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Seasonal response of photosynthetic characteristics and productivity of young Darjeeling tea clone to organic and inorganic fertilization.

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ABSTRACT

The physiological responses and yield of china-type high quality Darjeeling tea (Camellia sinensis L) clone T78 to organic and inorganic fertilization were investigated in the Darjeeling Hills during the different seasons of 2007 to 2010. Highest photosynthetic rate (P_N) was observed with the application of 60: 30: 60 kg^{-ha} basal through CAN, RP and MOP (T6), which was followed by farmyard manure (FYM) @ 5 tones + 30: 30: 60 kg^{-ha} basal through Urea, RP and MOP (T3) but the lowest with the application of FYM @ 10 $tones^{-ha}$ (T2). The maximum value of Pn was recorded in T6 during autumn, giving 38.6 percent increase over the control (T1), whereas in rains the lowest increase over the control (13.7 percent) was recorded with 60: 30: 60 kg^{-ha} basal through Urea, RP and MOP (T4). In general, higher P_N coincided with higher ψ_L values. T6 recorded highest transpiration rate (E) than other treatments. E increases in most of the treatments during rain. In general, the decrease in stomatal conductance (g_s) was more pronounced in moisture stress period. The maximum value of g_s was recorded in autumn in T6. In all treatments, vapour pressure deficit (VPD) was highest in summer and higher in autumn and winter than rain. Chlorophyll content (Chl) was greater in fertilized plots. Chl was recorded highest during autumn and lowest in moisture stress period. T6 showed maximum Chl and T1 recorded lowest. A positive correlation between Chl content and Pn existed in the present study. Highest yield was recorded in T6 and increased 47 percent over T1. The relation between photosynthesis and yield in tea are discussed.

***Key words**: Camellia sinensis,* fertilizers, F Y M, nitrogen, photosynthesis and processed tea

Tea is a heritage non-alcoholic beverage of the world. It is one of the economically important small, evergreen woody plantation crop predominantly grown in the humid tropical and subtropical regions. Darjeeling tea plants experiences various types of climatic conditions in Darjeeling hills such as low temperature, low soil moisture in winter foggy climate, high humidity and low levels of solar radiation. For proper maintenance of the health of tea bushes and to obtain high yield, a balanced fertilization and manuring is necessary at certain intervals throughout the year. It is also vital to integrate the various factors relating to climate, soil, plant and cultivation for achieving the maximum return from the investment on fertilizers and productivity of the soil. Though photosynthesis is mainly controlled by genetic characteristics, environmental factors also have significant influence (Sobhana *et al*., 1996). Differences in photosynthetic characteristics are related to light environment, leaf anatomy, physiology and nutrient status of the leaves (Natr, 1972). Fertilizer increased Pn both by enhancing Pn per unit area in healthy leaves and by increasing the proportion of sunlight intercepted by photosynthetically efficient leaves in tea (Smith *et al*., 1993a). Bisht and Chandel (1991) reported that Pn as well as physiological efficiencies of different nutrients increased with integrated nutrient management in Soybean. Nitrogen is reported to be the most common nutritional factor limiting P_N and biomass production (De Jong, 1982). Positive correlations between leaf nitrogen content and P_N have been reported for tea (Aoki, 1987; Sakai, 1987). Phosphorus may exert a direct effect on photosynthesis by modifying the energy metabolism and potassium indirectly affects photosynthesis through its effect on g_s (Sobhana et al., 1996). Natr (1992) emphasized that (1) mineral nutrients affect the photosynthesis at all levels of plant structure, (2) the photosynthesis has considerable influence on mineral nutrients uptake, distribution and utilization, (3) the photosynthesis should always be considered as only one factor among many others that are modified by changes of the mineral nutrition. The present study was undertaken to know the effect of fertilization on photosynthesis and associated characteristics and yield of young tea.

MATERIALS AND METHODS

The study was conducted at the Darjeeling Tea Research and Development Centre, Kurseong (26.9^0N, 88^012 E, altitude 1347 m). 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. Healthy, 24 month old transplants of Tukdah 78 (T78), a china-type high quality clone of commercial and scientific interest in the Darjeeling

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Hills were planted on 25th June, 1999 in the trial. The following treatments were laid out in a randomized block design: T1, control (no fertilizer); T2, application of farmyard manure (FYM) (nitrogen- 0.6, phosphoric acid (P_2O_5) – 0.17 and potash – 0.5 percent) @ 10 tones^{-ha}; T3, FYM @ 5 tones + 30: 30: 60 kg^{-ha} basal through Urea (nitrogen – 46 percent), rock phosphate (RP) (P_2O_5 – 20 and sulphur – 2.3 percent) and muriate of potash (MOP) (K_2O – 50 and chlorine 47 percent); T4, 60: 30: 60 kg^{-ha} basal through Urea, RP and MOP; T5, 60: 30: 60 kg^{-ha} basal through ammonium sulphate (nitrogen – 20.6 and sulphur – 24 percent) + RP + MOP; T6, 60: 30: 60 kg^{-ha} basal through calcium ammonium nitrate (CAN) (nitrogen – 25 and calcium – 8 percent), RP and MOP. Spacing for 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. There were three replications per treatment. Each replication consists of 30 plants. Young plants which died were immediately replaced with healthy transplants of the same clone. In order to bring the tea into production earlier, the primaries/ secondaries of the young plants were pegged by bending branches growing from the base of the plant outward and securing them into position with pegs made of pruned tea bushes or bamboo. The plants were not irrigated as this is the general practice in this region.

During 2007 to 2010, 84 – 100 months after field planting, P_N, g_s and E 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, 2002a). 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). At monthly intervals, Chl of freshly harvested leaves collected from the opposite branches to those for P_N measurement was estimated according to the method described by Arnon (1949), after extraction with 80% acetone in the dark and using the Hitachi (U 2000) double beam spectrophotometer. The outside bark diameter (girth) of the stem, 5 cm above the ground, was measured using a Vernier Caliper (ICI make).

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 (Anon., 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 until flushing starts again at the end of March.

The volumetric water content of the soil was determined gravimetrically in three replicates at two depths viz. 0 –15 cm and 15 – 30 cm. Simple correlations between the physiological and environmental variables were computed after pooling the respective data.

RESULTS AND DISCUSSION

Since there were no significant differences between the values obtained for the various physiological and climatic variables between 2007 and 2010, the values were grouped together and means of four years are presented.

Climate

The Darjeeling Tea Research & Development Centre is 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.

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 because 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.

Physiological characteristics

When the data from all fertilizer treatments were combined, highest P_N [11.07 μ mol (CO_2) $m^{-2}s^{-1}$] was observed with application of 60: 30: 60 kg^{-ha} basal through CAN, RP and MOP (T_6), which was followed by FYM @ 5 tones + 30: 30: 60 kg^{-ha} basal through Urea, RP and MOP [9.59 μ mol(CO_2) $m^{-2}s^{-1}$] (T_3) but the lowest with the application of FYM @ 10 tones.ha^{-1} [8.54 μ mol(CO_2) $m^{-2}s^{-1}$] (T_2) (Fig. 1). The maximum value of P_N [12.21 μ mol(CO_2) $m^{-2}s^{-1}$] was recorded in T6 during autumn, giving 38.6 percent increase over the control (T_1), whereas in rains the lowest increase over the control (13.7 percent) was recorded with 60: 30: 60 kg.ha^{-1} basal through Urea. RP and MOP (T_4). The maximum value of P_N recorded in the present study was of the same order of magnitude as those reported for tea (Ghosh Hajra and Kumar, 1999).

In Southern Highlands of Tanzania, Smith *et al.* (1993a) reported that fertilizer (combined with irrigation) at an annual application @ 225 kg N.ha^{-1} caused increase in P_N than the unfertilized and application of nitrogen @ 225 kg.ha $^{-1}$ treatment plots. When the atmosphere was dry during pre-monsoon (April) and plants were suffering from moisture stress till the end of May, the lower rate of P_N was recorded in all treatments and that may be due to low humidity or moisture stress. There is abundant evidence in the literature that P_N is inhibited by water stress (Balasimha *et al*. 1991; Sobrado, 1996; Ghosh Hajra and Kumar, 1999). With the onset of the monsoon rain in June, the plants were able to recover fully from the water stress and an increase in the water contents of the leaves. The increased water content helps in maintaining the turgidity of the assimilatory cells and the proper hydration of their protoplasm. In summer and rains, higher temperature prevailed but P_N was lowest in rain rather than autumn and winter.

Table 1: Weather parameter (mean of 2007 to 2010).

	Months											
Parameters	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Mean max. temp. (^{0}C)	12.9	16.6	17.5	19.6	21	22.7	24.2	23.4	22	21.1	18.7	15.4
Mean Min. temp. (^{0}C)	4.5	6.6	11.3	12.5	14.6	17.3	18.1	18.4	17.3	15	12	9.8
Mean sunshine-duration(hd^{-1})	5	4.3	4.8	4.9	2.7	1.2	0.4	1	1.7	2.6	4	4.5
Mean relative-humidity (%)	88.6	88	90	89	90	95.6	96.3	95.5	93.5	90.3	88.3	89
Total rainfall (mm)	5	9	30	67	257	958	1240	985	532	105	0	0
Mean wind velocity (Kmh^{-1})	3	3.2	3.5	4.8	4.7	5	5.8	4.1	4.9	4.7	3.6	3.1
Mean daily pan-evaporation (mm)	4.9	4.9	5.2	6.3	4.8	3.3	3.3	3	3.3	3.7	4.1	4.5
PPFD (μ mol m-2s-1)		884.1			1440.9			412.2			1289.3	

Table 2: Volumetric water content in plots at the time of experimentation (averages of each season for 2007 to 2010)

Season	Top soil	Sub soil
(0 – 15 cm)	(15 – 30 cm)	
Summer	14.5	15.7
Rain	33.2	34.1
Autumn	29.9	30.2
Winter	21.4	22.0

Table 3: Correlation coefficients among photosynthetic parameters and yield

Variables	Correlation coefficient (r) *	
Variable combination	Season	Treatment
PN and E	+ 0.410*	+ 0.908*
PN and gs	+ 0.136*	+ 0.951**
PN and WUE	+ 0.450*	+ 0.713*
PN and chlorophyll	+ 0.523*	+ 0.679*
PN and yield	- 0.698*	+ 0.804*
PN and ψL	- 0.417*	+ 0.616*
gs and E	+ 0.337*	+ 0.927*
PN and SD	- 0.653*	+ 0.849*
Yield and chlorophyll	+ 0.142*	+ 0.675*
ψL and E	+ 0.284*	+ 0.962**
WUE and Ci	- 0.743*	- 0.835*
Pn and VPD	- 0.042*	+ 0.058*

* $P \leq 0.05$; ** $P \leq 0.01$.

Low temperature accompanied by low soil moisture reduced P_N in winter than autumn. In summer, when PPFD increased from lower intensity 412 μ mol m^{-2}s^{-1} (during rain) to about 1289.3 μ mol m^{-2}s^{-1} (Table 1), the value of P_N in all treatments were higher than rain. In rains, humidity and soil moisture were highest, PPFD recorded lowest, sunshine hours were low (less than 1.5 hours per day) and P_N was at its lowest [7.40 μ mol (CO_2) m^{-2}s^{-1}]. Among the treatments, T1 showed lowest ψ_L while T6 recorded highest in all seasons (Fig. 4). In general, higher P_N coincided with higher ψ_L values. Among the seasons, ψ_L was lowest in summer and highest in rains. T6 recorded highest *E* than other treatments (Fig. 3). Transpiration rate was lowest in summer season and higher in rain, though the PPFD reached minimum but the temperature, Sm (Soil moisture), wind velocity and RH were reasonably high. Barbora, (1994) also reported a sharp decline of *E* with reduced soil moisture in Assam tea plantation. In general, the decrease in g_s was more pronounced in moisture stress period (Fig. 2). The maximum value of g_s [0.22 mol m^{-2}s^{-1}] was recorded in autumn in T6, giving 126 percent increase over the control, whereas the lowest increase (106 percent) over the control was recorded in rains with application of FYM @ 10 tones^{-ha} (T2). In all treatments, VPD was highest in summer and higher in autumn and winter than rain (Fig. 5). The volumetric water content of both top and sub-soils decreased gradually from autumn and declined rapidly during summer (Table 2).

The rate of pan evaporation was also gradually increased from autumn until summer. The maximum value of P_N [12.21 μ mol (CO_2) m^{-2}s^{-1}] was recorded up to a VPD of 2.2 kPa (T6); thereafter Pn declined slowly. In the present study, reduction in g_s with higher VPD values was observed. Similar finding has been reported in tea (Squire and Callender, 1981) and cocoa (Balasimha and Rajagopal, 1988). The decrease in g_s and E were more pronounced in summer when both soil and atmospheric moisture was low and demand for water was high. Thus, there was depression in P_N under transient water stress in summer. In different treatments, maximum WUE was associated with relatively lower $\psi_{L,}$ lower *E* and lower g_s (Figs. 6, 4, 3 and 2). Maximum WUE was recorded in winter [3.09 μ mol/ mmol^{-1}] and minimum in rainy season [1.79 μ mol mmol^{-1}]. A positive correlation existed between WUE and P_N (Table 3) which is in conformity with the findings of Ghosh Hajra and Kumar (2002). The relationship of P_N with Ci in different treatments was nonlinear. The maximum value of Ci (242 ppm) was recorded in unfertilized treatment (T1) and lowest (217.8 ppm) in T6 (Fig. 7). Among the seasons, Ci was lowest in winter (218 ppm) and highest in autumn (230 ppm). P_N / Ci were lowest (21.7) in autumn and no correlation was found with WUE.

Chl content was greater in fertilized plots than unfertilized control (T1). Chl was recorded highest during autumn and lowest in summer (moisture stress period) in all treatments (Fig. 8). T6 showed maximum Chl and T1 recorded lowest. A positive correlation between Chl content and P_N existed in the present study (Table 3) which is in conformity with the findings of Rajkumar et al. (2000). But negative correlations between Chl and P_N were also reported, e.g., in tobacco cultivar (Ananda Kumar, 1982) and citrus leaves (Syvertsen, 1984). The chlorophyll is the most important plant pigment playing a vital role in determining the photosynthetic efficiency and productivity of the plant. The Chl content in leaves vary with the day length, irradiance and radiation quality, temperature and nutrient status of the soil (Lewandowska and Jarvis, 1977). In the present study, total chl content was highest during winter and lowest in summer (moisture stress period) (Fig. 8). Decline in Chl due to water stress has also been reported in tea (Rajasekar *et al*., 1991). Reduced ability to form protochlorophyll was considered to be responsible for the inhibition of the development of the Chl under moisture stress (Hsiao, 1973). In general, higher P_N and yield coincided with higher percent of girth increment. Among the fertilizer treatments, T6 showed highest increment of girth (Fig. 9) as observed in case of P_N and yield. T2, T4 and T5 showed lowest increment of girth, P_N and yield.

Photosynthesis, related parameters and yield

The mean annual yield on plots receiving no fertilizer (T1) was only 438 kg ha^{-1} and highest mean annual yield was 645 kg ha^{-1} recorded in T6 which showed an increase of 47 percent by applying 60: 30: 60: kg ha^{-1} basal through CAN, RP and MOP. There were no significant differences in yield in T3 (583 kg ha^{-1}) and T4 (574 kg ha^{-1}) but these were higher than T2 (539 kg ha^{-1}) and T5 (569 kg ha^{-1}) (Fig. 10). The four year's yield trend of an experiment on the efficacy of split and basal application of organic and inorganic fertilizers in the optimization of tea yield conducted in Darjeeling hills revealed that single basal dose (during April/May) of CAN: DAP: MOP @ 60: 30: 60: gives highest return (Fig.11). In these low temperature hilly acidic tea soils the microbes responsible for the mineralisation of ammoniacal-nitrogen to nitrate-nitrogen is low. Hence it has been suggested that the highest yield for CAN – treated plots was perhaps primarily because of the immediate availability of nitrate – nitrogen from CAN (12.5% nitrate and ammoniacal nitrogen each) which other nitrogenous fertilizers lacked in viz., urea and ammonium sulphate which contains only the ammoniacal form of nitrogen.

There were also differences in the distribution of seasonal yield. Highest yield in all treatments were recorded in rains despite lowest P_N. Yield was then declined in autumn when P_N was highest. Moderate yield was recorded in April despite low soil moisture and a high rate of evaporation from the soil surface, but high air temperature, high sunshine hours and day length (more than 12 h) occurred in April. No yield was recorded during winter and moisture-stress period from second week of November until end of March. The day length of Kurseong was observed below 11 h during November and December and then gradually increased till August (13 h) (Ghosh Hajra and Kumar, 2002b). Experiments in Assam have shown that increasing the day length resulted in greater crop yield. However, shoot extension rates are also restricted by low temperatures and at the same time it confounds the effects of day length which can explain the majority of the seasonal yield differences (Stephens *et al*., 1998). There may, however, be some effect of day length in synchronizing shoot growth during short days leading to a larger peak when temperatures rise again at the end of the cool season (Matthews and Stephens, 1998).

The seasonal yield distribution varies primarily as a result of seasonal changes in temperature and the development of soil moisture stress during the dry season. Kericho in Kenya has the most even yield distribution with only a relatively small drop in production during dry season. By contrast Mufindi, Tanzania and Mulanje, Malawi showed marked seasonal variations in yield distribution. In Mulanje for instance, about 80 % of the annual yield from non-irrigated tea may be harvested during the five months from December to April (water surplus period) (Carr and Stephens, 1992). However, in Darjeeling 50 % of the annual crop is produced in the wet season (June to August). The yield development of six contrasting clones from Kenya, Malawi and Tanzania under a range of drought regimes has been studied by Burgess and Carr (1996). During the fourth year after planting, the yield of dried tea from one clone, labeled S15/ 10, reached. The large yields from young tea achieved by Burgess and Carr (1996) in their experimental field at commercial plant densities were possible through rapid establishment of crop cover by pegging prevention of drought stress by irrigation and the removal of a high proportion of a harvestable shoots by tightly controlled plucking.

A proportion of the carbon fixed by photosynthesis is used in maintenance respiration, and the remainder is then available for partitioning into shoot or root growth or into storage reserves (Smith *et. al*., 1993a). If photosynthesis and yield are closely coupled, the highest yield would be expected in autumn in all treatments when P_N was observed to be maximal. However, the highest yield was obtained in rains when P_N was minimal. The temperature (22 ^{0}C to 24 ^{0}C), relative humidity (95 to 96 %) and soil moisture were high during June to August. Relative air humidity of 80 – 90 % is favourable for growth of tea plant but shoot growth is inhibited and adversely affected if it is below 50 % and 40 % respectively (Huang, 1989). There is no correlation observed between seasonal P_N and yield (Table 3). However, there is a clear need for further investigations into the relationships between P_N and yield in established plots of various mature tea clones. Similar views are offered by the researchers in tea with respect of the establishment of a relationship between P_N and yield in young tea plantations (Smith *et. al*., 1993b; Ghosh Hajra and Kumar, 1999; Ghosh Hajra, 2001; Ghosh Hajra and Kumar, 2002).

The results indicate that the highest P_N recorded was in the T6 treatment which gives 47 percent higher production of processed tea over unfertilized control. The seasonal yield distribution varies primarily as a result of seasonal changes in temperature. Low PPFD and low temperature had significant inhibitory effects on P_N. Large populations of clone are required to determine correlations between Pn and yield.

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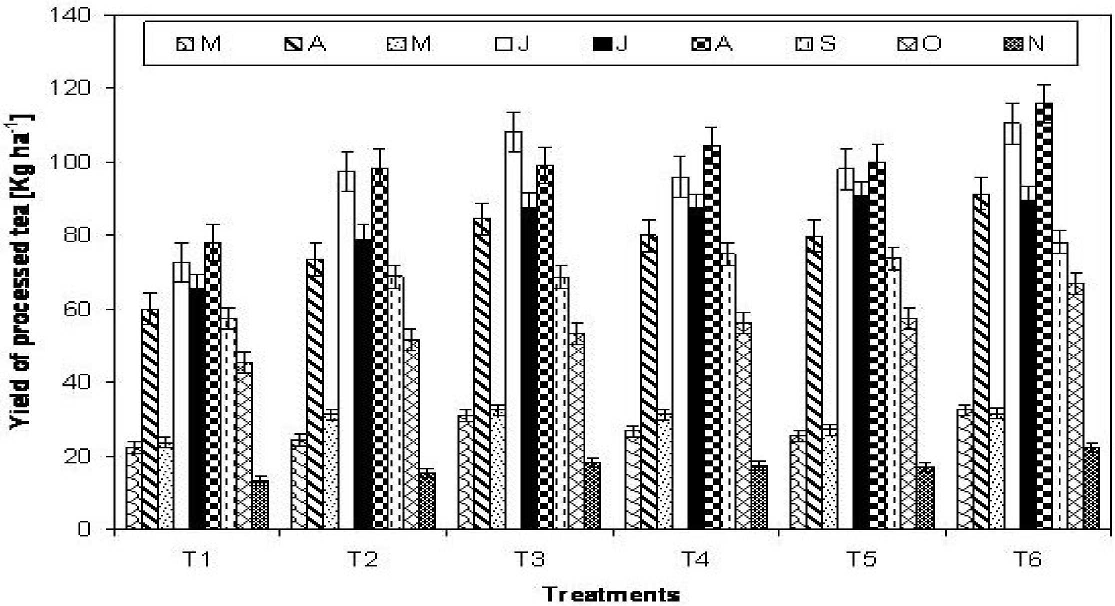

Fig. 11. Effect of fertilization on monthly yield of processed tea during the year 2007 to 2010. No harvesting from 2nd week of November to February. Vertical bars indicate standard error of the means. (CD at 5% = 25.626)

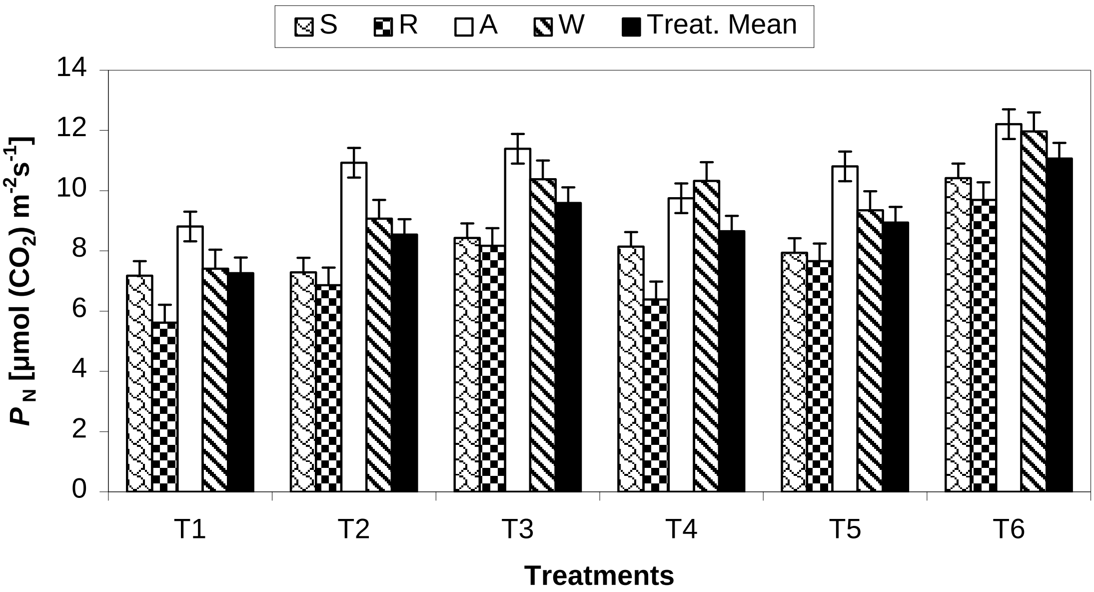

Fig. 1. Seasonal effect of fertilization on net photosynthetic rate (P_N) during the year 2007 to 2010.Vertical bars indicate standard error of the means. (CD at 5% = 1.490). - S= summer, R= Rain, A= Autumn, W= Winter

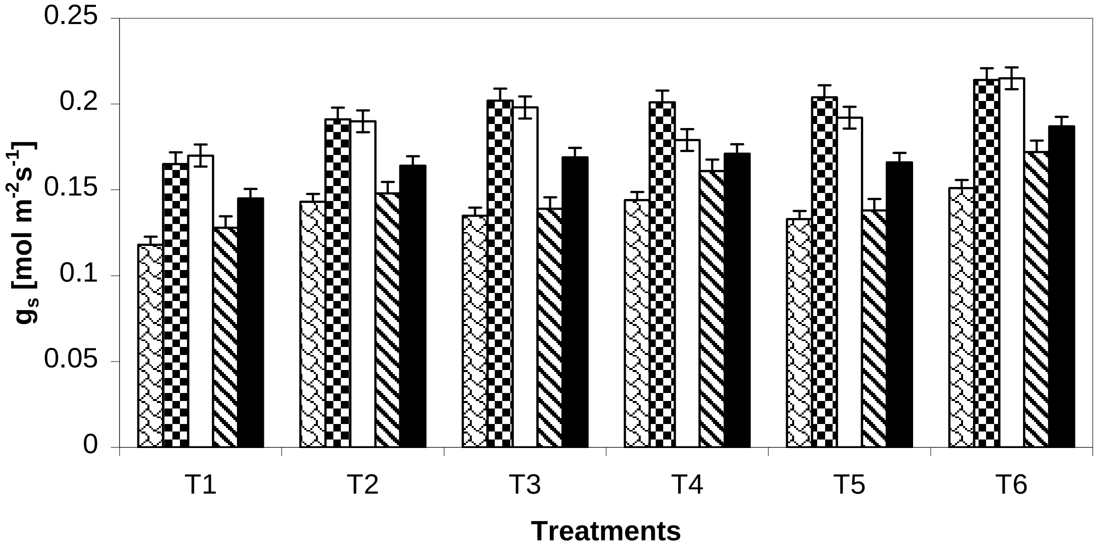

Fig. 2. Seasonal effect of fertilization on stomatal conductance (g_s) during the year 2007 to 2010. Vertical bars indicate standard error of the means.(CD at 5% = 0.018)- S= summer, R= Rain, A= Autumn, W= Winter

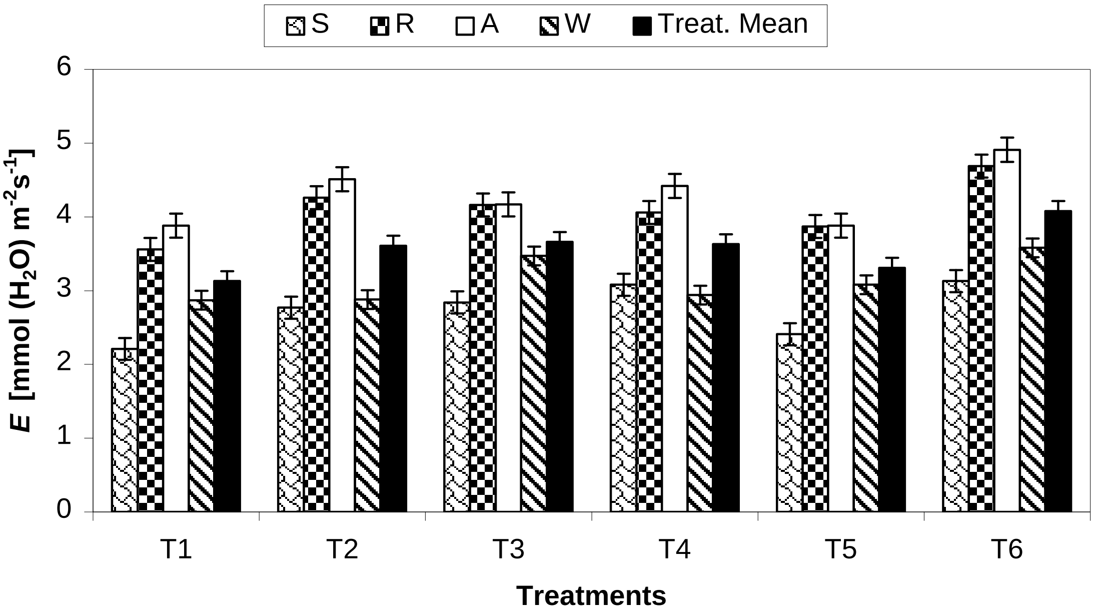

Fig. 3. Seasonal effect of fertilization on transpiration (*E*) during the year 2007 to 2010.Vertical bars indicate standard error of the means. (CD at 5% = 0.457)

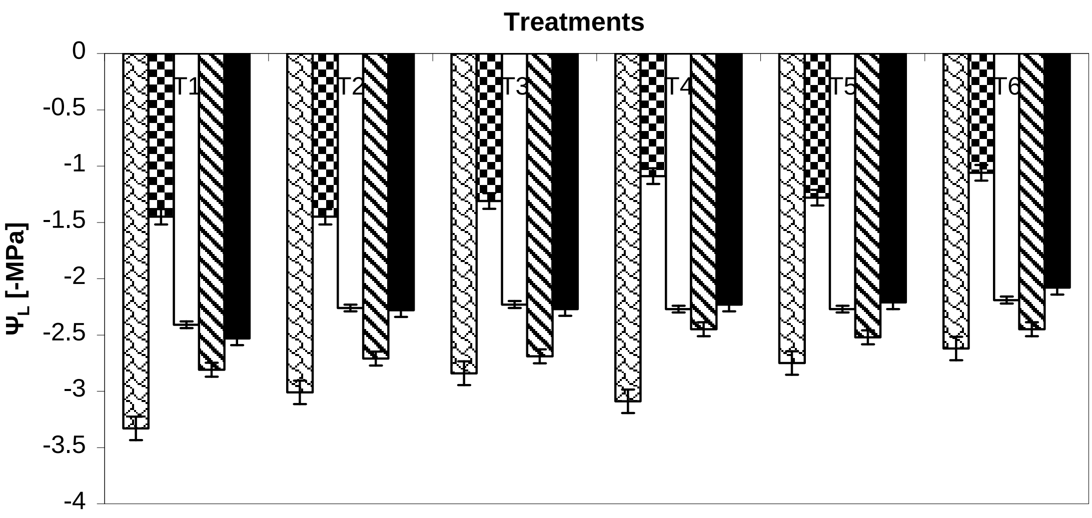

Fig. 4. Seasonal effect of fertilization on leaf water potential(Ψ_L) during the year 2007 to 2010.Vertical bars indicate standard error of the means. (CD at 5% = 0.212)

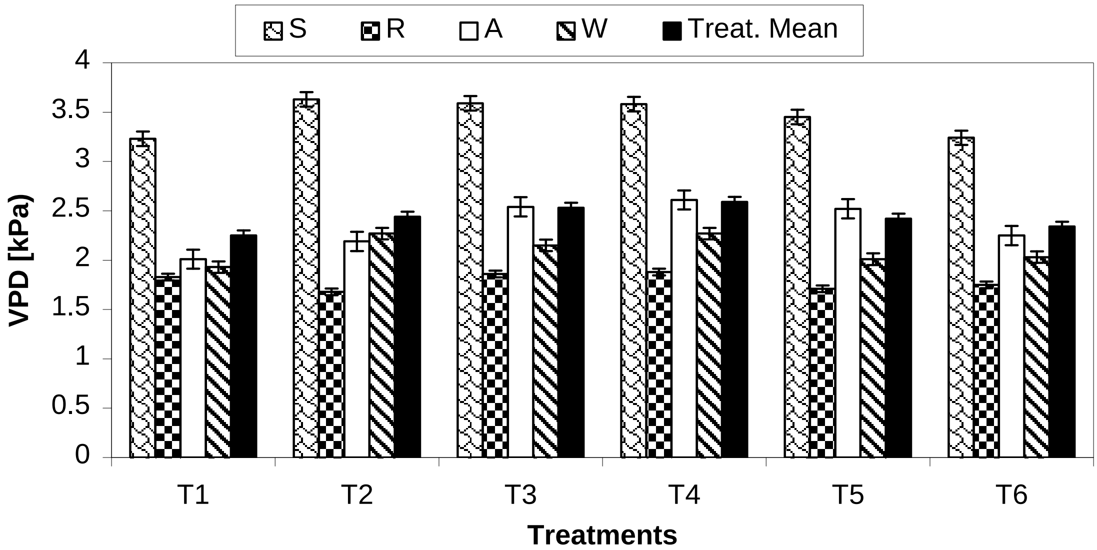

Fig. 5. Seasonal effect of fertilization on vapour pressure deficit (VPD) during the year 2007 to 2010.Vertical bars indicate standard error of the means. (CD at 5% = NS)- S= summer, R= Rain, A= Autumn, W= Winter

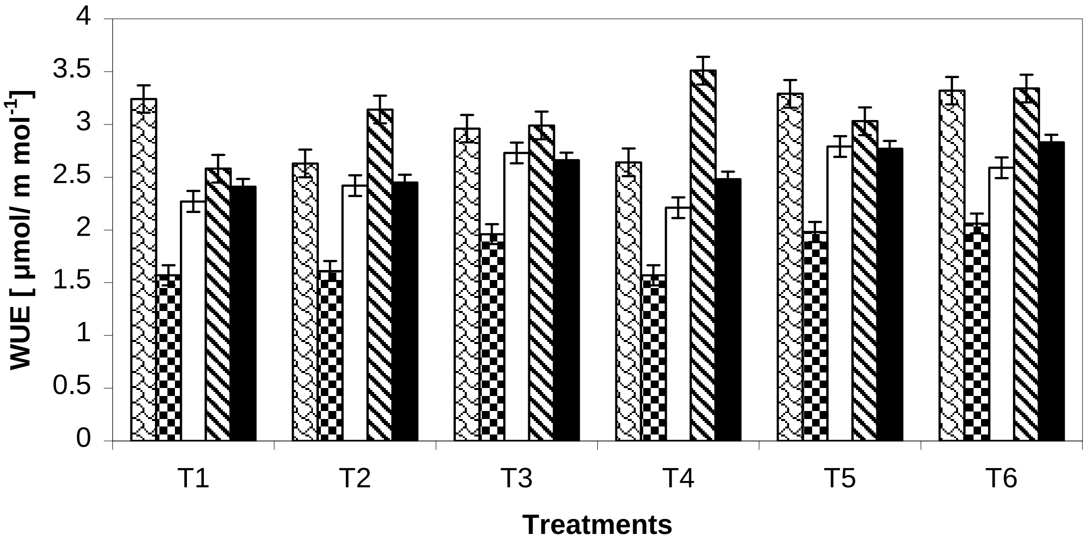

Fig. 6. Seasonal effect of fertilization on water use effeciency (WUE) during the year 2007 to 2010.Vertical bars indicate standard error of the means. (CD at 5% = NS) - S= summer, R= Rain, A= Autumn, W= Winter

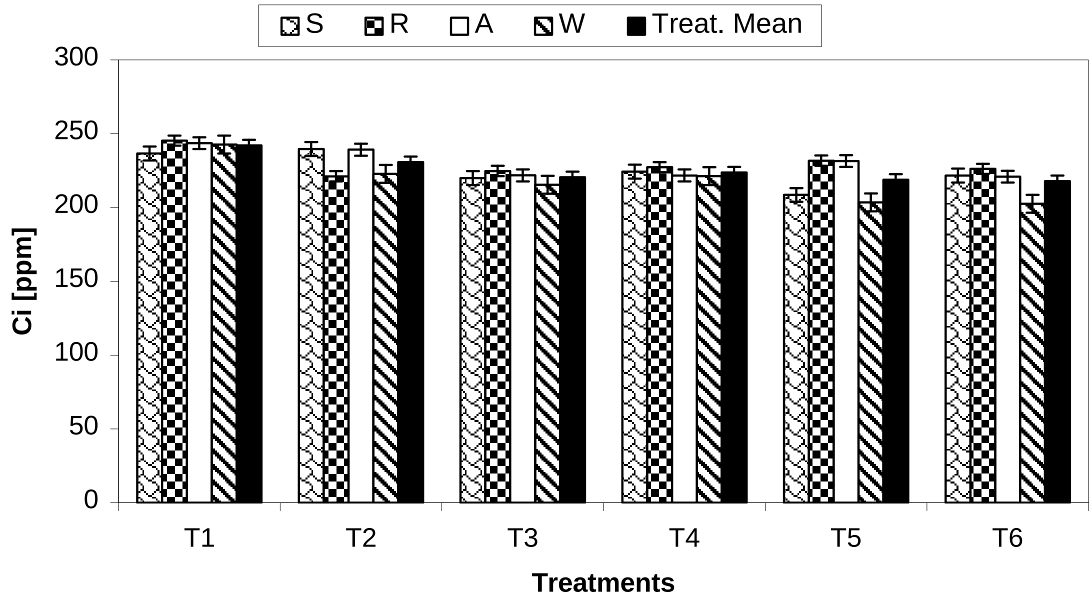

Fig. 7. Seasonal effect of fertilization on Intercellular CO_2 conc. (Ci) during the year 2007 to 2010.Vertical bars indicate standard error of the means. (CD at 5% = 7.078)

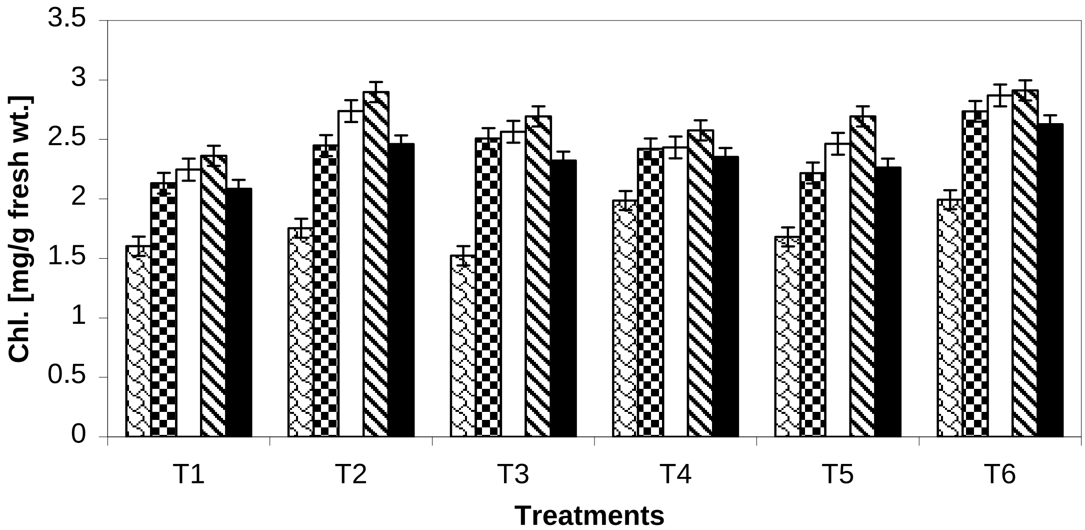

Fig. 8. Seasonal effect of fertilization on chlorophyll content (Chl) during the year 2007 to 2010.Vertical bars indicate standard error of the means. (CD at 5% = 0.232)

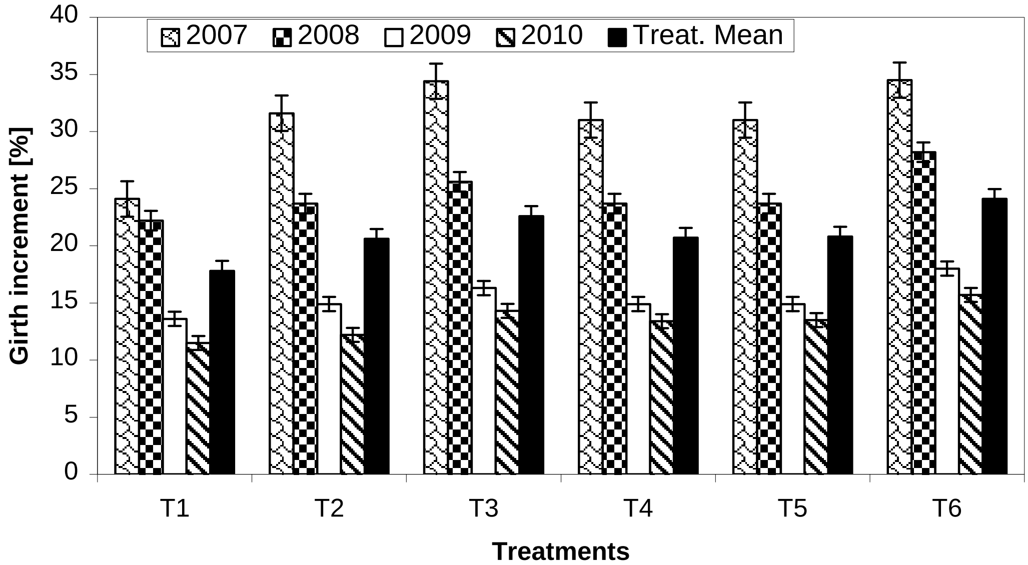

Fig. 9. Seasonal effect of fertilization on the yearly increment of girth during the year 2007 to 2010.Vertical bars indicate standard error of the means.

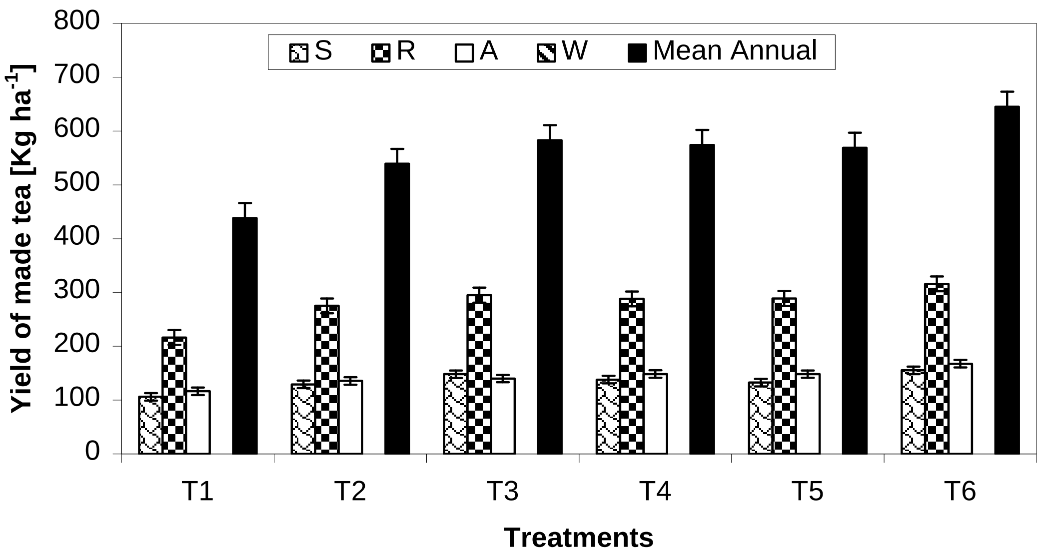

Fig. 10. Seasonal effect of fertilization on annual yield during the year 2007 to 2010. No harvesting during the winter. Vertical bars indicate standard error of the means. (CD at 5% = 25.626)