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EFFECT OF ALTITUDE ON SHOOT DEVELOPMENT OF CLONAL TEA WITH SPECIAL REFERENCE TO CLONAL SELECTION AND HARVESTING INTERVALS

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The effect of altitude on shoot development of two clones, TRI 2023 and 2025 was studied at five sites ranging from 30 to 1859 m. With the rise in altitude the duration of shoot replacement cycle (SRC) increased at a rate of 17.7 and 11.1d 1000 m^{-1} and the third phyllochron at 2.6 and 1.6d 1000 m^{-1} in clones TRI 2023 and TRI 2025 respectively ($p<0.01$). The effect of altitude on SRC and phyllochron was attributed to the change in mean air temperature of the sites. A highly significant genotype x environment interaction ($p<0.001$) was observed in the responses of SRC and phyllochron to altitude with large differences between the two clones at higher altitudes (lower temperatures) than at lower altitudes (higher temperatures).

The rate of shoot development was significantly higher ($p<0.001$) in clone TRI 2025 compared to that of clone TRI 2023 at each site. Clonal differences were observed in both base temperatures for shoot development and leaf expansion. The thermal responses are discussed with regard to possibilities of obtaining either larger yields or yield stability. The results also indicate a possibility in monitoring harvesting intervals of different clones in different ecological zones.

INTRODUCTION

Harvesting tea is a labour intensive operation. Therefore, timely harvesting in a given season or a location is important in order to maximise yield with higher labour efficiency. It is equally important to have clones with appropriate shoot growth habits to suit different ecological zones as well as clones which show yield stability in a wide environmental range. In Sri Lanka, tea is grown in three main ecological zones which are mainly differentiated by the altitude: Up-(>1200 m), mid-(600 – 1200 m) and low-country (<600 m). Among the climatic parameters of these three zones, mean air temperature was found highly correlated with altitude ($r^2 = 0.99$) with a lapse rate of 5.8^{0}C km^{-1} (Balasuriya, 1996). Therefore, mean air temperature should play an important role in influencing yield through its effect on shoot growth.

Effect of mean air temperature on rates of shoot extension and or development of various clones had been found in North East India (Hadfield, 1968; 1972), Malawi (Tanton, 1981), Tanzania (Burgess, 1992) and Kenya (Squire, Obaga and Othieno, 1993; Ng etich, 1995). Clonal differences in base temperatures for shoot growth had been reported by Stephens and Carr (1990) and Burgess (1992). Therefore, a low base temperature is an important physiological trait in selecting clones for cold environments or higher altitudes.

Response of leaf expansion to temperature could be used to plan harvesting intervals of tea in the different altitudes and seasons. Murty and Sharma (1989) have shown that phyllochrons could guide harvesting in N.E India using a forecasting method based on seasonal changes in mean air temperature. However in Sri Lanka, large fluctuations of mean air temperature within an ecological zone are absent. Therefore, the thermal response of shoot development should be able to assist in programming the harvesting intervals in the different ecological zones for different clones to maximise yield and labour efficiency.

Hence, the objective of this study is to quantify the responses of shoot development and leaf expansion to the change in altitude in order to facilitate guidance in harvesting and identify clonal selection criteria for higher yields and yield stability.

MATERIALS AND METHODS

Sites

A shoot development study was carried out from February to August 1994, at five sites located in the three main ecological zones: Glassaugh (1859 m), Nanu-oya; St. Coombs (1382 m), Talawakele; Vellai–oya (1300 m), Hatton; Strathdon (914 m). Hatton and Kottawa (30 m), Galle. A difference of 10.4^{0}C was found in the mean air temperature [(maximum + minimum)/2] between the highest (16.2^{0}C) and lowest (26.6^{0}C) altitudes. There was no moisture deficit during the experimental period and the saturation deficit of air did not exceed 1.3 kPa at any of the sites.

Clones

Two of the popularly grown clones in the island, TRI 2023 and TRI 2025 were used in this study. Clone TRI 2023 is ideally suited for lower elevations while TRI 2025 posseses general adaptability (Wickramaratne, 1981).

During the experimental period (February to August 1994) six sets of shoot generations were studied by plucking on six different dates and allowing the axillary bud to grow up to the harvesting stage of three leaves and a terminal bud.

Shoot development

Twenty shoots of each clone were tagged at each time after plucking an active bud with either two or three leaves above a true leaf. As the axillary bud grows into a shoot, the unfurling of the true leaves up to the third leaf was observed. The shoot replacement cycle (SRC) is the time taken (number of days) for the unfurling of the third true leaf from the time of shoot initiation (plucking). The mean air temperature was determined separately for the duration of each shoot replacement cycle.

Shoot development rate (1/t) is the development of shoot (up to the stage of three leaves and a terminal bud) expressed as a rate of growth and is computed as the reciprocal of the shoot replacement cycle (d^{-1}).

Phyllochron

Every week twenty shoots of each clone with the second true leaf just opened were tagged with polythene strips of two different colours and the number of days taken to unfurl the third successive leaf on each shoot was observed. The date was recorded with permanant ink on the polythene strip each time when a leaf unfurled. The time interval between the unfurling of two successive leaves is called a phyllochron which could be expressed in either time units (number of days) or thermal units (day ^{0}C above a base temperature).

Phyllochron development (leaf expansion) rate (1/tp) is the reciprocal of phyllochron (d^{-1}).

Base temperature (^{0}C) is the minimum temperature (Tb) beyond which either shoot development or leaf expansion does not take place.

RESULTS

Effect of altitude

Shoot Replacement Cycle

The duration of the shoot replacement cycle (SRC), time from plucking up to the unfurling of three true leaves of the axillary shoot increased linearly in both clones, TRI 2023 and TRI 2025 (r^2 = 0.94, 0.97 respectively) with the rise in altitude from 30 m (Kottawa) to 1859 m (Glassaugh) (Fig. 1). As a result at the highest site, the SRC of clone TRI 2023 became 32 days longer than that at the lowest site while this difference in clone TRI 2025 was only 20.2 days.

Also there was a distinct clonal difference in the duration of SRC at all five sites with shoots of clone TRI 2025 reaching the harvestable stage of three leaves and a terminal bud significantly earlier than those of clone TRI 2023 ($p<0.001$).

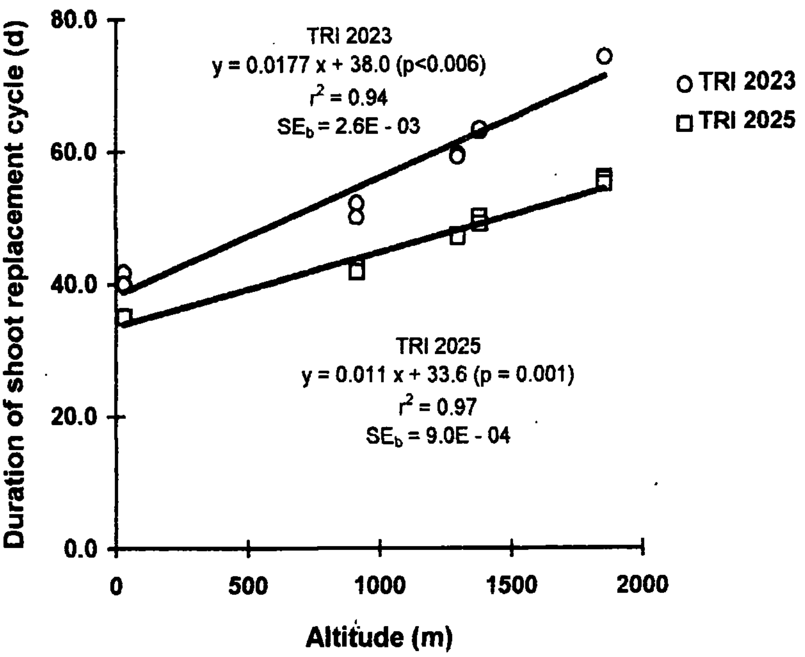

Fig. 1 – *Effect of altitude on duration of the shoot replacement cycle of clones TRI 2023 and TRI 2025*

The genotype (clone) x environment (altitude) interaction in the response of SRC to altitude was highly significant ($p<0.001$). This resulted from the fast rate of increase in the duration of SRC of clone TRI 2023 with the rise in altitude. The rate of increase in the duration of SRC per every 1000 m rise in altitude was 6.7 days faster in clone TRI 2023 than that of clone TRI 2025. Therefore a large difference of 19 days occurred between the durations of SRC of the two clones at the highest altitude site (Glassaugh) while this difference was only 6 days at the lowest altitude (Kottawa) and both differences were significant ($P<0.001$).

Phyllochron

The phyllochron followed a similar trend to that of the SRC. A clonal difference of two days ($p<0.001$) in the third phyllochron was observed at Glassaugh due to the relatively slow leaf unfurling of clone TRI 2023 with the increasing altitude (Table 1).

TABLE 1 – *Effect of altitude on phyllochron of clones TRI 2023 and TRI 2025*

			(d)		Third phyllochron
			Clone		
Site	*Altitude (m)*	*Mean air Temp. (°C)*	*TRI 2023*	*TRI 2025*	*Mean*
Kottawa	30	26.6	3.2	3.0	3.1
Strathdon	914	21.6	5.2	4.4	4.8
Vellai-oya	1300	19.3	6.2	5.2	5.7
Talawakelle	1382	18.8	6.2	5.0	5.6
Glassaugh	1859	16.2	8.2	6.0	7.1
Mean			5.8	4.7	
cv	11.4%				

	s. e. d.	LSD (0.001)
Clone	0.085	0.30
Altitude	0.134	0.44
Clone x Altitude	0.190	0.63

However the phyllochrons were similar at the lowest altitude, Kottawa. Such clonal differences in the response of phyllochron to the changing altitude resulted in a significant clone x altitude interaction ($p<0.001$). This was explained by the rapid increase in the duration of phyllochron per unit increase of altitude in clone TRI 2023 which was 63% faster ($p<0.001$) than that of clone TRI 2025 (Fig. 2).

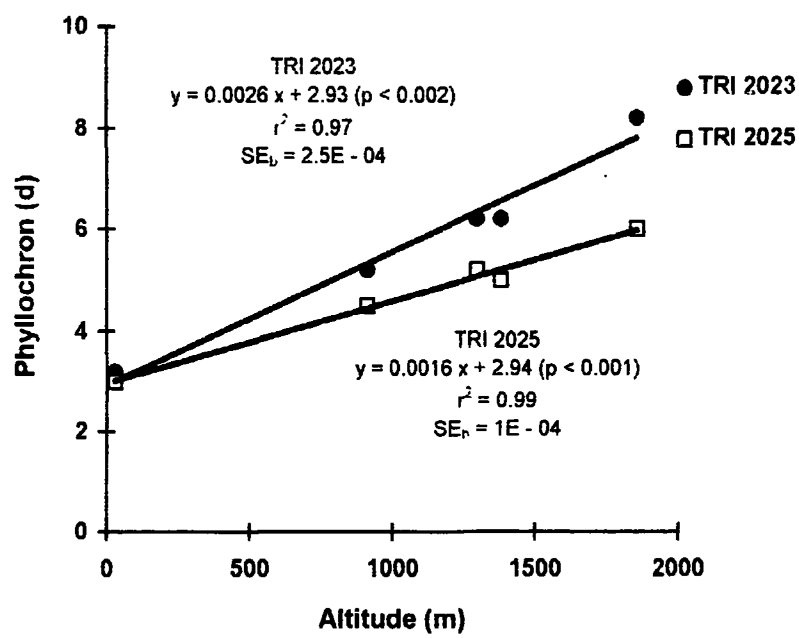

Fig. 2 – *Effect of altitude on the third phyllochron of clones TRI 2023 and TRI 2025*

Effect of temperature
SRC and phyllochron

Both the duration of SRC and phyllochron of the two clones showed a similar response to the changing mean air temperature across the five sites (Figs. 3 and 4). The thermal gradients show that an increase in mean air temperature by 1^0C could decrease the time taken to reach the harvestable stage (bud + 3 leaves) of shoots by 3 days in clone TRI 2023 ($p<0.006$) and by 2 days in clone TRI 2025 ($P<0.001$). (Fig. 3)

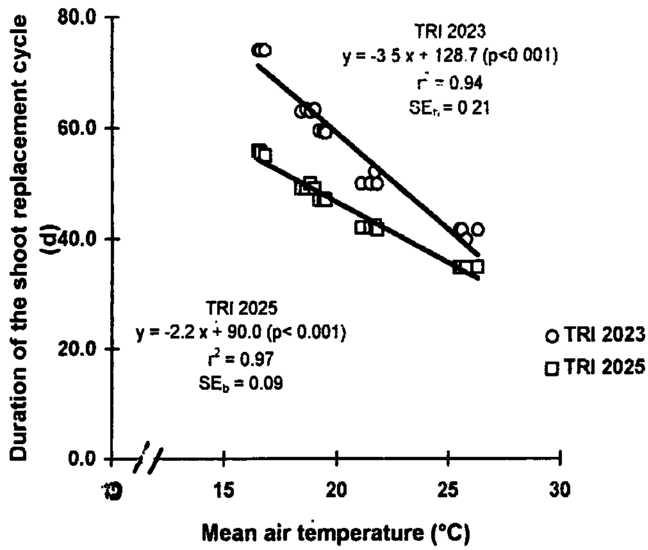

Fig. 3 – *Effect of mean air temperature on the duration of shoot replacement cycle of clones TRI 2023 and TRI 2025*

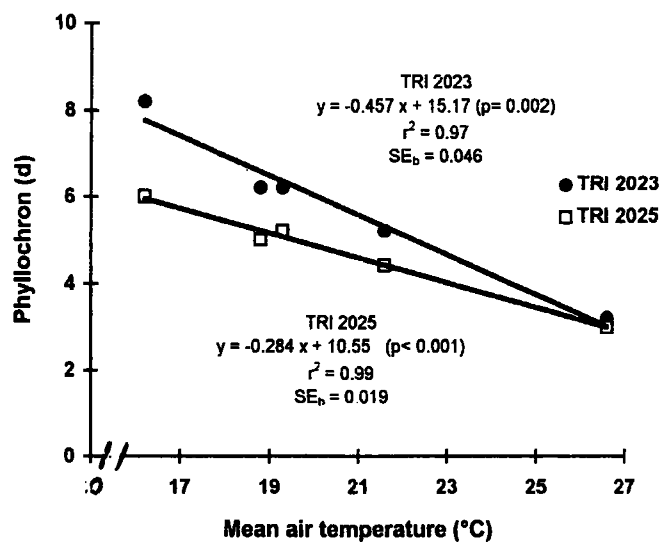

Fig. 4 – *Effect of mean air temperature on the third phyllochron of clones TRI 2023 and TRI 2025*

With the increasing mean air temperature the durations of both SRC and phyllochron dropped faster (at the rates of 1.3 d $^0C^{-1}$ and 0.2 d $^0C^{-1}$ respectively) in clone TRI 2023 than in clone TRI 2025 ($p<0.001$). However, the differences diminished at the highest mean air temperature of the test range (26.6^{0}C).

Rates of shoot and phyllochron development

The rates of shoot (1/t) and phyllochron (of the third leaf) development ($1/t_p$) of the two clones increased linearly with the rise in mean air temperature (Figs. 5 and 6).

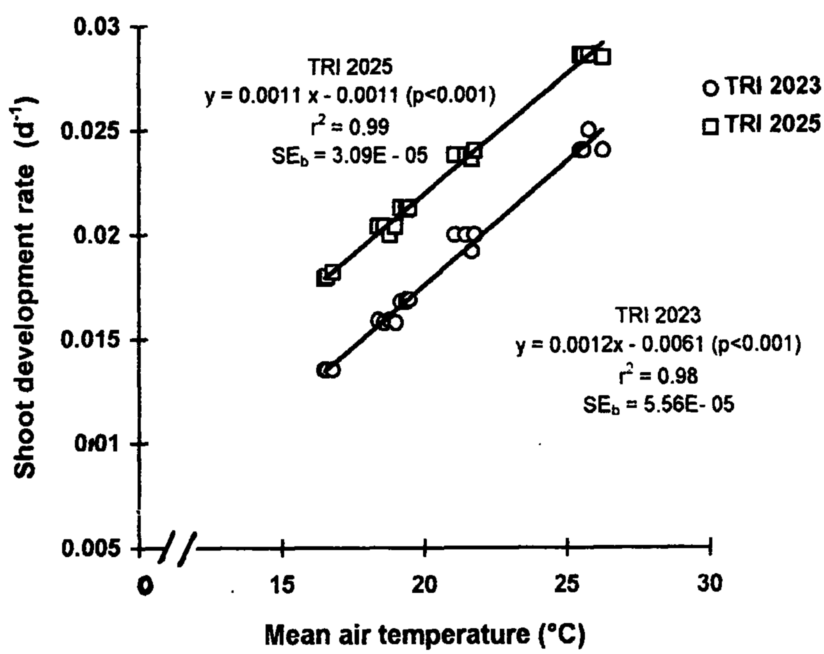

Fig. 5 – *Effect of mean air temperature on the rates of shoot development of clones TRI 2023 and TRI 2025.*

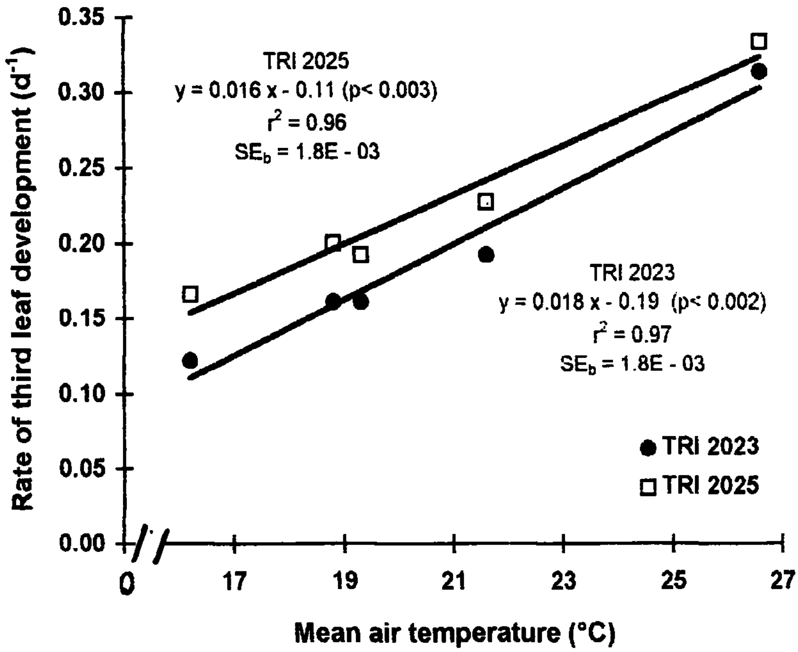

Fig. 6 – *Effect of mean air temperature on leaf development (third leaf) of clones TRI 2023 and TRI 2025.*

However, there was no clone x temperature interaction (shown by similar thermal gradients). The rates of shoot and the third leaf development were faster in clone TRI 2025 than in clone TRI 2023 across the temperature range ($p<0.001$). The following linear relationship of $1/t$ and $1/t_p$ and mean air temperature were obtained for each clone.

Clone TRI 2023

$1/t$	=	0.0012 Tmean	–	0.0061	R^2	=	98%	(1)
$1/t_p$	=	0.018 Tmean	–	0.19	R^2	=	97%	(2)

Clone TRI 2025

$$1/t = 0.0011\ \text{Tmean} - 0.0011 \qquad R^2 = 99\% \qquad (3)$$
$$1/t_p = 0.016\ \text{Tmean} - 0.11 \qquad R^2 = 96\% \qquad (4)$$

There was a significant correlation between the rates of shoot and phyllochron development (r = 0.97–0.98) of each clone which suggests that both 1/t and $1/t_p$ are influenced by the mean air temperature in a similar manner.

The base temperatures (T_b) calculated from the regression lines for 1/t and 1/*tp* of clone TRI 2023, 5°C and 11.1°C respectively were larger than those of clone TRI 2025, 1°C and 6.8°C (Table 2). However, 95% confidence limits for clone TRI 2023 were slightly larger than for TRI 2025.

Also it was interesting to note that the base temperatures were maintained at approximately a 4 °C difference between the two clones derived by either method (1/t or 1/*tp*) and a 6.0°C difference between the two methods within the same clone.

TABLE 2 – *Linear regression of shoot development rate (d^{-1}) and third leaf development rate (d^{-1}) on mean air temperature (°C) of the form y = bx – a, for clones TRI 2023 and TRI 2025.*

	1/t		1/*tp*	
	TRI 2023	*TRI 2025*	*TRI 2023*	*TRI 2025*
Slope (b)	0.0012	0.0011	0.018	0.016
SE of b	3.4E-05	2.2E-05	0.0018	0.0018
Intercept (a)	-6.1E-03	-1.0E-03	-0.188	-0.11
P	<0.001	<0.001	0.002	0.003
r^2	0.98	0.99	0.97	0.96
Base temperature (T*b*)				
(estimated)	5.0	1.0	11.1	6.8
95% confidence limits				
lower	6.9	1.9	16.0	11.0
Upper	3.8	0.1	8.3	5.0

The most distinct feature of clone TRI 2025 was that while possessing the lowest T*b* of the two, it had maintained a higher (P<0.001) 1/t and $1/t_p$ than clone TRI 2023 across the five sites. These two important physiological attributes of the thermal response of clone TRI 2025 suggest that it should either outyield clone TRI 2023 specially at cooler sites or attain yield stability over the entire altitude range. However, on the other hand the large thermal gradients of 1/t of clone TRI 2023 should either equate or outyield clone TRI 2025 at warmer sites.

DISCUSSION

In the absence of soil and air moisture deficits (during the experimental period from February to August 1994) it was evident that it was the mean air temperature which was mainly responsible for the differences in SRC as well as the phyllochrons between the clones and sites.

The significant clonal difference in SRC and third phyllochron suggests that within a site the shoots of these two clones have to be harvested at different intervals if similar plucking standards were to be maintained (either bud + 2 or 3 leaves). Also the relatively shorter SRCs of clone TRI 2025 at all sites indicate a higher number of SRCs per year for clone TRI 2025 than for clone TRI 2023 which may result in a relatively higher annual yield. This is specially an advantage at higher altitudes where the mean air temperatures are low throughout the year. The yield however, depends on two other yield components as well which need to be studied in terms of their responses to mean air temperature.

The slightly higher r^2 value obtained for the relations between the temperature and third phyllochron compared to that between temperature and SRC suggest that perhaps leaf development is a more reliable indicator of the temperature response of the two. Therefore base temperature derived from phyllochron (leaf) development could be a useful selection criteria in choosing clones for higher altitudes, cooler climates or for areas dominated by seasonal temperature fluctuations.

According to the results of this study, it shows that there is a clonal difference in T*b* for shoot development. However, the smaller values reported for 1/t compared to those of 1/t*p* suggest that factors other than temperature had interrupted the temperature dependent shoot development during the shoot replacement cycle.

Although clonal differences in the rate of shoot development were found absent at mean air temperatures above 17^{0}C (Stephens and Carr, 1990) in Tanzania, this study shows that in Sri Lanka such clonal differences could be observed in 1/t and 1/tp even at temperatures as high as 26.6^{0}C.

Also, the greater sensitivity of clone TRI 2023 to mean air temperature over clone TRI 2025 in this study should be one of the reasons for the large yields reported by Wickramaratne (1981) for clone TRI 2023 at Kottawa. However, clone TRI 2023 had outyielded clone TRI 2025 by 30% at Kottawa though its shoot development rate was significantly less than the other clone. This suggests that though SDR is one of the yield components, it cannot on its own decide the final yield of tea in a given location (environment). Therefore, this study reveals the importance of quantifying the responses of the other two yield components, the shoot population density (number of active shoots per unit area) and shoot mass to the dominating environmental parameters, such as temperature in a particular location/environment.

Further, a clone possesing a small thermal gradient in shoot development should be able to give a less variable yield over a wide temperature range. This can become a useful physiological attribute in selecting clones for different seasons (cool and warm). However, under environmental conditions in Sri Lanka this physiological trait is important in selection of clones for a wide temperature range (altitude) rather than for different seasons as seasonal differences due to air temperature are less marked.

This experiment has covered the largest mean air temperature range employed in a shoot growth study in tea so far and has shown that in the absence of other limiting factors the development of shoots is mainly and systematically influenced by the mean air temperature. Therefore, the partitioning of assimilates in tea to a large extent seems to be controlled by the growth of shoots. The growing shoots become a strong sink for assimilates where shoot growth is fast. This concept is the opposite of what had been suggested by Stephens and Carr (1993) that the temperature induced changes in the rate of shoot development is a result of partitioning of dry matter between shoots and roots.

However, the strength of the sink in shoots is not only decided by the temperature induced shoot development rates or the shoot population density and shoot mass but also by the responses of these yield components to other environmental factors such as nutritional status of soil, saturation deficit of air, soil moisture deficits and pest and diseases. The domination of limiting nutritional status of soil over the effects of temperature on shoot growth had been reported by Stephens and Carr (1993). These factors may sometimes override the effect of temperature on shoot development.

Therefore even in Sri Lanka, the advantage of relatively uniform distribution of mean air temperature could be obscured by the above mentioned factors thus causing seasonal yield fluctuations within a year.

The results of the study have significant practical implications and also provide sufficient ground for future work.

Selecting clones with low base temperatures with fast shoot development rates would be an advantage for areas where seasonal fluctations of mean air temperature dominate the environment.

In Sri Lanka large fluctuations of within year mean air temperatures are absent although there is a marked increase in mean air temperature from highest to the lowest altitude. Therefore, selection of clones with low base temperatures and fast shoot development rates is of great importance for higher altitudes.

Further, it is also important to investigate the response of the other two yield components: unit dry weight and shoot number per unit area to altitude which might provide useful information specially for selection of clones for different altitudes and temperature regimes.

The relationship between the mean air temperature and the phyllochron is a valuable guide in programming harvesting intervals. However, clonal differences in the response to temperature have to be taken into account. When a field of a particular clone is plucked, the subsequent harvesting could be done at intervals equal to one phyllochron.

Harvesting intervals for different altitudes could be predicted based on the phyllochron-temperature relation in clones. However, this concept will be most valid where no other environmental limiting factors are encountered.

Genotype (clone) x environment (temperature) interaction is an useful physiological attribute in selection of clones for different environments which should be further investigated in other yield components too.

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REFERENCES

BALASURIYA, JANAKIE. (1997). Effect of elevation on total dry matter production and yield of two clones in Sri Lanka. *S. L. J. Tea Sci.* (in press).

BURGESS, P. J. (1992). Responses of tea to drought in Southern Tanzania. *PhD Thesis.* Silsoe College. Cranfield Inst. of Tech. England.

HADFIELD, W. (1968). Leaf temperature, leaf pose and productivity of the tea bush. *Nature* London. **219,** 282-284.

HADFIELD, W. (1972). More light on shade. *Two and a bud.* **18,** 60–63.

MURTY, R. S. R. and SHARMA, V. S. (1989). Rationalisation of plucking intervals in tea: forecasting systems. In *Proc. of the Twenty-ninth UPASI Sci. Conf. Bull.* **43,** 6–15.

NG ETICH, K. W. (1995). An evaluation of the responses of some tea clones to environment in Kenya. *PhD Thesis.* Silsoe College, Cranfield, University England.

SQUIRE, G. R., OBAGA, S. M. O. and OTHIENO, C. O. (1993). Altitude, temperature and shoot production of tea in the Kenyan Highlands. *Expl. Agric.* **29,** 107–120.

STEPHENS, W. and CARR, M. K. V. (1990). Seasonal and clonal differernces in shoot extension rates and numbers in tea *(Camellia sinensis). Expl. Agric.* **26,** 83–98.

STEPHENS, W. and CARR, M. K. V. (1993). Responses of tea *(Camellia sinensis)* to irrigation and fertilizer. III Shoot extension and development. *Expl. Agric.* **29,** 323–339.

TANTON, T. W. (1981). Crop growth and yield of the tea bush. *Expl. Agri.* **17,** 323–331.

WICKRAMARATNE, M. R. T. (1981), Genotype-Environment interactions in tea *(Camellia sinensis L.)* and their implications in tea breeding and selection. *J. Agric. Sci.* Cambridge **96,** 471–478.