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Effect of Elevation on Net Total Dry Matter Production and Yield of Two Clones of Tea [*Camellia sinensis* (L.) O. Kuntz.] in Sri Lanka

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ABSTRACT *The effect of elevation on net total dry matter production (NTDM) and yield of two tea clones, TRI 2023 and TRI 2025, were studied at four sites located in an altitudinal range of 30 to 1859 m amsl in the wet zone of Sri Lanka. The elevation had no effect on both the NTDM production and the yield of clone TRI 2025. A 100 m rise in elevation increased the NTDM production of clone TRI 2023 by 130 kg ha^{-1} but the yield was reduced by 35 kg ha^{-1} during a period of 7 months thus suggesting the suitability of this clone specifically to lower elevations.*

The production of NTDM and that partitioned to harvestable shoots in clone TRI 2023 were strongly influenced by the mean air temperature of the test sites which showed an adiabatic lapse rate of 5.8^{0}C 1000 m^{-1} (r^2=0.99). The high mean air temperatures of the lower elevations caused a rapid growth in the bushes resulting in a fast rising plucking table but, it was not reflected in an increased NTDM production. Within a clone, the change in NTDM production was independent of the rates of photosynthesis and total leaf area per bush. The yield did not depend on the production of NTDM but was determined by the Harvest index as influenced by the environment.

INTRODUCTION

The yield of tea [*Camellia sinensis* (L.) O. Kuntz.]comprises of tender young shoots with a terminal bud and two to three young leaves harvested at regular intervals. Therefore, the proportion of the net total dry matter (NTDM) production which is partitioned to harvestable shoots becomes an important criteria in determining the yield of a tea bush. Tea in Sri Lanka

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is grown in a wide range of elevations and the yield was reported to vary even in the same clone grown in different parts of the island (Wickramaratne, 1981). Wickramaratne (1981) also showed that sites in lower elevations had a higher biological environmental index based on yield when compared to those in higher elevations. This suggests that the elevation influences the yields of tea grown in Sri Lanka.

Effect of elevation on tea yield in Kenya was also reported by Squire *et al.* (1993). Squire *et al.* (1993) showed that the yield of tea dropped at a rate of 200 to 300 kg ha^{-1} year^{-1} per 100 m rise in elevation. Thereby, the NTDM production and that partitioned into harvestable shoots are likely to be influenced by the elevation reflecting different yields at different elevations. However, no evidence is found as to the effect of elevation on these two physiological attributes of a tea bush.

Studies carried out in Kenya, Malawi and Assam revealed that the NTDM production of clonal tea in colder regions with higher elevations is higher than in the warmer regions with lower elevations (Barua, 1981, 1987; Barbora and Barua, 1988; Laycock and Otheino, 1978; Magambo and Cannel, 1981; Othieno, 1976, 1982; Tanton, 1979), while yield was *vice versa*. The relatively small amounts of NTDM produced in the warmer regions such as Assam (Barua and Sharma, 1982; Barbora and Barua, 1988) and Malawi (Tanton, 1979) suggested that out of the total dry matter production about 60–67% was lost by respiration thus causing differences in the NTDM production between warmer and colder regions. The rate of respiration of tea shoots was reported to have increased linearly over a wide temperature range from 20 to 40°C. The respiration rate has been reported to be higher in high yielding and lower in low yielding clones (Barbora and Barua, 1988) and had doubled when air temperature was increased by 10°C (Sakai, 1975). Therefore, to some extent, the clonal differences in the rate of respiration could be responsible for the clonal differences observed in the production of NTDM reported from North East India (Barua, 1959; Barbora and Barua, 1988), Kenya (Otheino, 1982), South India (Murty and Sharma, 1986) and Tanzania (Burgess, 1992).

Burgess (1992) and Ng'etich (1995) observed clonal differences in the partitioning of NTDM to shoots during different seasons of the year. Ng'etich (1995) reported that partitioning of dry matter to shoots increased during the warm seasons in Kenya. These observations infer that higher yields obtained at lower elevations (both in Kenya and Sri Lanka) are accounted for the increased partitioning of NTDM to harvested shoots probably influenced by the temperature. Then the increased rates of shoot growth in the warm lower elevations in Sri Lanka (Balasuriya, 1996a) could possibly be linked with the increased partitioning of the NTDM to shoots thus resulting in higher yields. The production of a large amount of NTDM in a tea bush may not necessarily result in a high yield. However, the Genotype–Environment interactions in the yield of tea reported by Wickramaratne (1981) could have resulted from the clonal differences either in the response of NTDM production or that partitioned to harvestable shoots or both in different environmental conditions.

Thus, the variability in the response of NTDM production and that partitioned to harvestable shoots in different environments could become an useful tool in the selection of clones for specific environmental conditions. Hence, the objective of this study was to investigate whether and how the varying elevations in Sri Lanka influence the production and partitioning of NTDM to shoots and the yield of two tea clones.

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 in the wet zone of Sri Lanka where tea is grown as a plantation crop. The first three sites are located in the central hilly area of the island and the fourth site is in the southern lowlands.

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 were 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.

In February, the bulk density of soil at each plot was measured from core samples (three samples per plot were taken from inter–rows) taken at 15, 30, 45, 60 and 75 cm depths from the ground level. The samples were oven-dried at 105°C until a constant weight was reached. Three random soil samples from a depth of 30 cm were taken from each plot at each site using a hand auger 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 were 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 Talawakelle (1382 m), were obtained from the weather records maintained at the meteorological stations.

Dry matter sampling

A field was 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 in each site and were marked from 1 to 8. The age of the two clones selected, TRI 2023 and TRI 2025 from the time of field planting was 14 years at Kottawa and Vellai–oya, 17 years at Strathdon and 19 years at Glassaugh.

In February, four bushes (one from each block) out of the selected eight from each clone in each site were uprooted. The soil around the bush was excavated up to a depth of 75 cm in an area of 0.3×0.6 m^2 (within and between rows) to remove all roots severed from the uprooted bush and then sieved. These roots were washed to remove soil adhered to them. Afterwards, the leaves, wood and roots of each bush were separated and their fresh weights were recorded. Three samples from each fraction; roots and leaves weighing 60–100 g and wood weighing 200–300 g from each bush were then oven dried at 90°C, until a constant weight was reached. These were then extrapolated to give the total dry weights of each of the three fractions (leaves, wood and roots) of a bush. The total dry weight of a single bush was calculated by the addition of the total dry weights of leaves, wood and roots.

The dry matter sampling was repeated at the end of August 1994. During the experimental period, the cultural and management practices of the bushes were carried out similarly in all the experimental sites.

Leaf area

Prior to drying the width and length of each leaf in every 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 calculate the leaf area. The leaf area of the sample was then extrapolated to the total leaf area (LA) of the bush. Leaf area index (LAI) was measured by dividing the leaf area of a single bush by the land area occupied by a single bush. Since the bushes had achieved complete ground cover, the LA was divided by 0.6×1.2 m^2 which is the spacing given for a bush. Specific leaf area was also calculated (Milthorpe, 1956).

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 (100 g) from each plot were oven dried at 90^{0}C to get the average dry weight of the harvest. 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), Talawakelle (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 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 μmol m^{-2} s^{-1}. The measurements were carried out on six mother leaves from each clone which had an active bud of 10 to 15 mm in length in the leaf axil.

Rise in the height of the plucking table

The height of the plucking table was measured as the height of the bush from the ground level to the surface of the bush. This was measured at three random places within each plot at every site which was marked by straight wooden poles of 1.0 m in length fixed to the ground. The height of the plucking table was marked on the poles using permanent ink at the beginning and end of the experiment and the difference between the two marks was taken as the total increase in height.

Experimental Design and data analysis

The experiment was a 2×4 factorial (2 clones: TRI 2023, TRI 2025 and 4 elevations: 30, 914, 1300, 1859 m amsl) with four replicates in a completely randomized design. Data were analysed using Genstat 5 (Rothamstead).

RESULTS

Environment

During the period from February to August 1994, a critical deficit of soil moisture (≥ 50 mm) or saturation vapour pressure of air (≥ 2.0 kPa) was not observed at any of the four sites. The fluctuations of mean air temperature ($T_{(mean)}$) between any two successive months were less than 1°C during this period (Figure 1a). Distribution of monthly rainfall for the same period showed that Strathdon and Vellai–oya received a higher rainfall than the other two sites (Figure 1b). Among the selected sites, Kottawa received a more uniformly distributed rainfall.

The average $T_{(mean)}$ (Figure 2a) 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 (Talawakelle, Hantane and Kottawa) plotted against the elevation of each site showed that $T_{(mean)}$ decreased linearly with the increase in elevation. The $T_{(mean)}$ dropped at a rate of 5.8°C per 1000 m rise in elevation. The average annual rainfall for the same period (Figure 2b) however, did not follow a systematic with the change in elevation.

The intercepted radiation could not be measured but assumed similar at all four test sites. Average daily sun–shine hours measured at three elevations (1382, 762 and 30 m) within the test range varied from 6.3 to 6.5.

The bulk density was the lowest in the first 15 cm of 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 varied between 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.

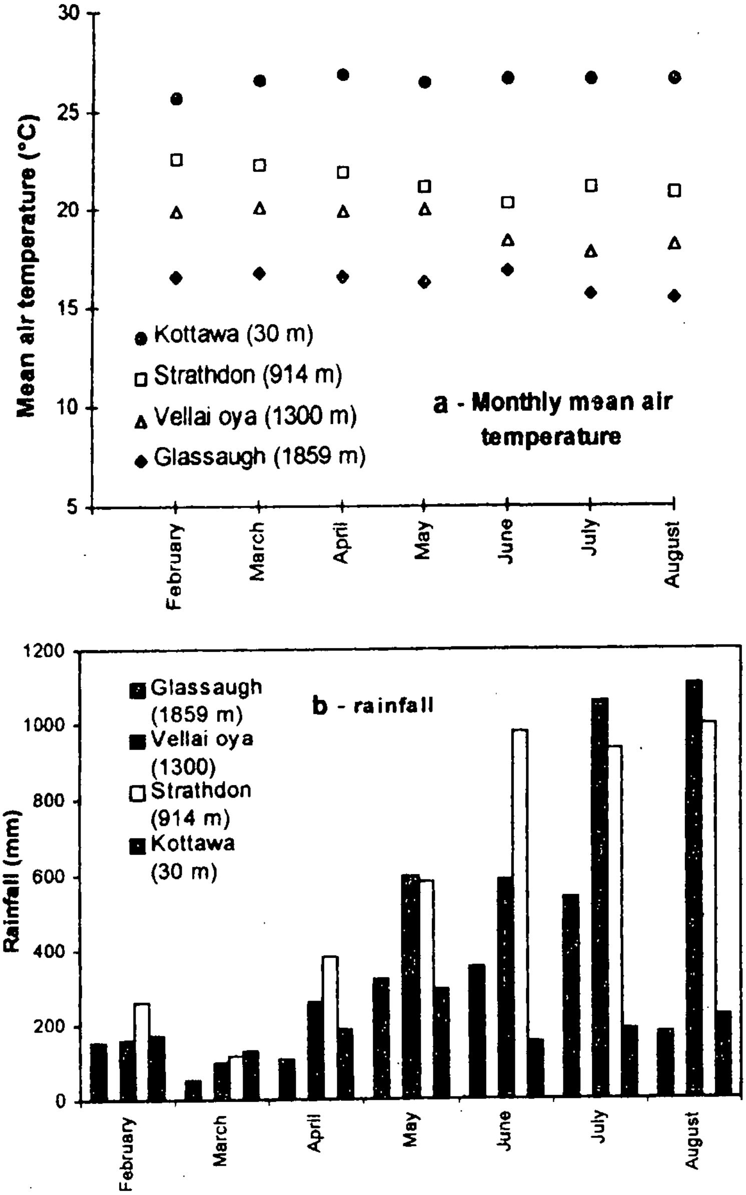

Figure 1. The distribution of monthly mean air temperature (a) and monthly rainfall (b) at the four sites during the period from February to August 1994.

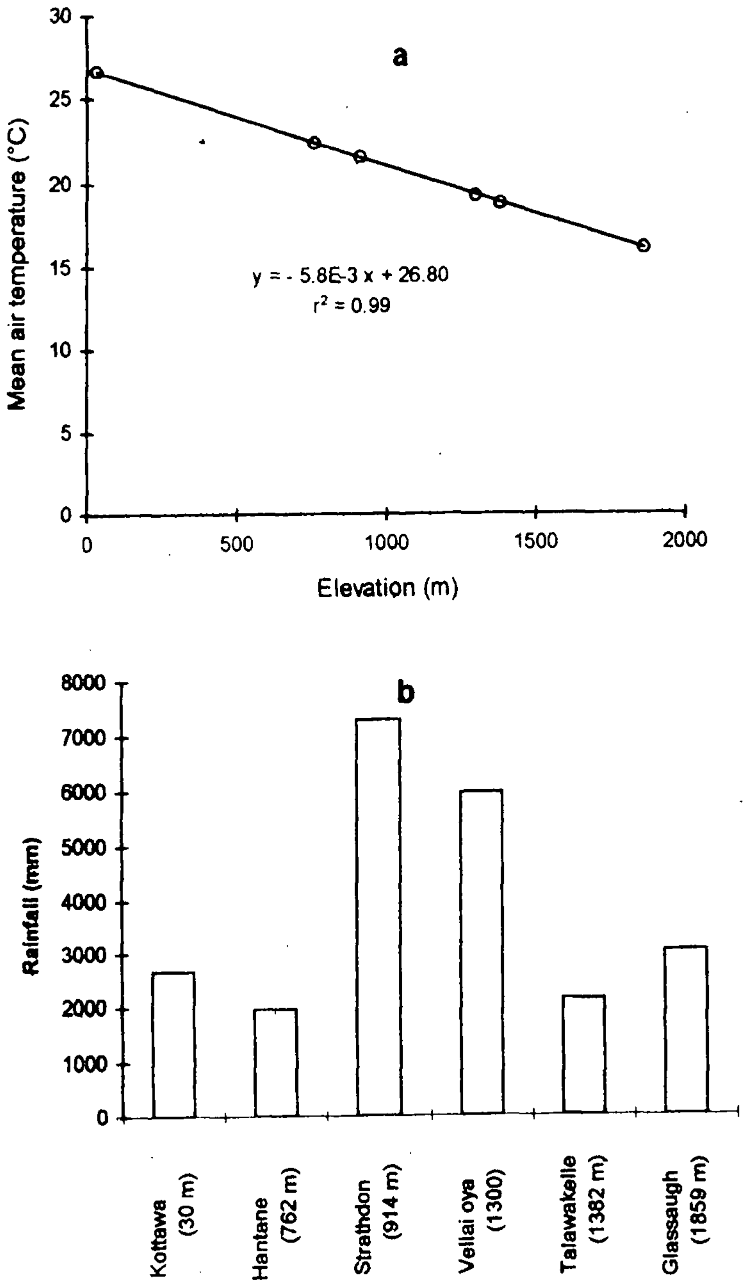

Figure 2. Change in mean air temperature (a) and mean annual rainfall (b) with elevation of six sites across the test range.

Net total dry matter production

Clone TRI 2023 produced a higher amount of NTDM than clone TRI 2025 at each of the four sites during the experimental period but the clonal difference became significantly larger (p=0.006) only at the two high elevations (Table 1). The production of NTDM in clone TRI 2025 however, was not affected by the change in elevation.

Table 1. Effect of elevation on net total dry matter production of clones TRI 2023 and 2025 during the period from February to August, 1994.

Site	Means of net total dry matter (t ha^{-1})		
	Clone		
	TRI 2023	TRI 2025	Difference
Kottawa (30 m)	5.6	5.0	0.6
Strathdon (914 m)	5.8	4.9	0.9
Vellai–Oya	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 × elevation (3 d.f.) 0.49 cv = 12.2 %
Effects of clone ($p<0.001$) and clone × elevation interaction ($p<0.002$) were significant.

With the rise in elevation the NTDM production of clone TRI 2023 increased at a rate of 1.3 t ha^{-1} km^{-1} ($p<0.05$, $r^2 = 0.67$). This was equivalent to a decrease in the NTDM production at a rate of 0.24 t ha^{-1} $^0C^{-1}$ as $T_{(mean)}$ increased with the fall in elevation (Figure 3). However, the linear response of NTDM of clone TRI 2023 to $T_{(mean)}$ was obscured due to relatively low values obtained for the production of NTDM at Strathdon and Vellai–oya.

Leaf area and rate of net photosynthesis

Although clone TRI 2023 produced more leaf area (LA) over clone TRI 2025 clonal differences were significant ($p<0.001$) only at the lowest

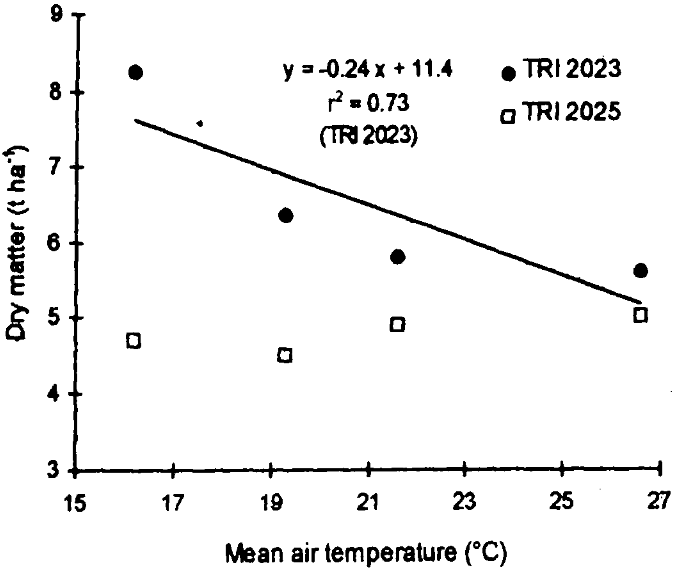

Figure 3. **Effect of mean air temperature on net total dry matter production of the two clones TRI 2023 and TRI 2025.**

(30 m) and the highest (1859 m) elevations of the test range (Table 2). The net photosynthetic rate (P) was also higher in clone TRI 2023 (Table 3) which had the higher LA and NTDM production than the other. Unlike LA, P and leaf area index (LAI) showed no response to the change in elevation.

At the end of experimental period, the increment of LA per bush of clone TRI 2025 was higher at lower elevations than at higher elevations. For every one meter fall in elevation the total leaf area increment of a bush increased by 0.5 m^2 and this was equivalent to a 0.08 m^2 increment in LA $bush^{-1}$ $^0C^{-1}$ ($p<0.05$) with the increase in $T_{(mean)}$ (Figure 4). However, such increments in LA was not reflected in a larger LA $bush^{-1}$ or a higher NTDM production in clone TRI 2025 when compared to TRI 2023.

Rise of the plucking table

The rate of increase in the height of plucking table was faster at lower elevations than at higher elevations. The rates of increase of the plucking table decreased gradually by 52.5 (TRI 2023) and 28.0 (TRI 2025) mm $month^{-1}$ 1000 m^{-1} as elevation rose from 30 to 1859 m and were highly

Table 2. **The leaf area (LA) and leaf area index (LAI) of clones TRI 2023 and TRI 2025.**

	Altitude (m)	LA (m^2 $bush^{-1}$)		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. Clone × elevation (3 d.f.) 0.29
S. E. Elevation (3 d.f.) 0.21 CV 9.8%
Effects of clone, elevation and clone x elevation interactions were significant at $p<0.001$ for LA.

Table 3. **The effect of elevation on mean net photosynthetic rate (P) of each of the two clones; TRI 2023 and TRI 2025.**

Site	Elevation (m)	P (μ mol m^{-2} s^{-1}) Clone	
		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 $p< 0.001$.

correlated with $T_{(mean)}$ (Figure 5). The clone × temperature interaction ($p<0.001$) could be attributed to the significant difference between the two thermal gradients of the clones.

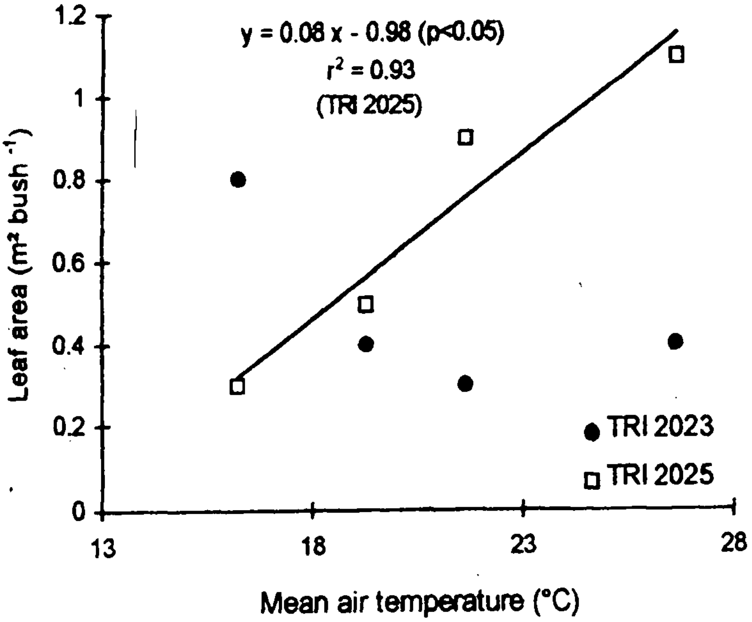

Figure 4. **Effect of mean air temperature on the increment of leaf area in a single bush of clones TRI 2023 and TRI 2025.**
[Note: Effects of clone, temperature and clone × temperature interaction were significant at $p< 0.001$.]

Interestingly, the response of the rate of increase in height of the plucking table in clone TRI 2023 was the opposite of that of the NTDM production to $T_{(mean)}$. The increments in the heights of the bushes however, did not indicate an increased NTDM production in any of the two clones.

The clone TRI 2023 which is the most temperature sensitive clone of the two, was 49 mm taller ($p<0.001$) than TRI 2025 at Kottawa (30 m), although both clones achieved similar increments of 32 mm in height, at the highest elevation in the test range.

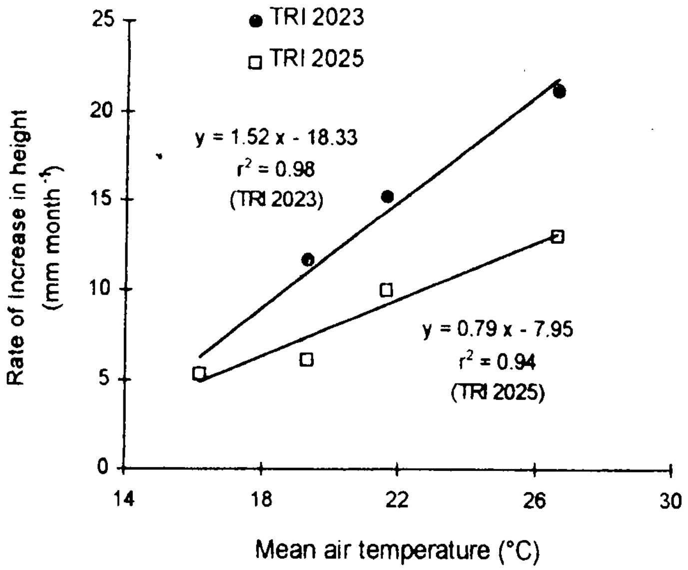

Figure 5. **Effect of mean air temperature on rate of increase in height of the plucking table.**

[Note: Effects of clone, temperature and clone × temperature interaction were significant at $p<0.001$].

Yield

Although the differences in yield of clone TRI 2023 between the three sites, Kottawa, Strathdon and Vellai–oya were not statistically significant, the increase in elevation by 1829 m caused a 36% reduction ($p<0.001$) in the yield (Table 4). This was amounted to a loss in yield of 730 kg ha^{-1} from that 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 $^{0}C^{-1}$ fall in $T_{(mean)}$. By contrast, clone TRI 2025 yielded similarly at the lowest and the highest elevations. However, there was a reduction in yield by 17 and 25% at the two mid sites of Strathdon (914 m) and Vellai–oya (1300 m). In addition, the clone TRI 2025 outyielded TRI 2023 by 41% ($p<0.001$) and 13% ($p<0.01$) at the highest and the lowest elevations, respectively.

Partitioning of dry matter to shoots

In clone TRI 2023, partitioning of NTDM to harvestable shoots or the Harvest index (HI) increased at a rate of 1% per 100 m fall in elevation.

This was equivalent to a decrease in the partitioning of NTDM at a rate of 1.8 % $^0C^{-1}$ as $T_{(mean)}$ fell from 26.6 to 16.2^{0}C (Figure 6).

The clone TRI 2025 partitioned a higher proportion of NTDM to shoots than TRI 2023 across the experimental sites. The similarity in the yields and the amount of NTDM partitioned to harvestable shoots of clone TRI 2025 at the two extremes of the test elevational/temperature range suggest that elevation or temperature had no effect on either of these two parameters. Therefore, the low yields and the low HI of clone TRI 2025 observed at Strathdon and Vellai-oya could rather be attributed to the environmental factors which are specific to the sites other than altitude or temperature.

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

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	

S.E. Clone (1 d.f.) 0.03 S.E. Clone × elevation (3 d.f.) 0.06
S.E. Site (3 d.f.) 0.04 CV 4.7 %
Effects of clone, site and clone × site interaction were significant at $p < 0.001$.

DISCUSSION

Both the NTDM production and yield of clone TRI 2023 were influenced by the mean air temperature which changed systematically with the change in elevation. The thermal sensitivity of NTDM production and that partitioned to harvestable shoots of clone TRI 2023 could be attributable to the clonal differences in both NTDM production and yield.

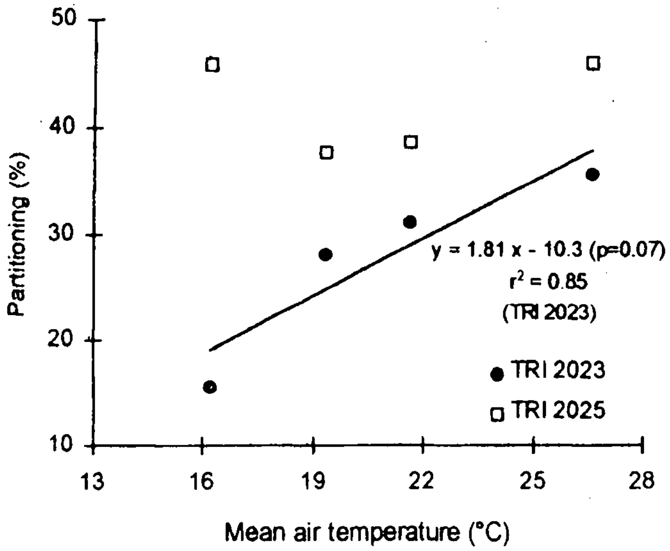

Figure 6. **Effect of mean air temperature on partitioning of net total dry matter production to shoots in clones TRI 2023 and TRI 2025.**

In the absence of environmental constraints such as soil moisture and vapour pressure deficits, 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 lower 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 test temperature range. In addition, this clone showed a stability both in yield and HI in the present study rather than a general adaptation shown by Wickramaratne (1981).

Results indicated that factors associated with the sites could have influenced the yield of both clones which necessitates improved cultural and management practices. The pH of soil at Strathdon and Vellai–oya were lower (4.2) than at other sites. The plots of clone TRI 2025 at both sites and clone TRI 2023 at Strathdon were located on a sloping land. It is possible that the factors such as high acidity and the leaching of nutrients caused by heavy rainfall (Figure 1b) had contributed to the poor yields of both clones at these two sites.

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 (capacity) of the sink in shoots for assimilates. The sink capacity depends on the 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 significant thermal gradients ($p<0.001$) when $T_{(mean)}$ rose from 16.2 to 26.6°C. Therefore, the low yields could be associated with an affected harvestable shoot population density (HSD) and the dry weight of a single harvestable shoot (*w*). In addition, the fact that $T_{(mean)}$ influenced the SDR but not yield in clone TRI 2025 highlights the necessity to investigate the influence of $T_{(mean)}$ on HSD and *w* in order to explain the similar yields given by this clone at the two extremes of the test elevation/temperature range. Further, it is important to clarify the genetic potential of clone TRI 2025 as a clone which possesses either stability or general adaptation by testing it in a wider elevational range.

Balasuriya (1996b) showed that the shoots of both clones at Kottawa could be harvested in three to four-day intervals according to their phyllochrons. The prolonged harvesting intervals of seven days adopted in this study therefore, lowered the yields by reducing the harvesting frequency and allowed the plucking table to rise higher (Figure 5). Thus, the yield could be improved by taking into consideration of physiological responses to environment.

The results infer that although tea in colder regions had produced more NTDM elsewhere clonal differences in dry matter accumulation were largely attributed to the thermal sensitivity, net photosynthetic rate and the leaf area. The rate of NTDM productions in N.E. India and Kericho, Kenya where the mean annual temperatures were 25.5±0.5°C and 17.5°C are comparable only with those in clone TRI 2023 at similar temperatures at Kottawa (26.6°C) and Glassaugh (16.2°C). The increase of the NTDM production in clone TRI 2023 which was a function of $T_{(mean)}$ could possibly be linked with a temperature-respiration relationship. Barbora and Barua (1988) linked the respiratory losses of dry matter (63%) to high air temperature. Thus, in colder regions the respiratory loss of dry matter is less with corresponding gain in NTDM of the whole bush which may not reflect in the yield of shoots. This is supported by the large NTDM productions of tea in Kenyan highlands which did not result in a higher crop (Othieno, 1982). Magambo and Cannell (1981) too showed that NTDM production and yield are inversely related though the reasons were not mentioned. Thus, the effect of temperature on yield of tea caused by influencing the sink capacity for assimilates in shoots rather than its effect on P or stored carbohydrates (Squire, 1979; Tanton, 1979; Squire and Callander, 1981) may be limited to clones such as TRI 2023 which had a temperature sensitive HI.

It was evident that the large LA and LAI of clone TRI 2023 at Kottawa did not contribute to a large production of NTDM. Such large LA was a result of large sized leaves at the warm lower elevations (Figure 7). The width and length of the leaves showed a distinct increase thus increasing leaf area of a single leaf as $T_{(mean)}$ increased with the drop in elevation (Figures 7 a–c). Nakayama and Harada (1962) reported that the leaf size of tea reached its maximum at 30°C. The increase in specific leaf area of both clones towards the higher elevations (Figure 7d) showed that the fall in $T_{(mean)}$ had reduced the specific leaf weights thereby increasing the number of leaves per unit weight (1.0 g) which is an adaptation to colder environments. The heavier leaves of both clones at the warmest site (Figure 7d) would have been able to minimise the sensible heat gain and delay the rise in leaf temperature (Monteith, 1981) in the absence of soil moisture deficits. Larger leaves were effective in transpirational cooling. However, larger leaves possibly could lower the NTDM production due to mutual shading.

Clonal differences in the response of respiration to temperature (Barbora and Barua, 1988) too may be expected to cause differences in NTDM production in clones. However, a hypothesis can be drawn from these results that gross dry matter production is genetically fixed for a clone and is associated with P and the LA but the net gain is influenced by the environment.

The large amounts of NTDM produced by clone TRI 2023 at elevations of ≥ 1300 m suggested a high conversion efficiency of solar energy. Thus the low yields could be attributed mainly to low harvest indices resulted from a fall in $T_{(mean)}$. On the other hand, HI could possibly be affected by the poor nutritional status of soil caused by the heavy rainfall at Vellai–oya and Strathdon which resulted in a limitation in the sink (shoots) for assimilates. Therefore, the results highlight the necessity for adopting proper soil management practices (*i.e.* SALT–Sloping Agricultural Land technique) to improve yields of tea in such areas which originally belonged to the rain–forests in the island. To understand the relatively stable (TRI 2025) and the sensitive (TRI 2023) harvest indices of the clones in this study the response of the density of harvestable shoot population and mean dry weight of a single harvestable shoot to $T_{(mean)}$ needs to be analysed.

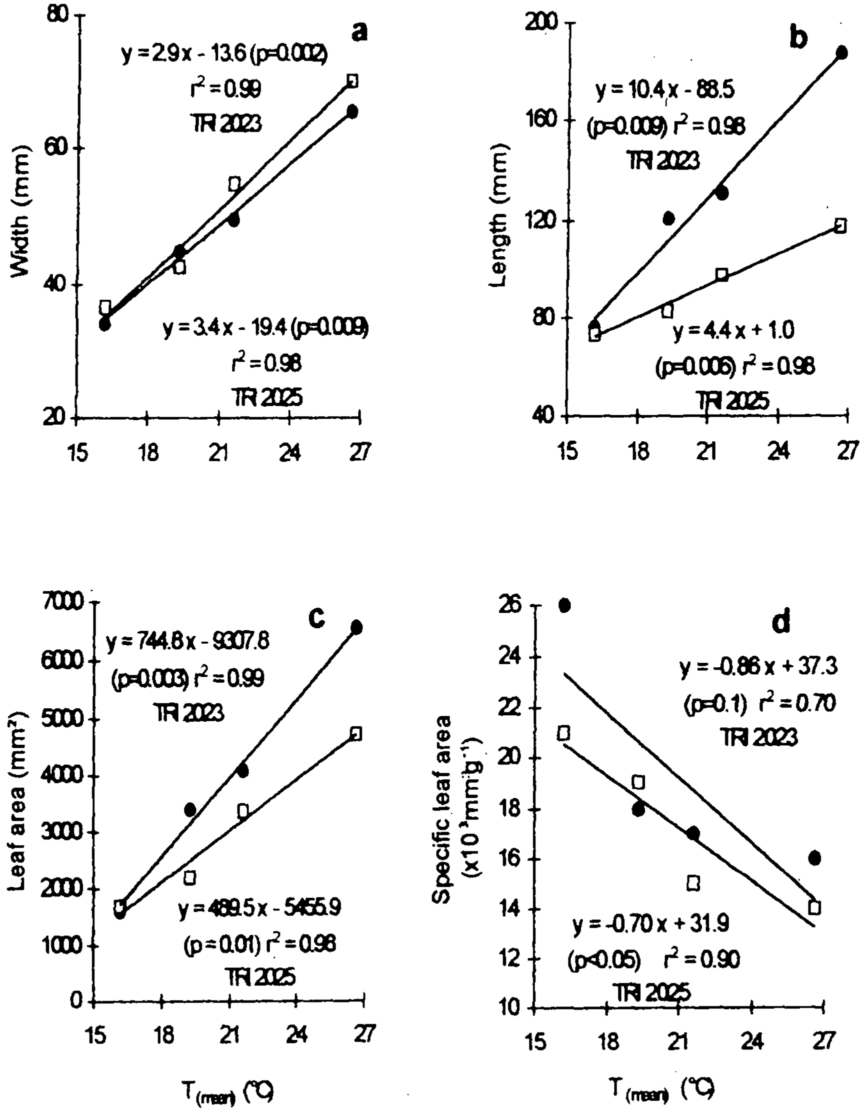

Figure 7. Leaf characteristics of the two clones TRI 2023 (●) and TRI 2025 (□) showing the response of width (a), length (b), area of a single maintenance leaf (c) and specific leaf area (d) to mean air temperature ($T_{(mean)}$).

CONCLUSIONS

The effect of elevation on net total dry matter production and that partitioned to harvestable shoots in clone TRI 2023 was caused largely by the differences in mean air temperature between the four elevations. The low air temperatures favoured the NTDM production but reduced the HI of this clone.

The low mean air temperatures at higher elevations (≥ 1300 m) had an advantage on the thermal sensitivity of clone TRI 2023 by producing a larger amount of NTDM when compared to clone TRI 2025. However, yield of clone TRI 2023 was highest at the lowest elevation. Yield and NTDM production indicated the existence of clone × temperature/elevation interactions. The clonal differences in net photosynthetic rate and leaf area were reflected in the differences in NTDM production between the two clones.

The rapid rates of the rise in height of the plucking table suggested an inefficient harvesting of shoots at lower elevations. However, this was not an indication of the NTDM production of the two clones.

Clone TRI 2023 was specifically suited for warmer regions while clone TRI 2025 showed stability in yield, harvest index and net total dry matter production within the test temperature range. However, there was evidence that the yield and the dry matter production of both clones were affected by other environmental factors which were associated with sites rather than elevation.

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