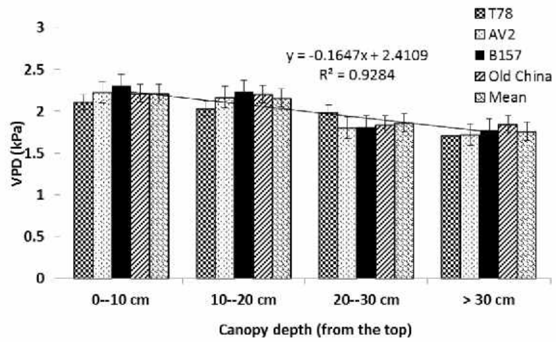

Fig. 10: Vapour pressure deficit (VPD) in different layer s of Darjeeling tea clones and old china plantation at Sungma Tea Estate, Darjeeling. Vertical bar indicate standard error of means.

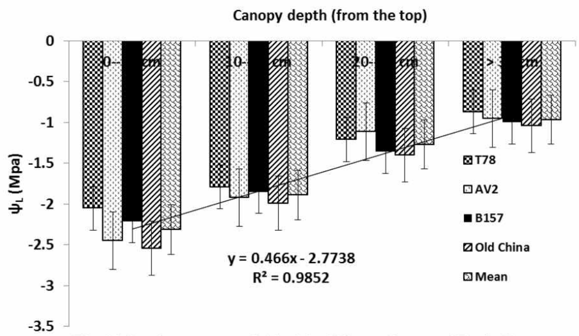

Fig. 11: Leaf water potential (ψ_L) in different layer s of Darjeeling tea clones and old china plantation at DTRDC, Kurseong. Vertical bar indicate standard error of means.

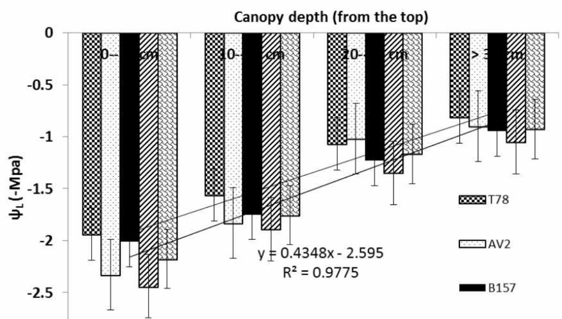

Fig. 12: Leaf water potential (ψ_L) in different layer s of Darjeeling tea clones and old china plantation at Sungma Tea Estate, Darjeeling. Vertical bar indicate standard error of means.

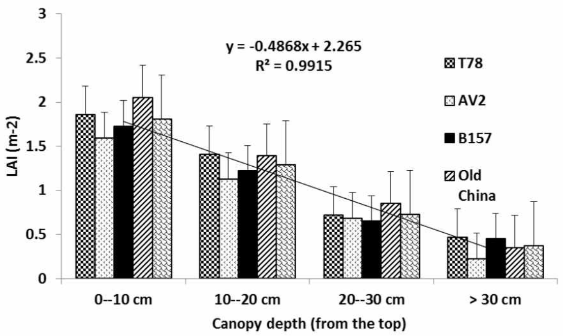

Fig. 13: Leaf area Index (LAI) in different layer s of Darjeeling tea clones and old china plantation at DTRDC, Kurseong. Vertical bar indicate standard error of means.

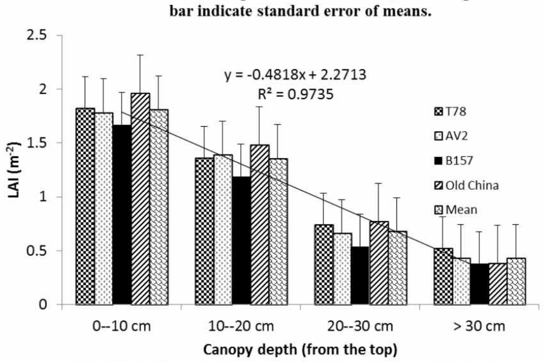

Fig. 14: Leaf area index (LAI) in different layer s of Darjeeling tea clones and old china plantation at Sungma Tea Estate, Darjeeling.Vertical bar indicate standard error of means.

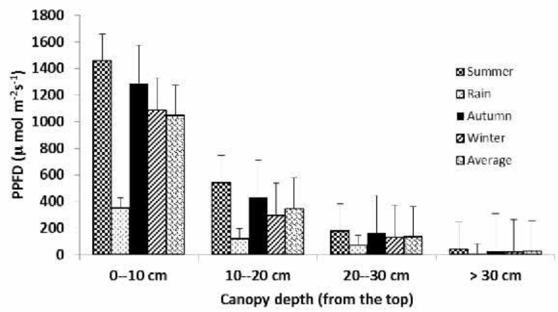

Fig. 15: Photosynthetic photon flux density (PPFD) in different layer s of Darjeeling tea plantation. Vertical bar indicate standard error of means.

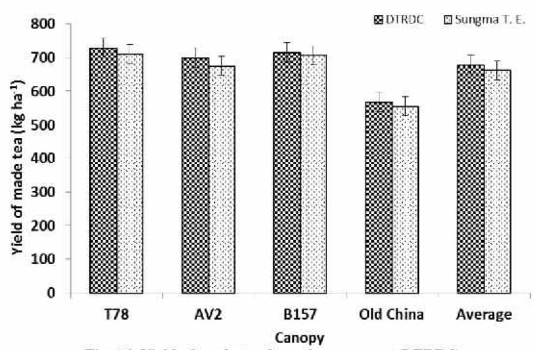

Fig. 16: Yield of made tea from the canopy at DTRDC, Kurseong and Sungma tea Estate, Darjeeling. Vertical bar indicate standard error of means. (CD at 5% = 116.078)

ACKNOWLEDGEMENTS

We are grateful to the Chairman and Deputy Chairman of the Tea Board of India for providing facilities and their generous support during the study. Computing assistance by Shri R. K. Chauhan of the Darjeeling Tea Research and Development Centre and management (Shri A. K. Jha and Shri S. Rathor) of Sungma Tea Estate, Darjeeling is appreciated.

REFERENCES

Anonymous. 1988. Tea Encyclopaedia. Tea Research Association, Jorhat, Assam, India, Serial no. **K185**, 1 – 4.

Barman, T. S., Baruah, U. and Sarma, A. K. 1992. Physiological importance of maintenance leaves in tea. Proc. 31st Tock. Conf., pp 42-9.

Carr, M. K. V. 1977. Changes in the water status of tea clones during dry weather in Kenya. *J. Agric. Sci*. (Cambridge) **89**:297-307.

Carr, M. K. V. 2000. Shoot growth plus plucking equals profit. TRIT Occasional Publication No.1, April 2000, Tea Research Institute of Tanzania, pp.1-7.

Ghosh. H. N. and Kumar, R. 1999. Seasonal variation in photosynthesis and productivity of young tea. *Expl. Agric.,* **35**: 71 – 85.

Ghosh, H. N. and Kumar, R. 2002. Diurnal and seasonal variations in gas exchange property of tea leaves. *J. Plant Biol.,* **29**: 169 – 73.

Kumar, R. and Bera, B. 2013. Seasonal response of photosynthetic characteristics and productivity of Yung Darjeeling Tea clone to organic and inorganic fertilization. *J. Crop Weed,* **9**: 142-53.

Leuning, R. and Sands, P. 1989. Theory and practice of a portable photosynthesis instrument. *Plant. Cell. Env.,* **15**: 669-78.

Li- Cor Inc. 1987. Li-6200 Portable Photosynthesis System, Instruction Manual. Li- Cor, Lincoln, NE, USA.

Matthews. R. B., Stephens. W. 1998. CUPPA-TEA: A simulation model describing seasonal yield variation and potential production of tea. 2. Biomass production and water use. *Exp. Agric*., **34**:369-89.

Manivel, L. and Hussain, S. 1992. Photosynthesis in tea. 1. Contribution of photosynthesis to pluckable shoots by maintenance leaves. Two Bud. **29**: 13-16.

Mohotti, A. J., Dennett, M. D., Lawlor, D. W. 2000. Electron transport as a limitation to photosynthesis of tea (*Camellia sinensis* (L.) O. Kuntze): a comparison with sunflower (*Helianthus annus* L.) with special reference to irradiance. *Trop. Agric*. *Res*. **12**:1-10.

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. Exp. Bot*. **53**:313-22.

Okano, K., Komaki, S., Matsuo, K., Hirose, D., Tatsumi, J. 1995. Analysis of canopy photosynthesis in mature tea (*Camellia sinensis* L.) bush at late autumn. Jap. *J. Crop Sci*. **64**:310-16.

Okano, K., Matsuo, K., Hirose, D., Tatsumi, J. 1996. Photosynthesis and productive structure of mature tea (*Camellia sinensis* L.) bush during growth of first flush. Jap. *J. Crop Sci*. **65**:108-13.

Roberts, G. R. and Keys, A. J. 1978. The mechanism of photosynthesis in the tea plant (*Camellia sinensis* L). *J. Expl. Bot*. **29**: 1403-07.

Raj K. R., Manivel, L., Marimuthu, S. 1993. Evaluation of clonal characteristics in mature tea. *J. Plantation Crops* **21**: 241-47.

Raj, K. R., Manivel, L. and Marimuthu, S. 1998. Longevity and factors influencing photosynthesis in tea leaves. *Photosynthetica* **35**:41-46.

Smith, B. G., Stephens, W., Burgess, P. J. and Carr, M. K. V. 1993. Effects of light, temperature, irrigation and fertilizer on photosynthetic rate in tea (*Camellia sinensis*). *Exp. Agric*. **29**:291-306.

Stephens, W. and Carr, M. K. V. 1991. Responses of tea (*Camellia sinensis*) to irrigation and fertilizer. I. Yield. *Exp. Agric*. **27**:177-91.

Squire, G. R. 1976. Xylem water potential and yield of tea (*Camellia sinensis*) clones in Malawi. *Exp. Agric*. **12**:289-97.

Squire, G. R. 1979. Weather, physiology and seasonality of tea (*Camellia sinensis*) yields in Malawi. *Exp. Agric*. **15**:321-30.

Squire, G. R. and Callande, R. B. A. 1981. Tea plantations. In: Kozlowski TT (ed), *Water Deficits and Plant Growth, Vol. VI,* pp.471-510. Academic Press, New York.

Tanton, T. W. 1979. Some factors limiting yields of tea (*Camellia sinensis*). *Exp. Agric*. **15**:187-92.

Williams, E. N. D. 1971. Investigations into certain aspects of water stress in tea. In: Carr, M.K.V., Carr S (eds) Water and the Tea Plant, pp.79-87. Tea Research Institute of East Africa, Kericho, Kenya.

Wescor, Inc. 1988. HR-33T microvoltmeter, Instruction Manual. Wescor Inc., Logan, Utah, USA.