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EFFECTS OF ENVIRONMENTAL FACTORS ON GROWTH AND YIELD OF TEA *(Camellia sinensis* L.) IN THE LOW-COUNTRY WET ZONE OF SRI LANKA

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The effects of environmental factors on population density, extension rate and weight of tea shoots of two contrasting tea clones were studied at the Tea Research Institute, Low-country Station, Ratnapura.

Analysis of data collected over a period of one year showed that dry weather during the first quarter of the year adversely affected yield components as a result of high plant water deficit. Increases in SVPD, SMD and temperature retarded the growth of tea and their critical levels were estimated to be approximately 1–1.2 kPa, 30–50 mm and 25–26°C, respectively.

INTRODUCTION

Tea yield is determined by the shoot population density and size of shoots harvested. However, the rate of extension of tea shoots are also found to be important in determining the yield as it affects the time taken to produce a harvestable tea shoot. The relative importance of these components in the determination of tea yield has been discussed by many workers (Tanton 1981a, 1981b, 1992; Odhiambo, Nyabundi and Chweya, 1993). These three parameters of yield are weather related. Of the environmental factors, soil moisture availability, temperature, saturation vapour pressure deficit and solar radiation are the most influential ones affecting growth and yield.

Stephens and Carr (1989) have reported on the adverse effect of soil moisture deficits on the size of harvestable shoot population and hence of tea yield. Occurrence of peaks and troughs in production has also been found to be due to the synchronization of shoot growth (Fordham, 1970; Fordham and Palmer-Jones, 1977, Tanton, 1992) which is affected by changes in weather.

The extension rate of tea shoots is temperature dependent and increases with increasing temperatures (Hoshina, Kosuge, Kozai and Honjo, 1983; Squire, 1979; Stephens and Carr, 1990). The lower limit i.e. base temperature for shoot extension has been estimated to be in the range of 7–15^{0}C (Carr and Stephens, 1992; Obaga, Squire and Langat, 1988; Stephens and Carr, 1990) but, the maximum or ceiling temperature above which growth is reduced has been more difficult to determine due to its correlation with other environmental factors such as high vapour pressure deficit. High soil moisture and saturation vapour pressure deficits also limit growth of shoots (Carr and Stephens 1992; Tanton, 1982a; Squire, 1979; Smith, Harvey and Cannell, 1993). Such reduction in growth under environmental stress is a result of low shoot water potential which affects cell turgor (Carr and Stephens, 1992; Squire, 1978).

Furthermore, environmental stress such as drought affects the size of growing shoots (Stephens and Carr, 1994), thus reducing the total weight of harvested crop. Portsmouth (1957) found a relationship between shoot weight at harvest and rainfall during the period of about two months before plucking.

Although some attempts have been made to correlate weather and tea yield in Sri Lanka (Devanathan, 1975; Kandiah and Thevadasan, 1980), little information is available on the influence of weather on individual yield components of different clones and the critical limits of most influential environmental factors. With a view to resolve some of these problems a field experiment was conducted to study the effect of weather on variation in tea yield determinants.

MATERIALS AND METHODS

This study was conducted on two tea clones differing in drought tolerance at the Tea Research Institute, Low-country station, Ratnapura (6^0 40'N, 80^0 25'E, 60 m amsl) during October/1992–October/1993. The tea clones selected were TRI 2025 drought tolerant and TRI 2023 drought susceptible planted at a spacing of 1.2 x 0.6m in the same field on a gentle slope in 1986. The bushes were in the second year of the pruning cycle at the time of commencement of the present study. Ten plots (5 plots/clone) each having 15 bushes were demarcated. They were plucked weekly to remove shoots with 2-3 leaves and a bud and the weight of harvested shoots recorded for a period of one year commencing from October/92 to include the dry and wet periods (defined as the period when soil moisture deficit was below and above 50 mm, respectively). One bush from each plot was selected from the centre of the plot and marked for counting shoots weekly. The total number of shoots on marked bushes was estimated by taking a direct count of harvested shoots and the growing shoots left in the bush after plucking. The total number of shoots with 3, 2 and 1 leaf and elongating buds (shoots with just unfurled scale leaves or a fish leaf) remaining on the bush were estimated by counting shoots on half the bush and doubling the results before adding to the number of harvested shoots to give the total shoot population density.

At weekly intervals, three shoots each having 3 leaves and an active bud were randomly selected from each of three bushes/plot. They were plucked to the third leaf (removing 2 leaves and a bud) and tagged for identification. A new generation of shoots growing from the plucked shoots was used for recording extension rates. After the emergence of scale leaves, the total length of the shoot (from base of the shoot to the base of the apical bud) was measured weekly using a vernier caliper or a ruler until more than 80-90% of shoots were ready for plucking (i.e. with more than 2 leaves).

Harvested shoots from marked bushes were separated into five groups viz., active shoots with 3 leaves, banjhi shoots with 3 leaves, active shoots with 2 leaves, banjhi shoots with 2 leaves and banjhi shoots with one leaf and counted and their fresh and dry weights (oven dried at 90^{0}C for 24 h) were recorded. The bush spread was estimated from the length and breadth of the plucking table at the conclusion of the study.

The soil moisture content was estimated, gravimetrically, by taking core samples at 30, 60 and 75 cm depths using a sampling corer (6.5 cm diameter), as the depth of the root system was measured to be (3 plants/clone) 75 cm. Sampling was restricted to the centre of the inter-rows and to one per plot per fortnight. However, during the long dry period (January-March), weekly assessments were carried out to determine precisely the maximum soil moisture deficit. Soil samples (200 g fresh weight) were oven dried at 105^{0}C to constant weight for the determination of moisture content.

Shoot water potential measurements were taken weekly from January-July, 1993 on tender apical shoots (with 2 leaves and an active bud) sampled from the centre of the bushes (5 shoots/clone) at 07.30-8.00 h. The stem of the shoot was cut just above the fish leaf before sealing tightly in the pressure chamber (Plant water status console, model–3005, USA) (Scholander, Hammel, Bradstreet and Hemmingsen, 1965; Squire, 1979).

Weather data for the period of experimentation were obtained from the station's Meteorological Unit. Results of the experiment were analyzed using the Minitab statistical package.

RESULTS

Effect of drought on shoot water potential

The total water content after free drainage i.e. at field capacity in the root zone, was estimated to be 214 mm. The maximum soil moisture deficit observed during the month of February, 1993 was 95-110 mm (Fig. 1). When clonal differences are considered, soil moisture deficits under the two different canopies differed by 10-20 mm, the higher deficits being associated with TRI 2023. In response to increase in soil moisture deficit, the pre-dawn shoot water potential of TRI 2025 and TRI 2023 decreased to their lowest levels i.e. -0.36 (±0.014) MPa and -0.46 (±0.025) MPa respectively during mid–February. Significantly higher shoot water potentials ($p<0.05$) were associated with TRI 2025 compared to TRI 2023 during the dry season. The relationship between pre-dawn shoot water potential and soil moisture deficit was studied by linear regression analysis (Fig. 2). Beyond soil moisture deficits of approximately 35–45 mm, there was a linear decline in shoot water potential. Clonal difference on this relationship was not significant.

Clonal and seasonal variation in shoot population

The total number of growing shoots showed more than a two-fold variation i.e. from about 100 to 230 shoots/bush (140–320 shoots/m^2). The weekly harvested shoot number showed wider fluctuations than those in the total shoot population varying from 22–95 shoots/bush (30–135 shoots/m^2). Clonal and seasonal variation in shoot population densities showed no significant differences in the total and harvested shoot population densities between the two clones (Table 1). However, the seasonal variation in shoot population density i.e. during dry and wet periods was significantly different for both clones. The total and harvested shoots per bush were reduced significantly by drought ($p<0.05$). The mean per cent values for harvested shoots were not significantly different. However, there was a significant reduction ($p<0.05$) in the harvested percentage of shoots as a result of drought.

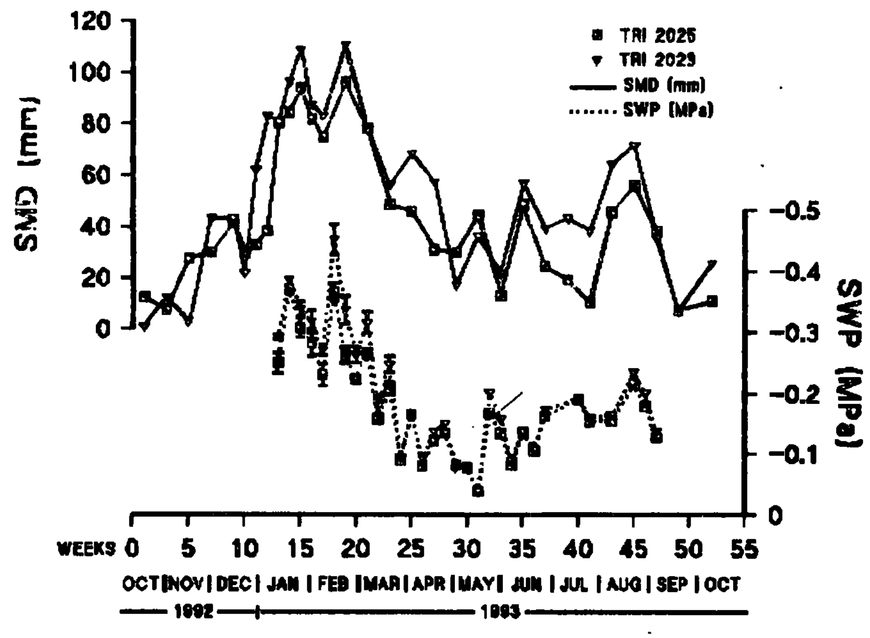

Fig. 1 – *Variation in soil moisture deficit (SMD) in the root zone and pre-dawn shoot water potential (SWP)*

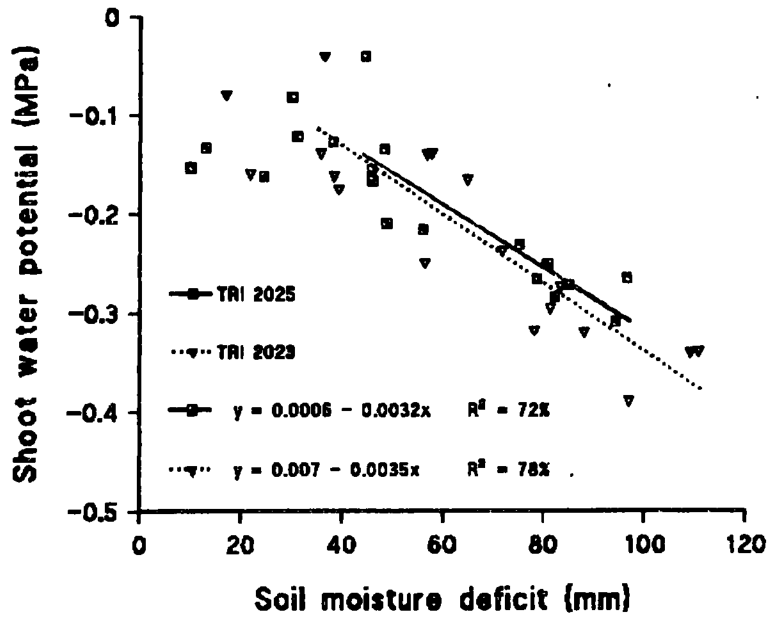

Fig. 2 – *Relationship between soil moisture deficit and pre-dawn shoot water potential*

TABLE 1 – *Total and harvested shoots/bush during wet and dry periods*

	Total shoots		*Harvested shoots*		*Harvested %*	
	TRI 2025	*TRI 2023*	*TRI 2025*	*TRI 2023*	*TRI 2025*	*TRI 2023*
Annual	163	159	51.0	51.9	31.0	32.2
(±SE)	(4.9)	(4.7)	(2.4)	(2.5)	(1.1)	(1.2)
Wet	172	168	57.6	62.8	32.6	34.7
(±SE)	(6.9)	(5.8)	(2.8)	(2.8)	(1.3)	(1.3)
Dry	151	148	43.2	39.9	26.4	25.1
(±SE)	(6.1)	(7.1)	(2.9)	(2.8)	(1.2)	(1.1)

Effect of saturation vapour pressure deficit (SVPD), temperature and soil moisture deficit on shoot population

The time taken to produce a harvestable tea shoot i.e. 3 leaves and a bud (shoot replacement cycle) during wet weather varied from 6 weeks (TRI 2025) to 7 weeks (TRI 2023) which extended from 8 weeks (TRI 2025) to 9 weeks (TRI 2023) during January-March. As there were only a few extended cycles, shoot population densities of TRI 2025 and TRI 2023 were averaged over 6 and 7 week periods respectively for reducing the variation due to plucking. SVPDs, temperatures and soil moisture deficits were also averaged over the same periods for studying the relationship between environmental factors and shoot population density.

The effects of SVPD and soil moisture deficit on total shoot population density are shown in Figs. 3 and 4 respectively. As there were no significant differences between linear regression relationships for the two clones, the data were pooled to determine the common estimates given. Increase in SVPD and soil moisture deficit reduced total shoot population density. The effect of SVPD was more evident when it exceeded a limit of about 1.2 kPa and similarly, the effect of soil moisture deficit was observed at moisture deficits above about 35 mm. The harvested shoot population density (HS, number of shoots/bush/week) also reduced with increasing SVPD (kPa) and soil moisture deficit (SMD, mm) as shown below, but there was no apparent limit below which it remained unaffected as observed in the previous relationships.

$HS = 76.3\ (\pm 2.2) - 16.4\ (\pm 1.3)\ SVPD,$
$R^2 = 62\%,\ p<0.001$

$HS = 71.0\ (\pm 2.0) - 0.39\ (\pm 0.03)\ SMD,$
$R^2 = 56\%,\ p<0.001$

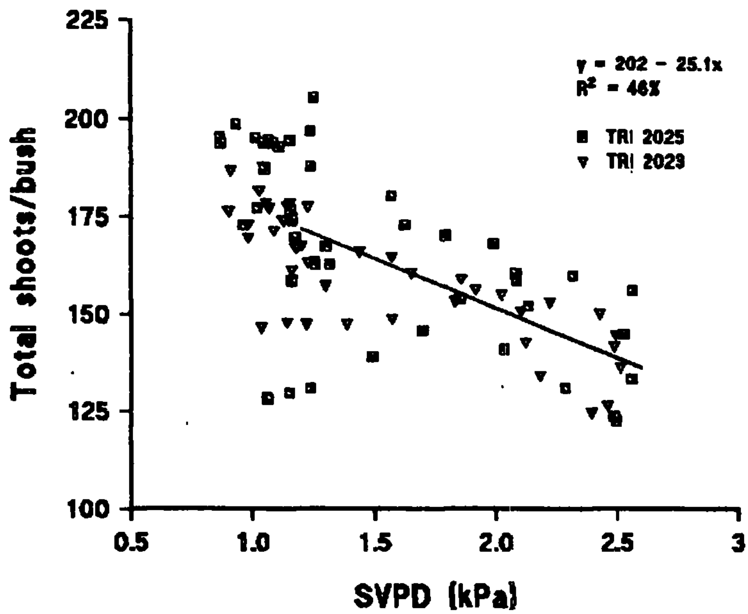

Fig. 3 – *Relationship between saturation vapour pressure deficit (SVPD) and total shoot population density*

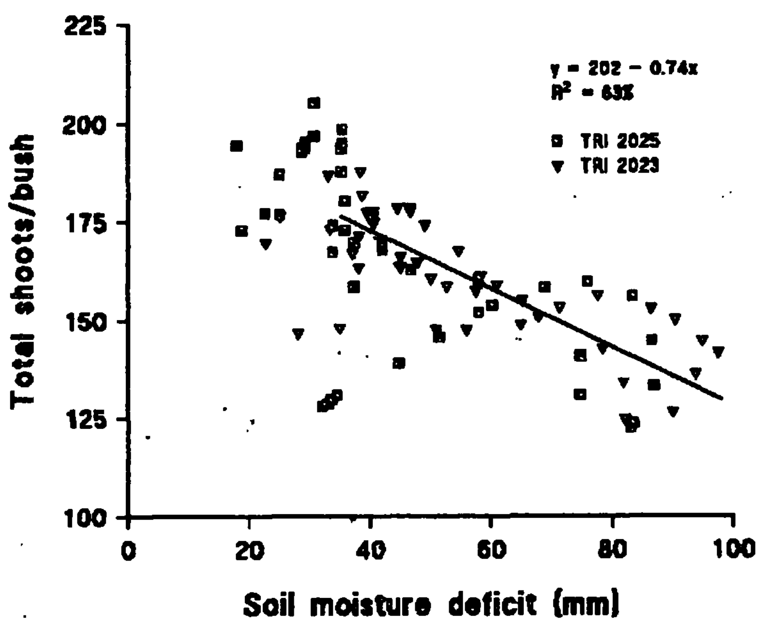

Fig. 4 – *Relationship between soil moisture deficit and total shoot population density*

Although the effect of temperature on total shoot population density was less clear, there was an apparent reduction in the population of harvested shoots with increasing temperatures as shown in Fig. 5. The data points in the graph are clustered around two levels corresponding to shoot populations from October/92 – March/93 with low values and April/93 – October/93 with high values.

Clonal and seasonal differences in shoot extension rate

Due to the rapid growth of tea shoots in the Low-country Wet Zone of Sri Lanka, shoot length, after opening of the fish leaf increased approximately linearly with time. Therefore, shoot extension rates, during the linear phase of growth estimated for each set of tagged shoots, were used to study the effects of environmental factors on shoot growth.

The clonal differences in shoot extension rates were not statistically significant ($p>0.05$). The extension rates of shoots of the two clones varied from 20–72 mm/week with an annual mean of 41–44 mm/week. Table 2 shows that the extension rates were significantly reduced ($p<0.001$) by the dry weather by as much as 18–28%. The rate of reduction in shoot extension rate in response to environmental stress, was not significantly different between clones and hence pooled estimates are given in Table 3. Increases in SVPD, temperature and soil moisture deficit had reduced shoot extension rate.

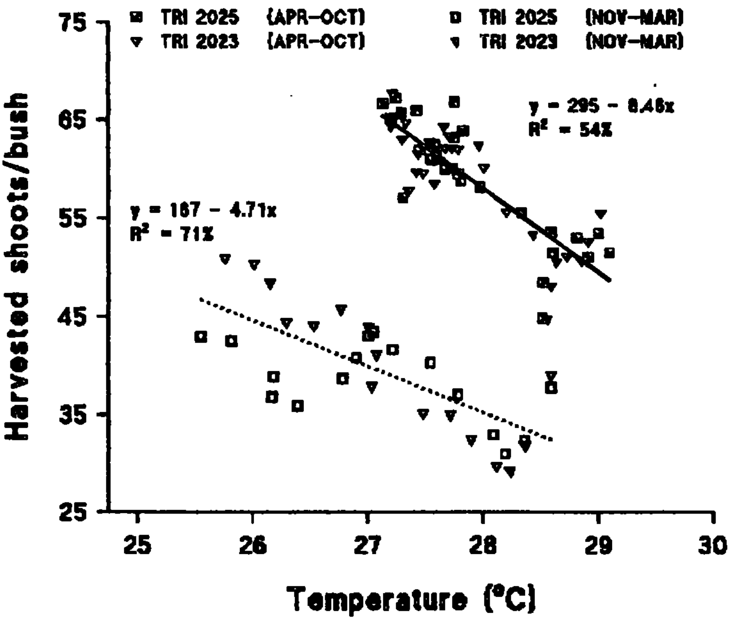

Fig. 5 – *Relationship between temperature and harvested shoot population density*

TABLE 2 – *Shoot extension rates during wet and dry periods*

	Shoot extension rate (mm/week)	
	TRI 2025	*TRI 2023*
Annual	43.7	40.7
(±SE)	(2.1)	(1.8)
Wet period	49.7	44.1
(±SE)	(2.4)	(2.1)
Dry period	35.6	36.0
(±SE)	(2.6)	(2.7)

TABLE 3 – *Regression coefficients (±SE) of the linear relationships between shoot extension rate and saturation vapour pressure deficit (SVPD), temperature and soil moisture deficit (SMD)*

Regression coefficient	*SVPD (kPa)*	*Temperature above 26°C*	*SMD (mm)*
a	54.4 (±3.18)	225 (±38.,0)	50.2 (±2.48)
b	−8.61 (±2.00)	−6.62 (±1.37)	−0.23 (±0.058)
R^2%	22	29	19
p<	0.001	0.001	0.001
n	66	59	60

Effect of SVPD, temperature and soil moisture deficit on shoot extension rate

The decline in shoot extension rates appeared to begin with increasing temperatures above approximately 26°C (Fig. 6). In a multiple linear regression relationship with all three environmental factors, only the temperature effect was significant. The individual effects of climatic factors on the growth of shoots was investigated by studying the residuals of regression models. SVPD had a significant negative linear relationship ($p<0.05$) with residuals of the multiple linear regression between rate of shoot extension and soil moisture deficit plus temperature, confirming the significant correlation between SVPD and extension rates previously demonstrated. Temperature and soil moisture deficit also showed a similar relationship with the residuals of multiple linear regression models between extension rates and the other two environmental factors ($p<0.01$).

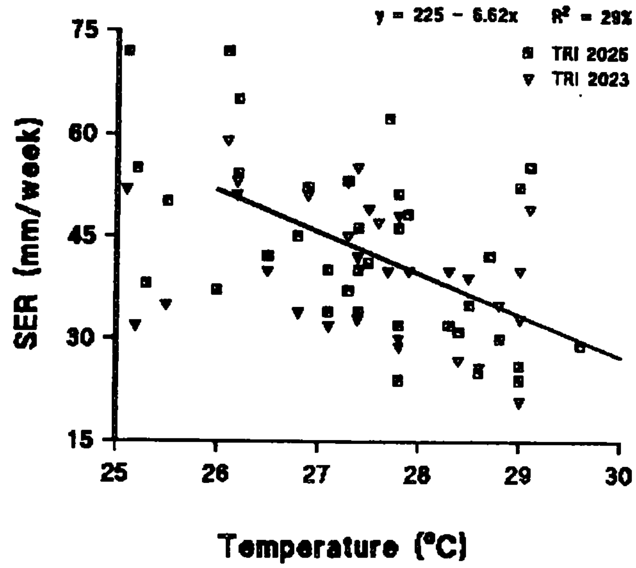

Fig. 6 – *Relationship between temperature and shoot extension rate (SER)*

Clonal and seasonal differences in shoot weight

The mean shoot weight varied from 0.149 to 0.250g for TRI 2025 and from 0.132 to 0.242g for TRI 2023. Table 4 shows the results analyzed for the clonal and seasonal differences in mean shoot dry weight. The mean shoot weight for the two clones was not significantly different. Further analysis of results for different categories of shoots, however, showed that 3 leaved shoots of TRI 2023 were heavier than those of TRI 2025 ($p<0.05$). The weight of three leaved shoots was 0.228 (±0.004)g for TRI 2023 and 0.213 (±0.004)g for TRI 2025. When considering the difference between wet and dry periods, the results of Table 4 show that the dry weight of shoots harvested during the dry period was significantly less than that during the wet period ($p<0.01$). This reduction was estimated to be about 15-16%.

Effect of SVPD, temperature and soil moisture deficit on shoot weight

The effects of environmental factors during 2 and 4 weeks before harvesting, on the weight of harvested shoots, were investigated. The results of the regression analyses for the effects of SVPD, temperature and soil moisture deficit on shoot weight were similar for both clones. Moreover, the relationships for both time periods were similar and therefore, only the relationship for the 4 week period is given in Table 5. The multiple regression analysis showed that the changes in SVPD, temperature and soil moisture deficit averaged over the past 4 week period accounted for 64–67% of the variation of shoot dry weight. In addition, it showed that most of the variation in shoot weight (53–64%) was attributable to the changes in temperature and SVPD.

TABLE 4 – *Dry weight of harvested shoots during wet and dry periods*

	Dry weight (g/shoot)	
	TRI 2025	*TRI 2023*
Annual	0.185	0.189
(±SE)	(0.004)	(0.003)
Wet period	0.193	0.199
(±SE)	(0.005)	(0.004)
Dry period	0.165	0.167
(±SE)	(0.003)	(0.004)

TABLE 5 – *Regression coefficients between weight of harvested shoots (g/shoot) and mean SVPD, temperature and soil moisture deficit (SMD) during 4 weeks prior to harvest*

Regres. coefficient	*SVPD (kPa)*	*Temperature (°C)*	*SMD (mm)*
a	0.233 (±0.006)	0.647 (±0.059)	0.212 (±0.005)
b	−0.024 (±0.004)	−0.017 (±0.002)	−0.0005 (±0.0001)
R^2 %	26	40	21
p<	0.001	0.001	0.001
n	104	104	58

However, the changes in shoot weight were closely related to temperature (i.e. has given a high R^2). The residuals of the regression analysis between shoot dry weight and temperature+soil moisture deficit had a negative linear relationship with SVPD and the residuals from the regression relationship between shoot dry weight and SVPD plus soil moisture deficit were adequately explained by the changes of temperature in a negative relationship. The residuals of the linear regression between shoot dry weight and SVPD plus temperature were also found to have a negative relationship with the recorded soil moisture deficits. Moreover, the decline effect appear to commence at soil moisture deficits above about 30–40 mm (Fig. 7).

DISCUSSION

The results of the present study have provided evidence on the adverse effects of environmental stress on tea yield. Regression analyses were done, on various combinations of parameters before any relationship was established. It was more difficult to separate the effect of high soil moisture deficit, SVPD and air temperature as they were highly interrelated under field conditions and changed simultaneously during the period of experimentation. However, their potential relationships were established by studying linear regression analysis between environmental factors and residuals of different relationships. Such an approach has been previously used by Smith *et al.* (1993).

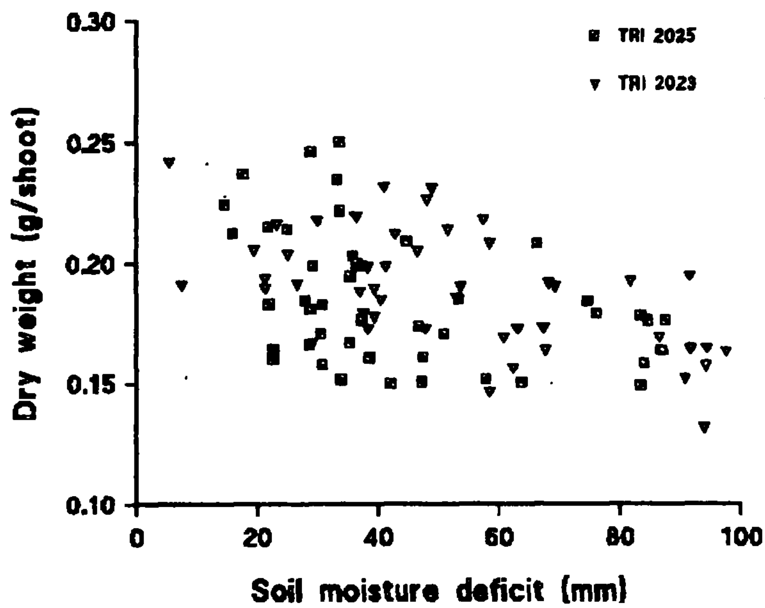

Fig. 7 – *Relationship between soil moisture deficit and mean shoot dry weight*

The results showed that shoot population density, growth rate and weight of shoots were significantly reduced by drought (Table 1, 2 and 4). The lack of available water in the soil and high evaporative demand during the periods of dry weather were responsible for creating high plant water deficits, as indicated by their low shoot water potentials. Though leaf temperatures were not recorded in this study, they would have been significantly higher than the recorded air temperatures, especially during the dry periods (Carr 1972; Hadfield, 1968) which can result in low rate of assimilation and high rate of respiratory loss (Barua, 1987; Hadfield, 1968; Odhiambo *et al.,* 1993; Squire, 1990). Under such conditions, growth of buds and shoots could be adversely affected thereby reducing shoot population, extension rate and weight.

As discussed previously multiple regression analysis showed that high temperature together with higher SVPD dominated the effect of soil moisture deficit on shoot weight. This implies that the growth of tea shoots can be affected by dry ambience even when there is adequate moisture in the soil (Carr, 1972; Carr, Dale and Stephens, 1987).

The critical limits of the environmental factors affecting yield components could not be accurately estimated. However, the apparent critical SVPD reducing shoot population density appeared to be about 1.2 kPa. Although, some workers have found a higher critical SVPD such as >2.3 kPa (Tanton, 1992), much lower values have also been reported for tea (Squire, 1979; Smith *et al.,* 1993) which supports the present findings. Moreover, the shoot population density was adversely affected when soil moisture deficit in the root zone exceeded about 35 mm. It was observed that the reduction in shoot water potential commenced when soil moisture deficit exceeded 35-45 mm. The critical soil moisture deficit reducing tea yield in African tea growing regions (i.e. 40-200 mm) is higher than the deficit found in this experiment (Burgess, 1993; Stephens and Carr, 1989) which could be due to differences in soil, environment and plant materials. The harvested shoot number also decreased with increasing temperatures approximately above 26^{0}C (Fig. 5). It has been shown that the temperatures above 23–30^{0}C are detrimental for growth of tea (Carr, 1972; Carr and Stephens, 1992; Smith *et al.,* 1993; Squire, 1979; Tanton, 1982b). The mean temperature in the Low-country Wet Zone of Sri Lanka is generally higher than 23^{0}C and this may account for the reduction in the number of harvested shoots with increasing temperatures.

The effect of temperature on extension rate observed in the present study (Fig. 6) was different from the majority of previously reported results which have generally shown a positive effect of increasing temperatures. This is because most of those studies have been conducted under lower temperature regimes than that of the present study. Increase in growth rate has been reported to commence above a base temperature of about 7–15^{0}C and this positive relationship has been widely used to model tea yields. However, a ceiling temperature (i.e. upper temperature limit) for shoot growth has not usually been taken into account in the day degree (thermal time) models. Although, the critical temperature needs to be further investigated under a wider temperature range and with different clones, the present results indicate that higher temperatures reduce shoot extension rate. This observation throws doubt on the applicability of general day degree concept in programming plucking under warm environmental conditions in Sri Lanka, especially in the low elevations.

It is evident from the foregoing that in an environment similar to that of the Low-country Wet Zone of Sri Lanka, higher soil moisture deficit and SVPD combined with higher temperatures appear to be the major constraints in limiting the productivity of tea plantations. Hence, modification of the microclimate around the tea bush by proper shade management and irrigation during dry spells will help increase the productivity of our tea lands.

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