

EFFECT OF ELEVATION ON NET TOTAL DRY MATTER PRODUCTION AND YIELD OF TWO CLONES OF TEA IN SRI LANKA

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The effect of elevation on net total dry matter production (NTDM) was the opposite to that of yield in clone TRI 2023 while elevation had no effect on both these attributes in clone TRI 2025. For every 100 m rise in elevation the yield of clone TRI 2023 was lost by 35 kg ha⁻¹ while the NTDM production increased by 130 kg ha⁻¹ thus suggesting the suitability of this clone specifically to lower elevations.

The production and partitioning of the NTDM to harvestable shoots in clone TRI 2023 were strongly influenced by the mean air temperature which fell at a rate of 5.8°C 1000 m⁻¹ ($r^2 = 0.99$) when elevation rose from 30 to 1859 m. Although the height of plucking table in both clones increased fast at lower elevations mainly due to the high mean air temperature, the rate of increase in height was not related to the NTDM production. Also, the NTDM of both clones at low elevations was independent of the effects of photosynthetic rate (P) and total leaf area per bush. Increase in yield did not depend on the increased NTDM production.

INTRODUCTION

The proportion of the net total dry matter (NTDM) which is partitioned to harvestable shoots determines the yield of a tea bush. In Sri Lanka, the higher yields are obtained in the lower elevations (Wickramaratne, 1981). However, it is not known whether the low yields obtained at higher elevations were due to low NTDM production or reduced partitioning of dry matter to shoots. Therefore, it is important to investigate how these two physiological attributes are affected by the dominant environmental factors across the wide altitudinal range where tea is grown.

Reports from Kenya, Malawi and Assam (Otheino, 1976, Laycock and Otheino, 1978; Tanton, 1979; Barua, 1981, 1987) suggest that NTDM production of clonal tea was higher in colder regions than in warmer areas while yield was vice versa. The large respiratory losses of 60 to 67% of the total dry matter produced in warmer regions could be attributable to the relatively small NTDM production in warm regions like Malawi (Tanton, 1979) and Assam (Barua and Sharma, 1982; Barbora and Barua, 1988). Therefore, the large amounts of NTDM (9 - 16 t ha⁻¹) produced in colder environments like Kenya (Magambo and Cannel, 1981; Othieno, 1982) compared to the relatively small amounts (4.5 - 10 t ha⁻¹) produced in warm regions like Assam (Barbora and Barua, 1988) may not necessarily result in high yields.

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Sakai (1975) reported that the rate of respiration of tea doubled when air temperature was increased by 10°C while Barbora and Barua (1988) showed a linear increase from 20 to 40°C. Further, Barbora and Barua (1988) showed that respiratory rates differ between clones; being larger in high yielding and lower in low yielding clones.

In Kenya, an increase in altitude by 100 m decreased yield by 200 to 300 kg ha⁻¹ (Squire, Obaga and Otheino, 1993). Large yields reported in low elevations in Sri Lanka (Wickramaratne, 1981) could be attributable to increased partitioning of NTDM to shoots due to high air temperatures shown by Barbora and Barua (1988) in Assam. Ng'etich (1995) showed that partitioning dry matter to shoots increased during the warm seasons in Kenya. This in turn could be related to temperature induced shoot growth. The positive linear response of the rates of shoot development to mean air temperature in the absence of other environmental constraints in Sri Lanka (Balasuriya, 1996), which increased the number of shoot replacement cycles for a given period of time could be one of the reasons for the high yields obtained at low elevations.

Clonal differences in the production of NTDM had been reported from North East India (Barua, 1959; Barbora and Barua, 1988), Kenya (Otheino, 1982), South India (Murty and Sharma, 1986) and Tanzania (Burgess, 1992). Further, Burgess (1992) and Ng'etich (1995) reported clonal differences in partitioning of NTDM to shoots for different seasons of the year.

Further, Wickramaratne (1981) reported clone x environment interactions for yield of tea in Sri Lanka. The differences in NTDM production and yield observed in different parts of the world suggest that there is a strong influence of the environment and clone on these two attributes. Therefore, the objective of this study is to investigate the effects of clone, elevation and clone x elevation interactions on yield and NTDM production of clonal tea.

MATERIALS AND METHODS

Sites

The four experimental sites selected i.e. Glassaugh (1859 m) Vellai oya (1300 m), Strathdon (914 m) and Kottawa (30 m) were described in a previous article (Balasuriya, 1996).

Environment

The total monthly rainfall and daily maximum and minimum air temperatures were calculated for the period from 01 February to 31 August 1994. The wet and dry bulb temperatures at 1300 hours was recorded for the same period. The daily mean air temperature (T_{mean}) was calculated as the average of the daily maximum and minimum air temperature.

Soil moisture content was determined (gravimetric method) using core samples (three samples per plot taken from inter-rows) taken weekly at 15, 30, 45, 60 and 75 cm depths during February and March and stopped after the heavy rains commenced. The samples

were dried in an oven at 105°C to a constant weight to measure the moisture content. The bulk density of soil was calculated at same depths using core samples at the beginning of the experiment taking three samples per plot per site.

Three random soil samples from a depth of 30 cm were taken of each plot using a hand auger at each of the four sites to measure the pH value of the soil.

From previous weather records maintained at each site the average monthly rainfall and daily mean air temperature was calculated for five consecutive years (1989-1993). To study the altitude - rainfall and altitude - mean air temperature relationship, data for the same period from two additional sites, Hantane (762 m) and Talawakele (1382 m) were obtained from the weather records maintained at the meteorological stations.

Dry matter sampling

A field has been selected with bushes which had just completed the second year of the pruning cycle (from the last pruning date) and four blocks were made comprising 35 bushes each. From each block two bushes were randomly selected thus giving a total number of eight bushes for a clone at one site and these bushes were marked from 1 to 8. In February, four bushes from a clone in each site (one bush from each of the four blocks) were uprooted with the root system and the fresh weight was recorded. The soil was excavated up to a depth of 75 cm in an area of 0.3 x 0.6 m² (within and between rows) around the bush to remove all roots severed from the uprooted bush and then sieved. These roots were washed to remove soil adhered to them. Afterwards each bush was separated into leaves, wood and roots. Three samples from each fraction; roots and leaves weighing 60 - 100 g and wood weighing 200 -300 g from each bush were oven dried at 90 °C, until a constant weight was reached. The total dry weight for each bush was then extrapolated separately.

The dry matter sampling was repeated at the end of August 1994. During the experimental period, the cultural and management practices of the bushes such as fertilizing, plucking and weeding were made similar at each of the four sites.

Leaf area

Prior to drying the width and length of each leaf in every leaf sample was measured as soon as the fresh weight was taken. The product of width and length of each leaf was then multiplied by 0.625 (Pethiyagoda and Rajendram, 1965) to find the leaf area. The leaf area of the sample was then extrapolated to the total leaf area of the bush (LA).

Leaf area Index (LAI) was measured by dividing the leaf area of a single bush by the land area a single bush has occupied. Since the bushes have achieved a complete ground cover, the LA was divided by 0.6 x 1.2 m² which is the spacing given for a bush. Specific leaf area is the total leaf area of a gram of an oven dried leaf sample.

Yield

In the same field, four adjacent plots from each clone comprising of 35 bushes per plot were marked and the yields were recorded weekly during the experimental period for each clone at each site. Two samples (about 100 g) from each plot were oven dried at 90°C to get the average dry weight of the plot harvest and then this was extrapolated to obtain the dry weight of the harvested shoots from a hectare.

Photosynthetic rate

In order to observe the photosynthetic rate at different elevations the net photosynthetic rate (P) was measured at three sites, Kottawa (30 m), Talawakele (1382 m) and Glassaugh (1859 m) using a LI-6200 Portable Photosynthetic System (LI-COR inc/LI-COR Ltd., Box 4425/4421, Super St., Lincoln, Nebraska, 68504, USA) on two clear days during the experimental period. The Photosynthetic meter was not available to take measurements at the other two sites, Strathdon and Vellai oya.

The readings were taken from 0800 to 1600 hours at hourly intervals on both days, when the light intensity did not fall beyond a photon flux density (PFD) of $900 \mu\text{mol m}^{-2} \text{s}^{-1}$. The measurements were carried out on six mother leaves from each clone which were carrying an active bud of 10 to 15 mm in length in the leaf axil.

Rise in the height of the plucking table

This was measured using permanently installed straight wooden poles at three random places within each plot of the two clones at each of the four sites. The height of the plucking table was marked on the poles using a permanent ink at the beginning and end of the experiment. The difference between the two marks on the pole was taken as the total increase in height.

Experimental Design and data analysis

The experiment was a 2 x 4 factorial with four replicates in a completely randomized design and the data were analysed using Genstat 5 (Rothamstead).

RESULTS

Environment

During the period from February to August 1994, critical deficits of soil moisture (> 50 mm) or saturation vapour pressure of air (≥ 2.0 kPa) were absent at any of the four sites. Also, fluctuations of mean air temperature ($T(\text{mean})$) between any two successive months were less than 1°C during this period (Fig. 1a). The distribution of monthly rainfall for the same period showed that Strathdon and Vellai oya received a higher rainfall than the other two sites (Fig. 1b). However, compared to other sites the monthly rainfall was more uniformly distributed in Kottawa.

The average $T(\text{mean})$ (Fig. 2a) and annual rainfall (Fig. 2b) of five consecutive years (1989-1993) at the three commercial estates (Glassaugh, Vellai Oya and Strathdon) and the three meteorological stations of the Tea Research Institute (Talawakele, Hantane and Kottawa) plotted against the elevation of each site showed that rainfall did not follow the change in elevation. However, $T(\text{mean})$ decreased systematically with the increase in elevation. The following relationship was found between the mean air temperature of air and the elevation.

$$T(\text{mean}) = - 0.0058 \cdot \text{altitude} + 26.8 \quad (p < 0.001) \quad (1)$$

The $T(\text{mean})$ dropped at a rate of 5.8°C per 1000 m rise in elevation. The intercepted radiation could not be measured but assumed less variable between the four test sites than temperature and rainfall. The average daily sun-shine hours measured at Talawakelle, Hantane and Kottawa varied from 6.3 to 6.5.

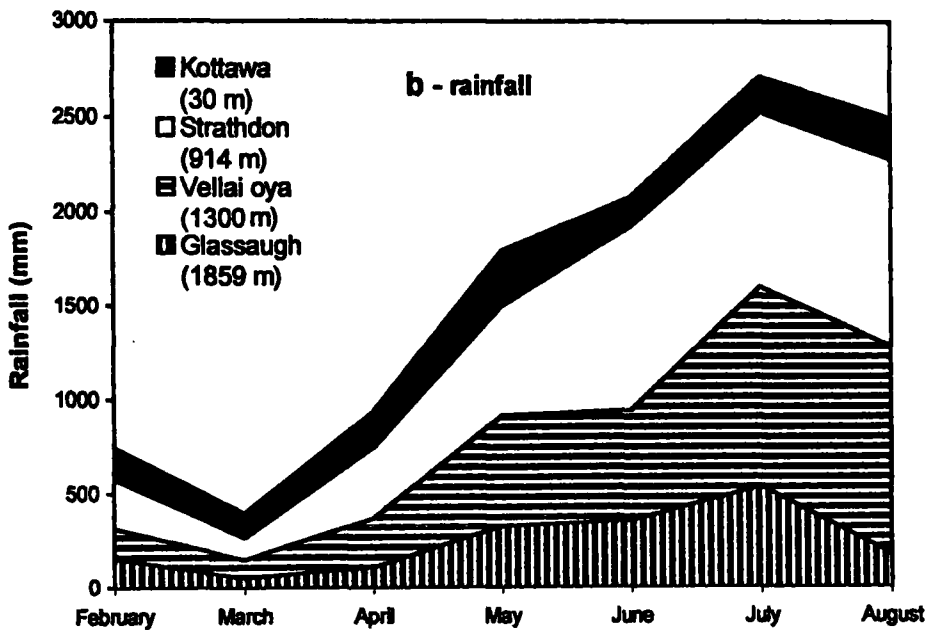
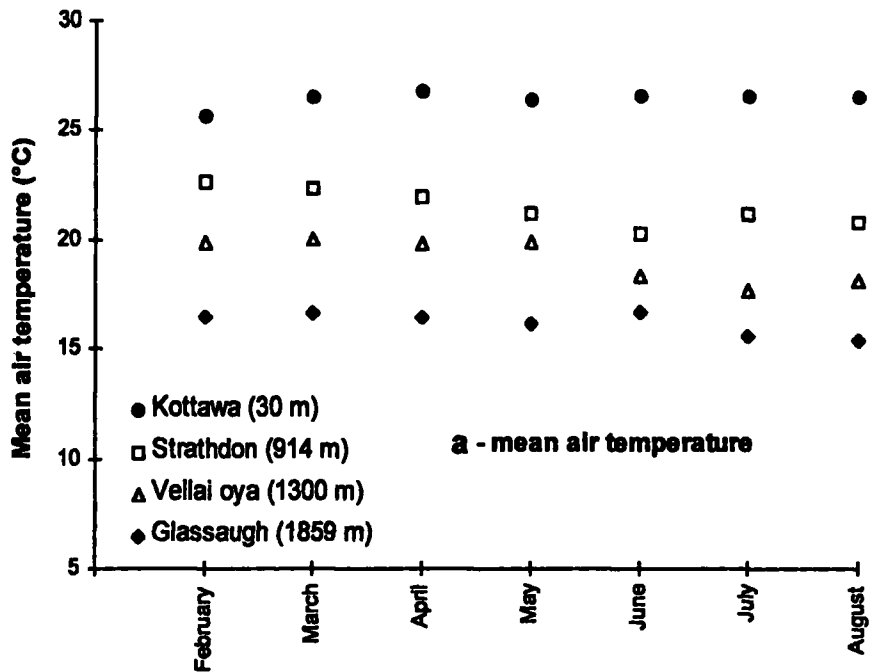


Fig. 1. The distribution of daily mean air temperature (a) and monthly rainfall(b) at the four sites during the period from February to August 1994.

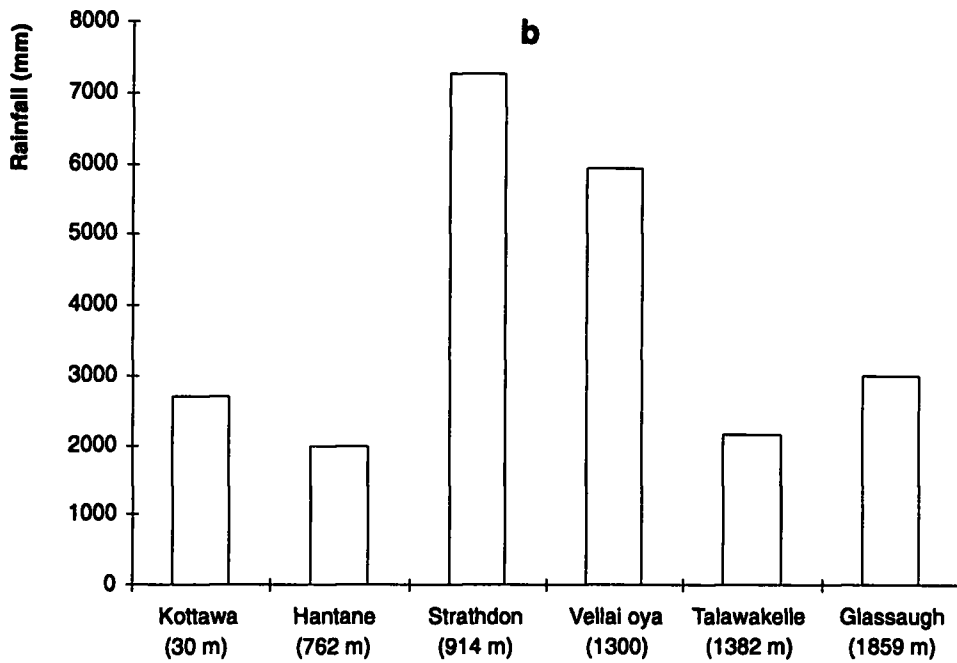
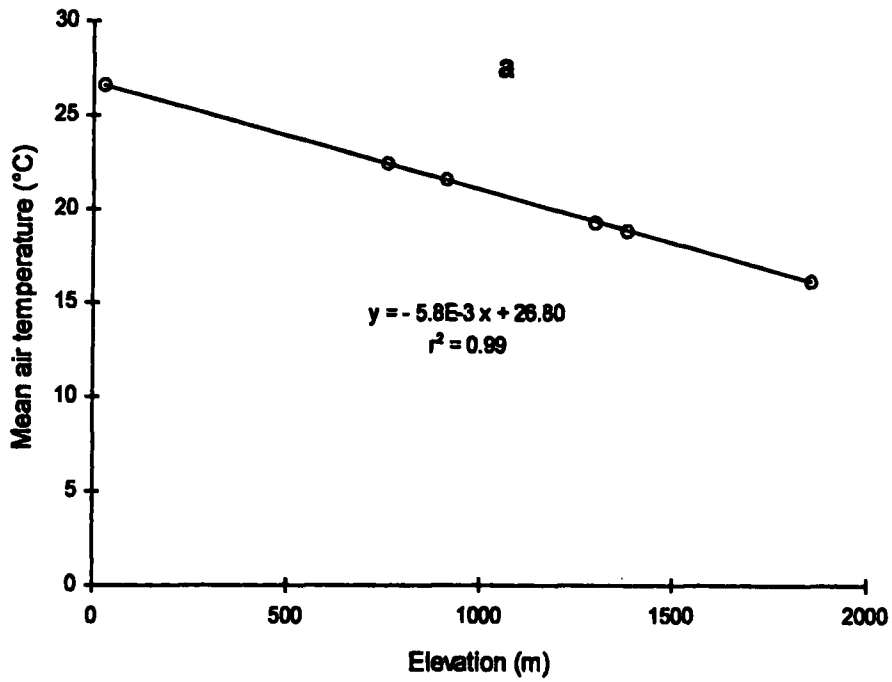


Fig. 2. Variation in mean air temperature (a) and mean annual rainfall (b) with elevation.

The bulk density measured was lowest in the first 15 cm of the soil at the four test sites. It was in the range of 0.6 to 0.8 g cm⁻³ at Glassaugh, 0.8 to 0.9 g cm⁻³ at Vellai oya and Strathdon and 0.8 to 1.0 g cm⁻³ in Kottawa. As depth increased from 15 to 90 cm, the bulk density increased from 1.0 to 1.25 g cm⁻³.

The soil pH was found in the range of 4.2 to 5.5. The lowest pH value of 4.2 was observed at Strathdon and in the experimental plots of clone TRI 2025 at Vellai oya.

Net total dry matter production

Clone TRI 2023 produced a higher amount of net total dry matter (NTDM) than clone TRI 2025 at each of the four sites during the experimental period (Table 1). Also the difference in the production of NTDM between the two clones increased with the increase in elevation from 30 to 1859 m ($p=0.006$). The production of NTDM in clone TRI 2025 however, was not sensitive to the change in elevation.

Table 1 - *Effect of elevation on net total dry matter production of two clones during the period from February to August, 1994*

Means of net total dry matter (t ha ⁻¹)			
Site	TRI 2023	TRI 2025	Clonal difference
Kottawa (30 m)	5.6	5.0	0.6
Strathdon (914 m)	5.8	4.9	0.9
Vellai oya (1300 m)	6.4	4.7	1.7
Glassaugh (1859 m)	8.3	4.7	3.6
Mean	6.5	4.8	

S. E. Clone (1 d.f.) 0.24

S. E. Elevation (3 d.f.) 0.35

S.E. Clone x elevation (3 d.f.) 0.49

cv = 12.2 %

Effects of clone ($p<0.001$) and clone x elevation interaction ($p<0.002$) were significant.

The net total dry weights of clone TRI 2023 increased linearly ($r^2=67\%$) at a rate of 1.3 t ha⁻¹ km⁻¹ ($p<0.05$) as elevation rose. A linear regression showed that NTDM decreased at a rate of 0.24 t ha⁻¹ °C⁻¹ (regression not significant) as $T(\text{mean})$ increased with decrease in elevation (Fig. 3). The linear response of NTDM in clone TRI 2023 to $T(\text{mean})$ was obscured by the relatively low values obtained for NTDM at Strathdon and Vellai oya.

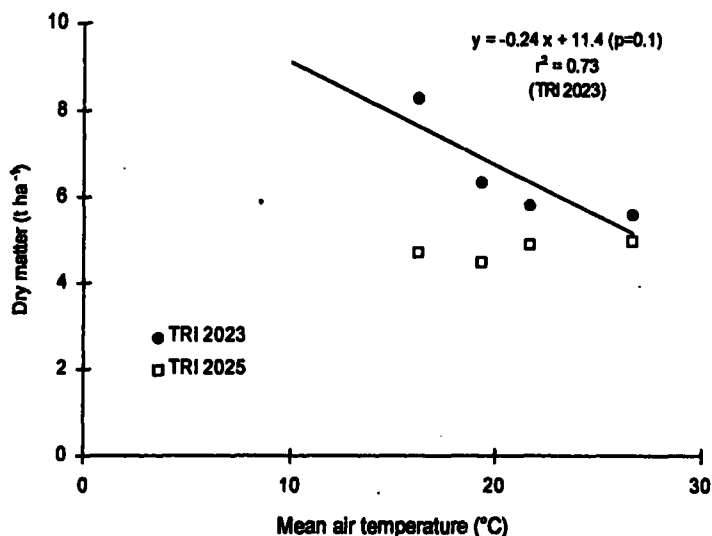


Fig. 3. Effect of mean air temperature on net total dry matter production of the two clones TRI 2023 and TRI 2025

Although the NTDM production of clone TRI 2023 was slightly higher than that of clone TRI 2025 at Strathdon and Kottawa, clonal differences were not statistically significant.

It was interesting to note the increase in NTDM of clone TRI 2023 at the two high elevations (1300 and 1859 m) while net photosynthetic rate (P) (Table 2) and leaf area (LA) (Table 3) remained unchanged. However, both P and LA of clone TRI 2023 were significantly higher than that of clone TRI 2025 ($p < 0.001$).

Although clone TRI 2023 produced more leaf area per bush than clone TRI 2025, clonal differences were significant ($p < 0.001$) only at the lowest (30 m) and the highest (1859 m) elevations. At these two sites, clone TRI 2023 produced 54 and 65 % more LA than clone TRI 2025. The leaf area index (LAI) showed no response to the change in elevation.

Table 2 - The effect of elevation on net photosynthetic rate (P) of each of the two clones; TRI 2023 and TRI 2025

Site	Elevation (m)	P ($\mu\text{mol m}^{-2}\text{s}^{-1}$)	
		TRI 2023	TRI 2025
Kottawa	30	11.8	9.1
Talawakelle	1382	12.0	9.0
Glassaugh	1859	11.6	9.0
Mean		11.8	9.1

S. E. Clone 0.07
CV 15.3 %

Effect of clone was significant at $p < 0.001$.

Table 3 - The leaf area (LA) ($\text{m}^2 \text{ bush}^{-1}$) and leaf area index (LAI) of clones TRI 2023 and TRI 2025

	Altitude (m)	LA ($\text{m}^2 \text{ bush}^{-1}$)		LAI	
		TRI 2023	TRI 2025	TRI 2023	TRI 2025
Kottawa	30	6.3	4.1	9.0	5.6
Strathdon	916	3.4	4.0	4.7	5.5
Vellai oya	1300	4.7	3.7	6.5	5.1
Glassaugh	1859	5.1	3.1	7.1	4.2
Mean		4.9	3.7	6.8	5.1

S. E. Clone (1 d.f) 0.15
 S. E. Elevation (3 d.f.) 0.21
 S. E. Clone x elevation (3 d.f.) 0.29
 CV 9.8%

Effects of clone, elevation and clone x elevation were significant at $p < 0.001$.

Leaf area increment

Although, leaf area (LA) of a single bush increased in both clones during the experimental period, in clone TRI 2025 the increment in LA was larger at lower elevations. This was shown by a systematic increase in the increment of LA at a rate of $0.5 \text{ m}^2 \text{ m}^{-1} \text{ bush}^{-1}$ with the decrease in elevation which was equivalent to a $0.08 \text{ m}^2 \text{ }^\circ\text{C}^{-1}$ ($p < 0.05$) increment in LA bush^{-1} as $T(\text{mean})$ increased (Fig. 4).

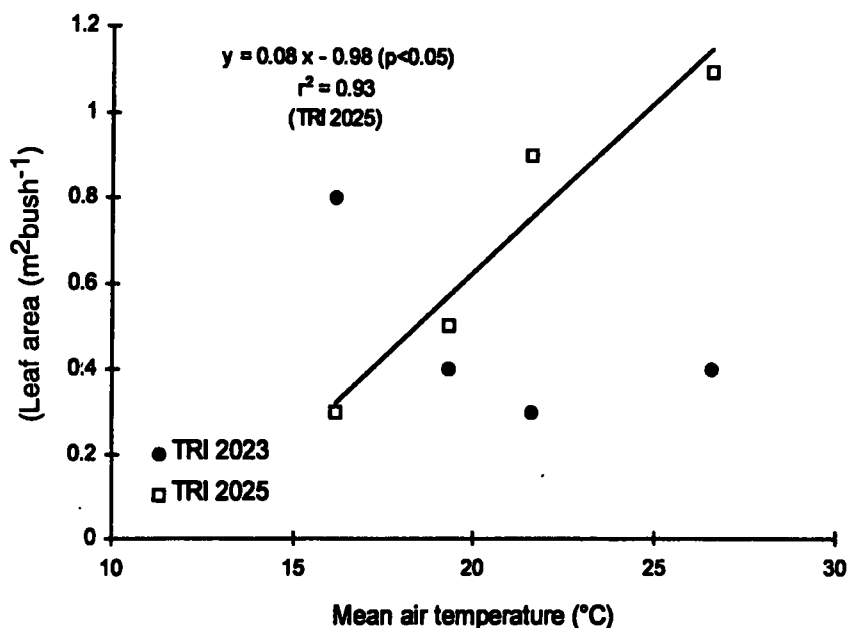


Fig. 4. Effect of mean air temperature on the increment of leaf area in a single bush of clones TRI 2023 and TRI 2025

Effects of clone, temperature and clone x temperature interaction was significant at $P < 0.001$.

Although the LA increment became higher in clone TRI 2025 than in clone TRI 2023 with the increase in $T(\text{mean})$ TRI 2023 possessed a larger total LA bush⁻¹ across the temperature range. Thus the LA and P could not be correlated with the increased NTDM production of clone TRI 2023 across the test temperature/ elevational range.

Rise of the plucking table

In both clones, the rate of increase in the plucking table height was faster at the lowest elevation of 30 m at Kottawa than at the other sites. The rate of increase decreased gradually with the increase in elevation at the rates of 52.5 and 28.0 mm month⁻¹ 1000 m⁻¹ in the two clones TRI 2023 and TRI 2025 respectively. The rise in height was highly correlated with $T(\text{mean})$ as shown in Figure 5. The significant difference between the two thermal gradients of the clones was responsible for the clone x temperature interaction ($p < 0.001$) (Fig. 5).

The change in NTDM production of clones across the temperature/ elevation range could not be correlated with that in the rates of the increment in the plucking table height.

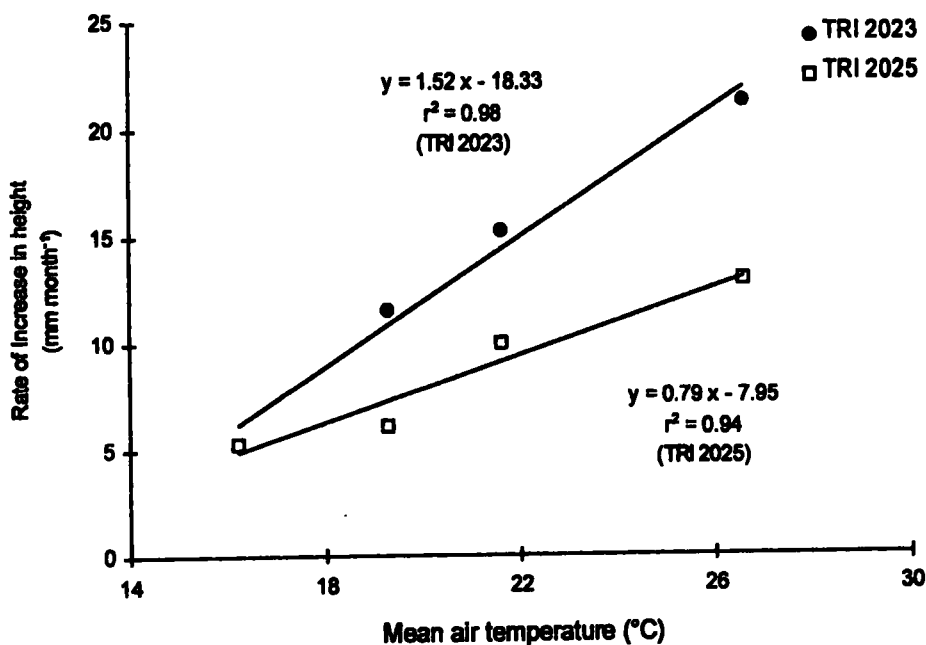


Fig. 5. Effect of mean air temperature on rate of increase in height of the plucking table

Effects of clone, temperature and clone x temperature interaction was significant at $p < 0.001$.

At the coldest site, Glassaugh (1859 m) plucking table heights of both clones showed a similar increase of 32 mm at the end of the experimental period. However, at the warmest site, Kottawa the plucking table of clone TRI 2023 had risen 49 mm higher ($P<0.001$) than that of clone TRI 2025.

Yield

In clone TRI 2023, although the yield did not differ significantly between the three sites Kottawa, Strathdon and Vellai oya it showed a significant reduction ($p<0.001$) as the elevation increased up to 1859 m (Table 4). Between the highest and the lowest elevation the loss of yield was amounted to 730 kg ha⁻¹ ($p<0.001$). This was a 36 % reduction in the yield which was obtained at Kottawa.

A linear regression of yield on elevation showed that per every 300 m rise in elevation, yield of clone TRI 2023 was reduced by 105 kg ha⁻¹ which was equivalent to a loss in yield by 60 kg °C⁻¹ fall in $T_{(mean)}$.

By contrast, the change in yield of clone TRI 2025 with elevation was not consistent. While yields were similar at the highest and the lowest elevations, about 17 and 25 % reductions in yield from those were observed at Strathdon (914 m) and Vellai oya (1300 m) respectively.

Clone TRI 2025 outyielded clone TRI 2023 by 41% ($p<0.001$) at the highest elevation and by 13 % ($p<0.01$) at the lowest elevation.

Site	Elevation (m)	Yield (t ha ⁻¹)		
		TRI 2023	TRI 2025	Mean
Kottawa	30	2.03	2.30	2.16
Strathdon	914	1.84	1.90	1.87
Vellai oya	1300	1.82	1.73	1.77
Glassaugh	1859	1.30	2.20	1.75
Mean		1.75	2.03	

Table 4 - Effect of elevation on yield of clones TRI 2023 and TRI 2025

S.E. Clone (1 d.f.)	0.03
S.E. Site (3 d.f.)	0.04
S.E. Clone x Site (3 d.f.)	0.06
CV	4.7 %

Effects of clone, site and clone x site interaction were significant at $p<0.001$.

Partitioning of dry matter to shoots

In clone TRI 2023, partitioning of NTDM to harvestable shoots or Harvest index (HI) increased at a rate of 1 % 100 m fall in elevation. This was equivalent to a decrease in partitioning at a rate of 1.8 % °C⁻¹ (regression just not significant) as T_(mean) fell from 26.6 to 16.2 °C (Fig. 6).

Averaged over four sites, clone TRI 2025 partitioned a higher proportion of NTDM to shoots than clone TRI 2023. The similar yields and partitioning of NTDM to harvestable shoots observed at the two extremes of the test elevational range suggest that elevation or temperature had no effect on either of these two parameters. Therefore, it is likely that factors other than elevation or temperature which were associated with site were responsible for the low yields and reduced partitioning of NTDM to shoots observed in clone TRI 2025 at Strathdon and Vellai oya.

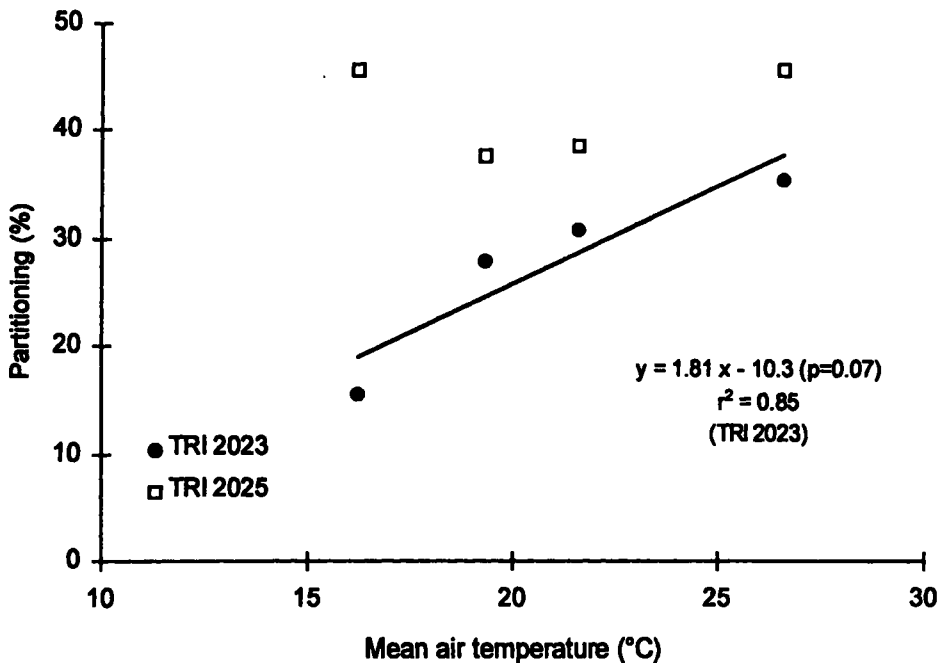


Fig.6 Effect of mean air temperature on partitioning of net total dry matter production to shoots in clones TRI 2023 and TRI 2025

DISCUSSION

Both NTDM and yield of clone TRI 2023 were influenced by the change in elevation mainly due to the variation in mean air temperature. The most distinct difference between the two clones was the relatively higher thermal sensitivity in the production and partitioning of NTDM of clone TRI 2023 against clone TRI 2025.

In the absence of other environmental limitations, the change in $T_{(mean)}$ explained a high percentage in the variability of NTDM production and yield in clone TRI 2023. Therefore, this clone is particularly suitable for warm regions or low elevations in Sri Lanka. On the other hand, the yield and NTDM production were both relatively stable in clone TRI 2025 which makes it suitable to be grown anywhere within the tested temperature range. A general adaptation to a range of environment which was suggested by Wickramaratne (1981) could not be observed either in yield or HI of this clone.

Although other environmental factors were not limiting the cultural or management practices which may not necessarily be associated with elevation but with the site could have influenced the yield of both clones. The pH of soil at Strathdon and Vellai oya were lower (4.2) compared to the other sites and the plots of clone TRI 2025 at both sites and clone TRI 2023 at Strathdon were found on a sloping land. It is possible that factors such as high acidity and the leaching of nutrients which are associated with heavy rainfall (Fig. 1b) had lowered the yield of both clones.

The low yields at Vellai oya and Strathdon which resulted from a decreased partitioning of NTDM to harvestable shoots (HI) might have occurred due to a reduction in the size of the sink for assimilates in shoots. The size of the sink for assimilates depends on the active shoot population density, shoot development rate (SDR) and the rate at which dry matter fills the developing shoot. However, SDR of both clones which had been tested in the same elevational range during the same experimental period (Balasuriya, 1996a) showed a linear increase ($r^2=0.98$) with the rise in $T_{(mean)}$ from 16.2 to 26.6°C. Therefore, the other two yield components (harvestable shoot population density and dry weight of a single harvestable shoot) might have been affected by the environmental factors associated with the site that reduced were yields of both clones.

Also, yield of clone TRI 2025 did not increase with the $T_{(mean)}$ as did SDR. Therefore, it is important to find out how temperature affected the other two yield components in order to give similar yields for clone TRI 2025 at the highest and the lowest elevations. Also, It is important to determine whether clone TRI 2025 posses general adaptation as stated by Wickramaratne (1981) or stability in yield which is shown in this study.

It may be possible to increase the yield of both clones at the lowest elevation, (Kottawa), if shoots are harvested in less than seven-day intervals. Shoots of both clones at Kottawa are ready to be harvested in three to four-day intervals according to the size of their phyllochrons (Balasuriya 1996b). The prolonged harvesting intervals therefore, had allowed the plucking table to rise higher (Fig. 5) and yield to be come low due to unharvested leaves at lower elevations.

In comparison of the two clones, TRI 2023 produced a larger NTDM production (averaged across the four sites) which could be attributed to its high P rate (Table 2). However, the relatively high P rate which remained stable across the test temperature range did not explain the large NTDM production of clone TRI 2023, at the two low mean air temperatures. Also, the increased NTDM production at low mean air temperatures did not result in an increased yield.

Squire (1979), Tanton (1979) and Squire and Callander (1981) suggested that temperature is more likely to affect yield by influencing the size of the 'sink' for assimilates in shoots than by its effect on photosynthesis or stored carbohydrates (dry matter). Magambo and Cannell (1981) showed that NTDM production and yield are inversely related. However, the results of this study suggest that their observations may be limited to clones such as TRI 2023 of which the HI is influenced by the temperature.

The large LA and LAI observed at Kottawa was due to the largest leaves at lower elevations compared to the smaller leaves at higher elevations. It is therefore, possible that the mutual shading had made the leaves at lower layers of the canopy to become less productive thus producing less NTDM. The specific leaf area of both clones increased with the elevations (Fig. 7) when the low $T(\text{mean})$ decreased the specific leaf weights thereby increasing the number of leaves with less weight specially in clone TRI 2023 as shown by its larger LA (Table 3). Nakayama and Harada (1962) too reported that the leaf size of tea increased with temperature with its maximum at 30°C.

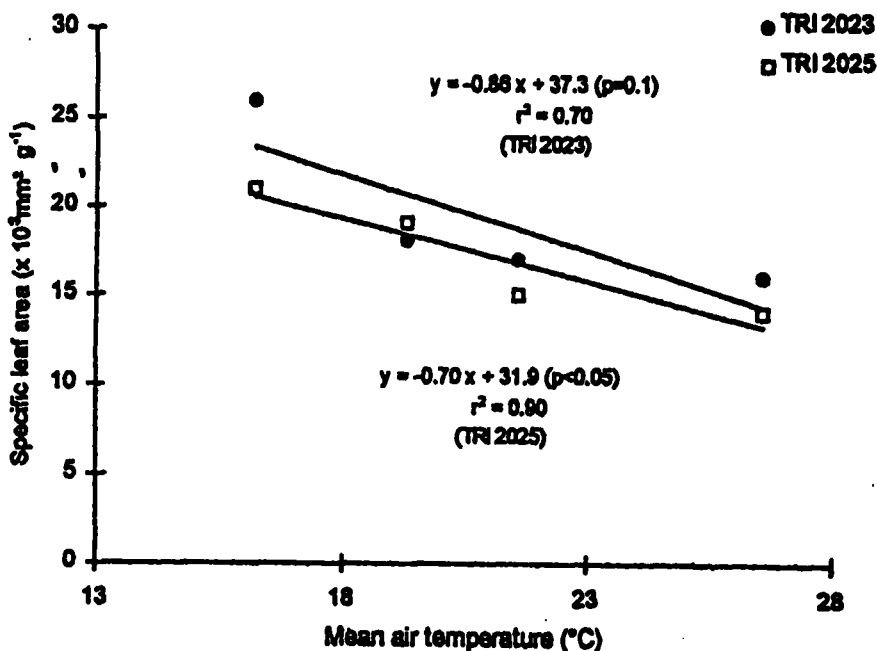


Fig. 7- Effect of mean air temperature on the specific leaf area of the two clones TRI 2023 and TRI 2025

The low NTDM production at lower elevations could also be associated with the large respiratory rates due to high air temperatures. Barbora and Barua (1988) showed that, the growth processes are accelerated due to high air temperatures. This was also shown by the fast rate of increase in the height of the plucking table of both clones (Fig. 5) as well as by the fast rates of shoot development at lower elevations (Balasuriya, 1996). Therefore, the NTDM production in clone TRI 2023 could have been reduced due to a loss of dry matter by an increased respiration rate at lower elevations.

In comparison of the NTDM production by clonal tea in different parts of the world (Otheino 1976; Laycock and Otheino, 1978; Tanton, 1979; Barua, 1981; 1987), colder environments had always produced more dry matter than warmer environments. For an example, the NTDM production of $10.2 \text{ kg ha}^{-1} \text{ year}^{-1}$ in clone SID 3/5 in N.E. India (Barbora and Barua, 1988), where the mean annual air temperature was $25.5^{\circ}\text{C} \pm 0.5^{\circ}\text{C}$ is comparable with the NTDM produced by each of the two clones at a similar temperature at Kottawa (26.6°C). On the other hand, the NTDM production of clone TRI 2023 at Glassaugh (16.2°C) was comparable with the NTDM production of $16.9 \text{ t ha}^{-1} \text{ year}^{-1}$ (clone 6/8) at Kericho in Kenya (Magambo and Cannell, 1981) where the annual mean air temperature was 17.5°C . Therefore, the reduced respiratory rates of temperature sensitive clones at higher elevations or colder environments should partly be responsible for their large NTDM productions.

By contrast, the increased respiratory rates due to high air temperature at low elevations had not caused a difference in the amount of NTDM produced in clone TRI 2025 between the four test elevations. The heavier leaves than those of clones TRI 2023 (Fig. 7) would have been able to minimise the sensible heat gain and delay the rise in leaf temperature (Monteith, 1981), at warmer sites where water was freely available while larger leaves were effective in transpirational cooling to do the same. Therefore, the respiratory losses at warm environments might have been less with the corresponding gain in net weight of the whole plant of clone TRI 2025 compared to that of clone TRI 2023.

This suggests that temperature can influence the NTDM production in clonal tea through respiration and the clonal response to temperature should vary. (Barbora and Barua, 1988) had shown different rates of respiration for clones; high rates in high yielding clones and low rates in low yielding clones.

A hypothesis can be drawn from these results that gross dry matter production may be genetically fixed for a clone and is associated with P and the LA. The net gain however is influenced genetically and also by the environment.

Although a rapid increase in plucking table at lower elevations may indicate a fast accumulation of dry matter in the above ground parts of the bush it was not reflected in NTDM production of the entire bush. This could be due to the different pattern of the partitioning of assimilates (dry matter) within the bush. A fast rising plucking table could be attributed to either the addition of new layers of leaves or production of more wood or both. Therefore, to understand the low NTDM production and the fast rising plucking table

at different temperatures the dry matter partitioning of the bush has to be investigated at all four sites.

On the other hand, low yields of clone TRI 2023 at higher elevations cannot be attributed to a reduced conversion efficiency as the NTDM production was significantly higher at Glassaugh and Vellai oya than at the other two sites (Table 1). Thus a limitation cannot occur in the solar energy received and the fraction of this energy intercepted by the canopy at Glassaugh and Vellai oya. These facts are in favour with the argument that the decrease in yield was due to a decreased harvest index (HI) as influenced by the low mean air temperature.

A limitation can occur in the soil nutrient status due to high intensity of rainfall (which was not measured) at Vellai oya and Strathdon that might indirectly affect the partitioning of dry matter to shoots (HI) by creating a limitation in the sink for assimilates in shoots of both clones. Therefore, the results suggest the necessity of adopting proper soil management practices (i.e. SALT technique) to improve and prevent decline in yield in these areas which originally belonged to the rain-forests in the island.

To understand how HI of clone TRI 2023 was affected by temperature the effect of temperature on the two yield components (density of harvestable shoot population and mean dry weight of a single harvestable shoot) of this clones needs to be analysed. On the other hand, the HI of clone TRI 2025 was not generally affected by the differences in mean air temperature between the four sites. Therefore, the HI of this clone could be genetically fixed.

CONCLUSIONS

The effect of elevation on net total dry matter and that partitioned to harvestable shoots in clone TRI 2023 was caused largely by the differences in mean air temperature between the four sites.

The lower mean air temperatures at higher altitudes (>1300 m) had an advantage on NTDM in clone TRI 2023 over clone TRI 2025 which suggests that clonal differences in dry matter production exist at varying air temperatures. This is an indication of a clone x temperature/ elevation interaction.

The low NTDM production of clone TRI 2023 at lower elevations, Kottawa and Strathdon could have been due to the large respiratory losses of dry matter at high mean air temperatures of these two sites. Also, the NTDM production was independent of P and LA of the bush of this clone.

The increased rates of the rise in plucking table height with the increase in mean air temperature did not indicate a high NTDM production in both clones but suggested that an efficient harvesting of both clones at lower elevations is needed.

The small harvest indices observed in clone TRI 2023 at higher elevations suggested that large yields from this clone cannot be obtained in places where low mean air temperature dominates the environment. This clone is more suitable for warm regions.

Between the two clones tested, clone TRI 2025 shows a relatively stable dry matter production as well as yield across the test temperature/ elevational range. However, there may be other environmental factors which can affect the yield of this clone by influencing the sink for assimilates in the shoots.

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