S.L.J Tea Sci. 69(1 & 2), 40-50, 2004, *Printed in Sri Lanka*
(Reproduced from the Proceedings of the First Symposium on Plantation Crop Research published in July 8-9, 2004)

Effect of Soil Moisture Deficit and Temperature on Dry Matter Accumulation in Tea Shoots

M A Wijeratne
Tea Research Institute of Sri Lanka, Low Country Station, Ratnapura, Sri Lanka

ABSTRACT

The effect of soil-moisture deficit and temperature on dry-matter accumulation in tea shoots of mature tea bushes, in the low-country wet zone of Sri Lanka, was studied at St Joachim Estate, Tea Research Institute, Low Country Station, Ratnapura.

The annual dry-matter accumulation in young tea shoots was estimated to be about 10-13 mt ha^{-1} of which about 48-58% was harvested, with the balance being added to the canopy. The harvested proportion was comparable to the proportion of dry mass removed (or harvested) from a single shoot, which was affected by clonal characteristics such as inter-nodal length. Soil-moisture deficits reduced dry-matter accumulation in tea shoots, and the critical moisture deficits were around 30 mm for the drought-susceptible tea clone, TRI 2023, and 42 mm for the drought-tolerant clone, TRI 2025. The highest dry-matter accumulation in shoots of these two clones were found to be at ambient temperatures of 26.9 °C and 27.7 °C, respectively.

These results show that drought-tolerant clones can withstand greater soil-moisture stress, and higher temperature regimes in relation to dry-matter accumulation in shoots, than drought-susceptible clones.

Key words: soil-moisture deficit, shoot yield

INTRODUCTION

A part of the assimilates, produced by mature leaves in the canopy of the tea bush, is partitioned between the components of the bush, such as the growing buds and shoots, the stems and the roots which are presumably the storage organs. The rest of the assimilates is used in respiration. The respiratory losses are greater than the dry matter accumulated in the bush, and account for about 60-67% of total dry matter production (Barbora and Barua, 1988; Rahman, 1988; Tanton, 1979).

In commercial tea plantations, frequent harvesting of shoots removes a significant amount of dry matter accumulated in the shoots. The harvest index of tea is reported to be about 14-26% depending on clones and plant densities (Burgess, 1992; Magambo et al., 1988; Tanton, 1979).

Growing shoots are the major sinks for carbohydrates assimilated by the leaves of the canopy. The sink capacity is greatest in the elongating buds even in comparison to the larger shoots. Manivel and Hussain (1986) found that the sink capacity of an unopened, growing bud declines to about 30% when it unfolds its first leaf. Barua (1987) reported that the sink capacity of the first, second and third leaves, from the apex of a shoot with three leaves, was 70, 40 and 30% that of the apical bud. It is, therefore, clear that the elongating buds and younger shoots on the plucking table are strong sinks for assimilates.

The yield of tea is greatly dependent on dry-matter accumulation in the tea shoots, and is affected by climatic factors and management policies, mainly the harvesting practices. Therefore, studies on dry-matter accumulation in tea shoots, in relation to environmental factors, are of great importance. Further, the findings of such studies are also helpful in choosing suitable plucking policies, based on weather conditions and clonal characteristics. Many studies have been conducted in other tea-growing countries (India and in African countries) on dry-matter production, partitioning and accumulation in tea shoots (Burgess, 1992; Marimuthu et al., 1994; Mathews and Stephens, 1998). However, similar information on dry-matter accumulation in tea shoots, in relation to environmental factors, in the tea-growing regions of Sri Lanka is lacking. Hence this study was conducted with the objective of estimating dry-matter accumulation in tea shoots based on yield components, and the effects of soil-moisture deficit and ambient temperature on dry-matter accumulation in tea shoots in the low-country wet zone of Sri Lanka.

MATERIALS AND METHODS

Two tea clones, the drought-tolerant TRI 2025 and the drought-susceptible TRI 2023, were selected from Field No. 2 at St Joachim Estate, Tea Research Institute, Ratnapura. The bushes were planted at 1.2 x 0.6 m (approximately 12,500 bushes ha^{-1}). They were seven years old, and were in the second year of their pruning cycle.

Ten plots (five plots per clone), each having 15 bushes, were demarcated for recording data on yield, shoot population density, weight of shoots and soil moisture, over a period of one year. Shoots were harvested at weekly intervals, leaving the most mature normal leaf unplucked ('mother-leaf plucking'). A few shoots were occasionally harvested below the mother leaf, in order to maintain the level of the plucking table. Shoot counts (total and harvested) were made at weekly intervals, on five randomly selected tea bushes from each clone (one bush $plot^{-1}$), over a period of one year. The total shoot population density was ascertained by counting all the growing shoots (elongating buds, shoots with fish or scale leaves only, and shoots with one to four normal leaves) on half of the tea bush before harvesting them and doubling the count. The number of shoots left after plucking was also counted separately for each category, in the same way.

The weight of full, growing shoots of all categories was measured at weekly intervals by removing the shoots from tea bushes not used for recording shoot density. Harvested shoots were separated into different groups, based on the number of leaves and their stage of growth (active or dormant), and weighed. The dry-matter content of shoots was also recorded at each harvesting, by oven-drying a sample of shoots to constant weight at 90 °C.

The weekly increase in shoot dry weight W (g $bush^{-1}$ $week^{-1}$), or the amount of weekly dry-matter accumulation in shoots, is given by the following relationship:

$$W = W_T - W_L$$

where W_T is the total dry weight of shoots (g $bush^{-1}$) immediately prior to harvesting, and W_L is the total dry weight of shoots (g $bush^{-1}$) remaining after the previous harvesting. Dry-matter accumulation in the shoot butt, and in the mature leaves left after plucking, was not considered in this exercise as dry-matter partitioning to such tissues was reported to be negligible (Barua, 1987; Manivel and Hussain, 1986).

Weather data were taken from the meteorological station at the Tea Research Institute, Ratnapura. The soil-moisture content was determined gravimetrically, by taking core-samples at 30, 60 and 75 cm depths, using a sampling corer (diameter=6.5 cm). The depth of the root system was measured by excavating roots (3 bushes $clone^{-1}$), and was found to be 75 cm.

In order to minimize soil disturbance and root damage, sampling was done at fortnightly intervals at the centre of the inter-row. However, sampling was done at weekly intervals during dry months. A soil sample of 200 g (fresh weight) was oven-dried to constant weight at 105 °C, in order to determine moisture content on a dry weight basis. The total moisture content at field capacity was 214 mm. The mean weekly temperature, and the soil-moisture deficit, were also calculated. The height of the plucking table (5 bushes $plot^{-1}$) was also measured, and mean values were calculated separately for each clone.

Data were analyzed using the Minitab statistical package. The results are given with standard errors in parenthesis (±SE). Clonal and seasonal comparisons were made by the sample t test, and the relationships between the dry-matter accumulation in shoots, and the soil-moisture deficit and temperature, were evaluated by regression analysis.

Of these two environmental factors, the more influential one affecting shoot growth in the low country was the soil-moisture deficit. Hence, the critical soil-moisture deficits affecting dry-matter accumulation in shoots were first established by regression analysis. In order to establish the relationship between temperature and weekly dry-matter accumulation in shoots, the data corresponding to soil-moisture deficits higher than the critical limit were excluded.

RESULTS

Weekly dry-matter accumulation in shoots of TRI 2025 bushes ranged from 5.6 to 28.4 g $bush^{-1}$ $week^{-1}$, while in TRI 2023 it ranged from 6.6 to 37.0 g $bush^{-1}$ $week^{-1}$. The statistically analyzed results are given in Table 1.

Table 1. Mean dry-matter accumulation in tea shoots over different periods (g/bush/week). Wet and dry periods were defined based on the critical soil-moisture deficits of each clone.

	TRI 2025	TRI 2023
Annual (±SE)	15.9 (0.81)	19.9 (1.26)
Wet (±SE)	17.7 (0.97)	23.1 (1.35)
Dry (±SE)	12.9 (1.07)	14.8 (1.63)

Weekly dry-matter accumulation in shoots was significantly higher in TRI 2023 bushes than in TRI 2025 bushes ($p<0.01$). For both clones, dry-matter accumulation in shoots during dry periods (that is, periods during which soil-moisture deficits were above the critical limits shown below) was significantly lower than that during wet months ($p<0.01$), the reduction being about 27-36%. The total, annual dry-matter accumulation in shoots (summation of the weekly dry matter accumulation) was about 825 g $bush^{-1}$ (10 mt ha^{-1}) for TRI 2025, and 1064 g $bush^{-1}$ (13 mt ha^{-1}) for TRI 2023. Of these amounts, 482 g was harvested from a TRI 2025 bush, and 514 g from a TRI 2023 bush.

The proportion of shoot dry mass harvested from the total shoot dry mass of the bush at plucking, and also from the weekly increase in shoot dry mass, was tabulated for wet and dry periods separately (Table 2). The harvested percentage of shoot dry mass (both from the total and the weekly increment) for TRI 2023 is significantly lower than that for TRI 2025 ($p<0.001$). The annual means were 28.7% and 33.9% for total shoot dry mass, and 48.3% and 58.4% for the weekly increment for the same clones, respectively.

When analyzed separately for wet and dry periods, it was observed that the dry weather had significantly reduced the proportion of shoot dry mass harvested from the bushes ($p<0.05$). The positive linear relationship between weekly dry matter accumulation in the shoots, and weekly harvested shoot dry mass (that is, the yield), is shown in Fig. 1, where the regression coefficients are close to the estimated mean percentages given in Table 2. The intercepts were not significantly different from zero ($p>0.05$), and hence the regression lines were drawn through the origin.

Table 2. Mean harvested proportion of shoot dry mass over different periods. Wet and dry periods were defined based on the critical soil-moisture deficits of each clone.

	Harvested proportion of total shoot dry mass (%)		Harvested proportion of weekly increment (%)	
	TRI 2025	TRI 2023	TRI 2025	TRI 2023
Annual (±SE)	33.9 (0.90)	28.7 (0.89)	58.4 (1.5)	48.3 (1.2)
Wet (±SE)	35.9 (1.2)	31.2 (0.7)	61.5 (2.0)	49.7 (1.4)
Dry (±SE)	30.8 (1.0)	24.9 (1.6)	53.0 (2.3)	44.0 (1.8)

During the experimentation, it was also estimated that about 59.5% of the dry mass of a single growing shoot was harvested from TRI 2025, compared to about 48.5% for TRI 2023. Bush height at the end of the experiment was 97.2 (±1.1) cm for TRI 2025 bushes, and 106.8 (±2.5) cm for TRI 2023 bushes.

With regard to the effect of temperature and the soil-moisture deficit on dry-matter accumulation in shoots, it was assumed that the main limiting factor for growth of tea during dry weather was the soil-moisture deficit, and that during wet weather it was temperature. Accordingly, the effect of soil-moisture deficit on dry-matter accumulation in shoots, and their critical limits, were first established, and then the effect of temperature on dry-matter accumulation in tea shoots was studied, excluding the effect of soil-moisture deficit. The variation of the soil-moisture content in the root zone of the two clones is shown in Fig. 2, and the effects of soil-moisture deficit and temperature on dry matter accumulation in shoots are shown in Figs. 3-6. The critical soil-moisture deficit was first established by the polynomial curve, and then the effect of the soil-moisture deficit was estimated by the gradient of the linear trend line.

Increases in the soil-moisture deficit caused decreases in dry-matter accumulation in shoots of both clones, irrespective of their ability to tolerate drought. However, the critical moisture deficits, above which the dry-matter accumulation in the shoots was affected, were around 30 mm for the drought-susceptible TRI 2023, and around 42 mm for the drought-tolerant TRI 2025. When considering the effect of temperature, the highest dry-matter accumulation in the shoots was found at 26.9 °C in TRI 2023, and 27.7 °C in TRI 2025.

DISCUSSION

Total, and weekly, accumulation of dry matter in tea shoots, and the harvested proportion of shoot dry mass in relation to varying soil-moisture deficits and ambient temperatures, were estimated based on yield components.

The results showed that the dry-matter accumulation in shoots of the drought-tolerant clone, TRI 2025, was significantly less than in the drought-susceptible clone, TRI 2023. The annual, total shoot dry mass produced by a TRI 2025 bush was estimated to be about 77% of that produced by a TRI 2023 bush. However, the yield records during the experimentation showed no significant difference between these two clones.

The annual yield of TRI 2023 was only about 6% higher than that of TRI 2025, that is 6,425 kg ha^{-1} yr^{1} and 6,025 kg ha^{-1} yr^{-1}, respectively. This was due to differences in the harvested proportions of shoot dry-mass between the two clones. A higher proportion of shoot dry-mass, accumulated over a period of one year, had been harvested from the TRI 2025 bushes compared to the TRI 2023 bushes, that is 58% and 48%, respectively ($p<0.05$). This conclusion was further supported by the harvested proportion of a single growing shoot, which was 59.5% and 48.5% for TRI 2025 and TRI 2023, respectively. These results show that TRI 2023 bushes retain more dry matter than TRI 2025.

Although not recorded in this experiment, a separate analysis of root-starch reserves of these two clones have shown that the root-starch reserves of TRI 2023 was higher than that of TRI 2025 (Anon., 1996).

The results of the present study show that the harvested proportion of total dry matter accumulated in shoots (the annual total of weekly increments in shoot dry mass) was the same as the harvested proportion of a single growing shoot. Therefore, total dry-matter accumulation in the shoots (TDM) could be estimated approximately by yield (Y), and the harvested proportion of a single growing shoot (HP), as given below. Y and HP vary with the plucking policies such as severity (point at which the shoot is removed), and the standard of harvesting (size of the harvested shoot). Hence, if a mixture of different systems of harvesting is adopted, a mean value of the harvested proportion needs to be considered.

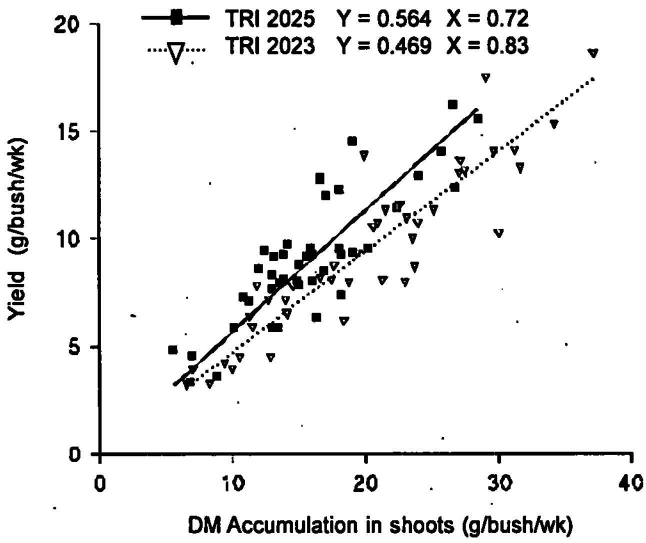

Figure 1. Relationship between weekly dry matter accumulation in tea shoots and harvested shoot dry mass (yield).

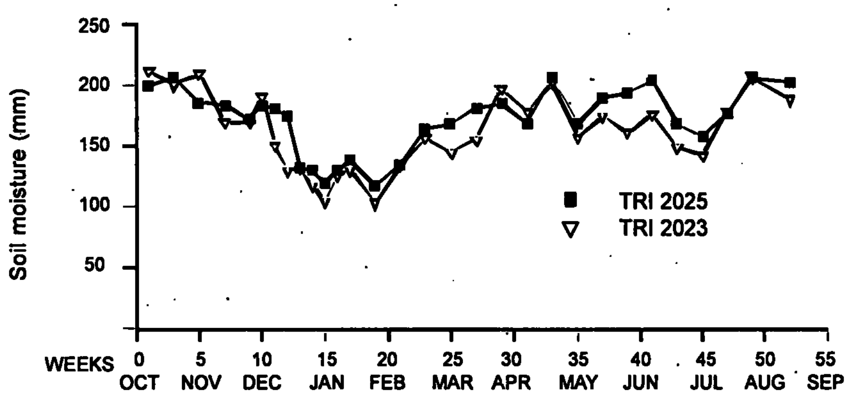

Figure 2. Soil moisture content in the root zone over the experimental period.

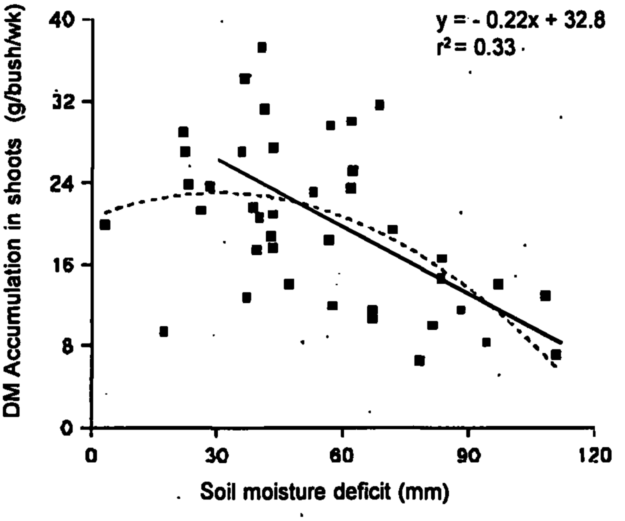

Figure 3. Effect of soil moisture deficit on dry matter accumulation in tea shoots (TRI 2023).

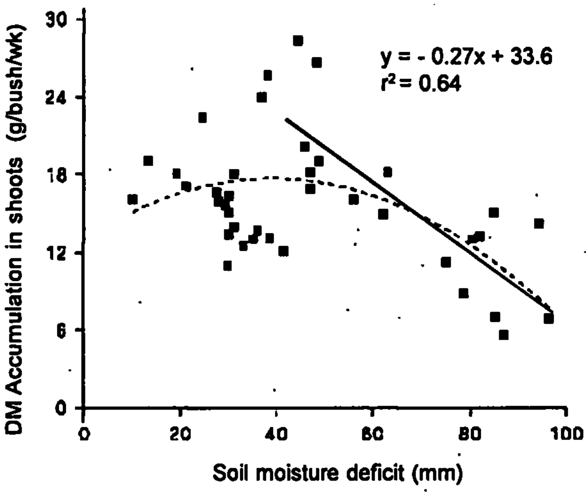

Figure 4. Effect of soil moisture deficit on dry matter accumulation in tea shoots (TRI 2025).

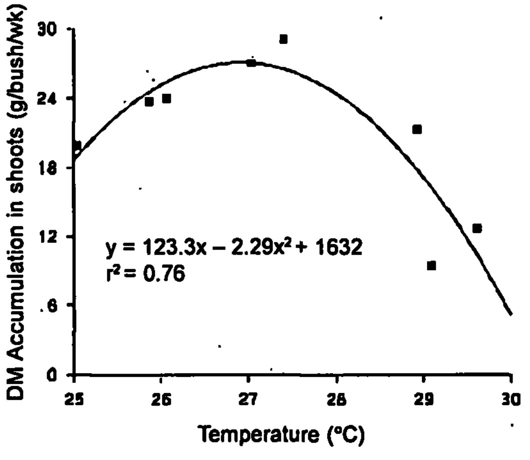

Figure 5. Effect of temperature on dry matter accumulation in tea shoots (TRI 2023).

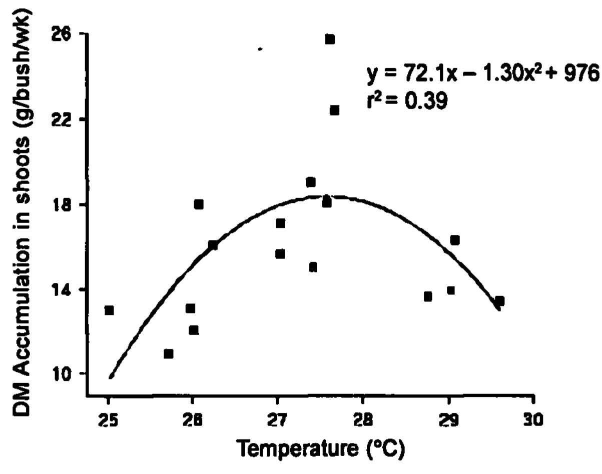

Figure 6. Effect of temperature on dry matter accumulation in tea shoots (TRI 2025).

TDM (kg ha^{-1} yr^{-1}) = Y (kg ha^{-1} yr^{-1}) / HP (%)

The harvested proportion of a single shoot recorded in this study was comparatively lower than that reported by Tanton (1979, 1992) for the SFS 204 clone in Malawi, namely 62-87%, which could be due to differences in shoot characteristics and harvesting policies.

The differences in the harvested proportions of a single growing shoot of the two clones, TRI 2023 and 2025, were attributable to their shoot characteristics. The internodes of TRI 2023 shoots are longer than the internodes of TRI 2025 shoots (Wickramaratne, 1981). Therefore, the proportion of the dry mass of a shoot left after plucking would be greater in TRI 2023 than in TRI 2025. This result was also confirmed by differences in the height of the plucking table. The height of the plucking table of TRI 2023 was greater than that of TRI 2025: 106.8 (±2.5) cm and 97.2 (±1.1) cm, respectively. These results suggest that the shoot characteristics, and the plucking policies, can have a marked influence on the canopy structure and the yield of harvested tea bushes.

Dry weather limits dry matter production and accumulation in shoots. Despite the differences in drought-tolerant capabilities of the two clones, the soil-moisture deficit reduces dry-matter accumulation in the shoots of both clones. However, the critical soil-moisture deficits affecting dry-matter accumulation in shoots were estimated to be about 30 mm for TRI 2023, and about 42 mm for TRI 2025. These values were close to the critical soil-moisture deficits affecting shoot-water potential of the two clones, at the same location, that is 35 mm and 45 mm, respectively (Wijeratne, 1996). However, the soil-moisture deficits of the most effective root zone (the top layers of soil) would have been much higher than the critical limit estimated for the entire root zone (75 cm).

The results show that shoot growth of the drought-susceptible clone, TRI 2023, was affected by moisture stress earlier than in the drought-tolerant clone, TRI 2025. Wijeratne (1996, 2001) reported that the shoot population density and the shoot extension rate of these two clones decline at temperatures above 26-27 °C, which were close to the temperatures estimated for maximum dry-matter accumulation in the shoots. These results show that the performance of drought-tolerant clones, under dry weather conditions and at high ambient temperatures, is superior to drought-susceptible clones.

CONCLUSIONS

1). The amount of dry matter accumulated in tea shoots could be estimated by yield, and by the harvested proportion of a single shoot.

2). About 48-58% of the total dry matter accumulated in tea shoots is harvested, and the rest added to the canopy of the tea bush.

3). Dry-matter accumulation in tea shoots is significantly reduced at soil-moisture deficits above 30-42 mm, and the optimum temperature for dry-matter accumulation in tea shoots was found to be around 26.9- 27.7 °C.

4). The performance of drought-tolerant clones under dry weather conditions, and at higher ambient temperatures, was superior to that of drought-susceptible clones.

REFERENCES

Anon. 1996 Report of the Plant Physiology Division. Annual Report of the Tea Research Institute of Sri Lanka, p. 79-86.

Barbora, A C and Barua, D N 1988. Respiratory losses and partition of assimilates in tea bushes (*Camellia sinensis* L.) under plucking. Two and a Bud 35, 75-82.

Barua, D N 1987 Tea. *In*: Tree Crop Physiology (eds. M R Sethuraj, A S Raghavendra.), p. 225-246. Elsevier, Amsterdam.

Burgess, P J 1992 Dry matter production and partitioning by clone 6/8. Ngwazi Tea Research Unit, Quarterly Report No.9, 11-16.

Magambo, M J S, Omolo J G and Othieno C O 1988. The effect of plant density on yield, harvest index and dry matter production. Bulletin, United Planters Association of South India, No.40, 7-14.

Manivel, L and Hussain, S 1986 Relative sink capacity of developing tea shoots. Two and a Bud 33, 30-38.

Marimuthu, S, Raj Kumar, R and Manivel, L 1994 Factors affecting partitioning of assimilates in tea. J. Nuclear Agric. Biol. 23, 219-223.

Matthews, R B and 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, 369-389.

Rahman, F 1988 Physiology of the tea bush. Two and a Bud 35, 1-14.

Tanton, T W 1979 Some factors limiting yield of tea (*Camellia sinensis*). Exp. Agric. 15, 187-191.

Tanton, T W 1992 Tea crop physiology. *In*: Tea: Cultivation to Consumption. eds. K C Willson, M N Clifford, p. 173-199. Chapman and Hall, London.

Wijeratne, M A 1996 Effect of environmental factors on growth and yield of tea (*Camellia sinensis* L.) in the low country wet zone of Sri Lanka. S.L.J.Tea Sci. 64, 21-34.

Wijeratne, M A 2001 Shoot Growth and Harvesting of Tea. Tea Research Institute of Sri Lanka, Talawakelle, Sri Lanka.

Wickramaratne, M R T 1981 Variation in some leaf characteristics in tea (*Camellia sinensis* L.) and their use in the identification of clones. Tea Q. 50, 183-189.