Tea Q. **52** (2), 64-80, Printed in Sri Lanka

GROWTH ANALYSIS STUDIES IN CLONAL TEA (*CAMELLIA SINENSIS* (L.) O. KUNTZE)

G. Wadasinghe and D. T. Wettasinghe*

(*Tea Research Institute of Sri Lanka, Low-country Station, Ratnapura, Sri Lanka*)

An experiment was carried out at the Tea Research Institute of Sri Lanka, St Joachim Estate (90 m amsl) with the objective of identifying the growth components of four popular tea clones viz. TRI 2023, TRI 2026, TRI 2025 and DN, as a means of explaining their growth and yield performances.

The estimation of growth analysis parameters, viz. NAR, RGR and SLA etc. was performed by adopting polynomial regression to calculate best fitted curves. By doing this it was possible to over-come the high variability which is normally experienced with the traditional approach, especially in the case of perennial woody plants.

The order of growth performance of the clones studied was rated as TRI 2023 > TRI 2026 > TRI 2025 > DN. The superior performance of clone TRI 2023 could be attributed to its ability to divert the major part of the photosynthates for the production of leaves and to its quick regenerative capacity after pruning. TRI 2026 had similar attributes. The poor performance of clone TRI 2025 could be attributed to its rapid early growth resulting in a dense leaf canopy which may not be photosynthetically very efficient. Clone DN diverted most of the photosynthates towards production of roots and stems, restricting the leaf growth, resulting in a small canopy. Therefore, the overall dry matter production was limited, but the well developed root system would have been one of the reasons for its drought tolerant qualities. Similarly rapid root growth, especially at the early stage was observed in clone TRI 2025, which again is considered a drought tolerant clone.

INTRODUCTION

Growth analysis techniques had been used in many crop-yield studies in the past. The traditional approach is to assess plant growth by obtaining large samples at infrequent intervals. This was based on the assumption that dry weight accumulation of the whole plant obeyed the law of compound interest (Gregory, 1918), Blackman, 1919). But the work of Briggs, Kidd and West (1920) revealed that the relative growth rate (RGR) of a plant is not a constant, but changes in a rather complex way, even during the purely vegetative phase of growth. Further, the inevitable variation due to sampling errors (Vernon and Allison, 1963) may result in the calculation and statistical analysis of growth analysis parameters becoming more difficult and too complicated.

Developments in statistical techniques and the common availability of high speed computer facilities has resulted in a significant development in the field of plant growth analysis in recent years. Vernon and Allison (1963) suggested that the high variability in estimates of net assimilation rate (NAR) could be reduced by fitting curves to dry weight and leaf area. They in fact used a quadratic equation

---

* Present Address: Coconut Research Institute of Sri Lanka, Lunuwila.

to describe the time dependent changes in total dry weight and leaf area, and derived NAR by differentiation. They found that the use of regression analysis substantially smoothed the fluctuation in estimates of NAR over a period of time compared with the estimate derived from the harvest interval approach. Polynomial regression analysis has become a very useful and popular tool in estimating plant growth analysis components. It allows the experimenter to use frequent, small harvests which evens out the flow of work and thus makes it possible to deal with larger number of treatments than by the older method of larger samples at long intervals. The method also reduces the risk of losing information within harvest intervals.

Huges and Freeman (1967) improved Vernon and Allison's application of regression analysis, firstly, by transforming the raw data of dry weight and leaf area to natural logarithms, thus making the variance independent of the means and, secondly, by calculating standard errors for estimates of the derived functions. Curves for RGRs are obtained by differentiation of the regression equation and progress curves of NAR and leaf area ratio (LAR) are also derived similarly.

Nicholas and Calder (1973) explained a simple, but reliable method of selecting the appropriate polynomial model for any set of data. The analysis of variance of linear, quadratic and cubic regression equations were calculated and the best polynomial regression is decided on the fiducial limits (95% Probability). By incorporating a step-wise regression procedure in a computer programme, Hunt and Parson (1974) were able to improve this method considerably. Polynomial regression of the first to third order were fitted independently to dry weight and leaf area according to inbuilt statistical tests on trends in the input data. A further improvement to this method was achieved by adopting "Segmentation" procedure, it which the total dry weight curve is divided into segments and each segments treated independently. The objective of this procedure was to obtain the most suitable curve and to avoid serious systemic deviations between the data and the fitted curve.

During the last two decades, polynomial regression to derive best fitted curves in plant growth analysis studies have been used extensively. More complete review of these studies can be found elsewhere (Hunt and Parson, 1974).

Plant Growth Analysis of Perennial Woody Plants

Growth analysis has most often been performed on herbaceous plants, both annuals and perennials, and only very little in perennial woody plants. This was mainly due to the complexity of growth, the very high variability between samples and the difficulty encountered in assessing plant growth. In fact, working on tea, Barua (1970) conlcuded that "It is not possible to carry out growth analysis on mature tea".

The only perennial woody plant in which detailed studies using growth analysis have been made is apple (Vyvyan 1957; Dudney 1973; 1974, Maggs, 1959, 1964, 1965, Holland 1967; Avery 1969; 1970). Being a temperate deciduous tree, the apple plant provides a comparatively convenient example for growth analysis studies.

In most of the other evergreen, tropical woody plants' growth analysis studies have been confined mainly to the nursery or early growth periods. Working on oil palms under nursery conditions, and Rees (1963) Rees and Chapas (1963) were able to estimate NAR, RGR, CGR (Crop Growth Rate), LGR (Leaf Growth

Rate) and show their inter-relationships. A similar study was reported on rubber (Templeton, 1968) in which growth analysis was carried out upto 7 years after bud grafting.

Tea

Tea has been grown in Sri Lanka as an evergreen plantation crop for more than a century. Due to the high productivity of improved clonal tea, most of the seedling tea in plantations are now gradually being replaced by clonal tea. One of the important characteristics of clonal tea, in contrast to seedling tea, is its high standard of uniformity. Nevertheless, in a mature population of clonal tea, 70% of the yield is derived from 48% of the plants at the lower elevations (Nathaniel, 1976).

Plucking of tea shoots is normally carried out at 5 - 9-day intervals, with pruning once in 2 - 5 years, depending on the elevation. Individual shoots were shown to grow from initiation to a harvestable size in a mean period of 63.7 days in the dry season and 42.6 days during the rainy season and the distribution of growth within the plant was found to be uneven. Shoot density in the central zone of the bush was double that in the intermediate zone and four times that in the peripheral zone (Nathaniel, 1976).

By measuring photosynthetic activity of tea leaves, Tanton (1977) concluded that the photosynthesis at present yield levels is not a limiting factor and that the number of shoots per unit area and the rate of shoot growth are more important. Shatilow and Alchivieldiani (1980) reported differences in photosynthetic efficiency between tea clones. They showed that the rate of photosynthesis depends on leaf morphology, leaf position on the plant and environmental conditions. A significantly higher dry matter production was observed in plucked compared with unplucked plants of the same clone (Magambo 1978). Huxely (1975) showed that on theoretical grounds, tea bushes should be capable of producing about 4 times the maximum observed yield.

Photosynthetic ability was observed to develop gradually in a young expanding tea leaf and the maximum capacity was not reached until the leaf reached its final size (Barua 1960). Among the shoots examined from the plucking baskets, Magambo (1975) reported that the first leaf, the one nearest to active bud was about 22% while the second leaf was about 38% of the leaf area of the fully expanded mature leaf.

The observations suggest that the young shoots harvested from a tea bush must be dependent, to a large extent, on the assimilates manufactured by the maintenance leaves.

The total dry matter production and its distribution to the various parts of the bush was studied by Magambo (1978), using different tea clones. He found that the highest yielding clone was not necessarily that with the highest rate of dry matter production, but it might be the one which diverted the highest proportion of dry matter to new leaf production.

A quantitative study of the changes in the early growth of vigorous and slow growing tea clones showed that net assimilation rate was higher in the slow growing clone but the greater leaf area and leaf area duration of the vigorous clone contributed to greater dry matter production in the vigorous clone (Kathiravetpillai and Kulasegaram, 1981).

The major drawback confronting growth analysis studies in tea is the large amount of tedious experimental work involved. Normally the tea bush carries a large, dense maintenance canopy, so that accurate estimation of leaf area is always cumbersome. It has a large, extensive root system, which often produces a mat of feeder roots. Therefore, excavating tea plants and separating roots from the soil is an extremely tedious, laborious and time-consuming operation. This is particularly so, during dry weather.

The present study was carried out with the prime objective of identifying the growth components of four popular tea clones viz. TRI 2023, TRI 2026, TRI 2025 and DN, as a means of explaining their growth and yield performance.

MATERIALS AND METHODS

The experiment was conducted at the Tea Research Institute of Sri Lanka, St Joachim Estate, Ratnapura (90 m above mean sea level). The four tea clones used in this study were chosen on the basis of their yield performance and their ability to withstand drought conditions. All four clones are commonly cultivated in Sri Lanka, especially at the lower elevations. The TRI 20 series are normally considered high-yielding and can be ranked as TRI 2023, TRI 2026 and TRI 2025, in order of their yield performance. Clone DN gives very poor yields, but it has marked ability to withstand drought. Clones TRI 2026 and TRI 2023 are susceptible to drought, while TRI 2025 is tolerant. In addition, these four clones show marked differences in growth habit. The design of the experiment was Randomized Blocks with four replicates. In each plot, 150 plants were planted and allowed to establish for about two months before taking any harvest. The date of first harvest was decided after a series of non-destructive growth measurements. The whole experimental period was divided into three phases for convenience of interpretation of results.

Phase 1 — From the first harvest to first cut given at *36 cm from ground level—about six months period.

Phase 2 — From the first cut to second cut given at *46 cm from the ground level (7th - 11th month).

Phase 3 — From the second cut until the last harvest. Plucking commenced after the second cut (12th - 38th month).

* These cuts are pruning treatments given to induce bush formation, and this is the normal practice in tea plantations

In each harvest, a series of growth measurements were taken viz total dry weight, leaf dry weight and leaf area. Leaf area was estimated by "punched disc" method, using a cork borer (Pethiyagoda and Rajendram, 1965). In phase 1 and 2, harvests were at three weeks intervals and in Phase 3, this was increased to six weeks. The data were analysed using the Hewlett Packard HP 9830A programmable calculator at Wye College, University of London Statistical Unit. The computor programmes (Polynomial regression upto 4th order and growth analysis) used in this study were written by Dr. W. E. Peat of Wye College.

The first step was to decide the best polynomial regression equation, which adequately described the trend of dry matter, leaf area and leaf dry weight change with time. The raw data as entered into the programme were transformed to natural logarithms and analyses of variance were used as the basis for deciding the best fitting regression. This procedure is illustrated using the dry weight for TRI 2025 in Phase 3 (Table 1). These equations were then used to calculate growth analysis components viz. NAR, RGR, LAR and SLA, etc.; and the trend with time were estimated.

All the statistical analyses were made individually for each growth phase. At each harvest, three plants were taken from each plot and the means of these three plants were used in the analysis. In Phase 3, the yield data were not included in the calculation of growth analysis parameters.

RESULTS

A detailed analysis of variance for the different degree of regressions for dry weights of clone TRI 2025 are given in Table 1. The variance ratios of the linear regression (Degree 1) was statistically significant, but at the same time, the deviations from this regression was also significant. Therefore, it is clear that the relationship of dry weight with time in this treatment was non-linear. Similar results were obtained for quadratic regression (Degree 2) and therefore the analysis was continued for cubic regression (Degree 3). In this instance, the variance ratios for the cubic regression over the previous regression were, significant, but the deviation from this regression was not significant. Further, in the regression of Degree 4, only the regression term was significant and the rest were not significant. Therefore, the best fitting curve to describe the trend of dry weight change in TRI 2025 in Phase 3, is the cubic polynomial (Fig. 1). Even after obtaining best fitting curve, there was substantial deviation of raw data from the expected values. This is unavoidable in a crop like tea, in which there is always very high experimental error due to difficulties in excavating the root system, handling of bulk samples etc. The same procedure was followed with all sets of data.

The best fitting correlation co-efficients are given in Table 2.

The use of only statistically significant correlation co-efficients to describe a growth curve is one of the pre-requisites in adopting the curve fitting approach for the correlation of expected growth analysis parameters (Hunt, 1978).

The principles involved are:

Assume that Log_e Dry Weight (Log_e W) and Log_e Leaf Area (Log_e A) are best fitted to regression of Degree 2.

The equations are:

(i) $\text{Log}_e\ W = a + bt + ct^2$

(ii) $\text{Log}_e\ A = a^1 + b^1t + c^1t^2$

Where a, b, c, a^1, b^1 and c^1 are constants.

By differentiating (i) and (ii) above

$$\text{Relative growth rate} = \frac{d(\text{Log}_e W)}{dt} = b + 2ct$$

$$\text{And Net Assimilation Rate} = \frac{1}{A} \cdot \frac{dW}{dt} = \frac{b + 2ct}{a^1 + b^1t + c^1t^2}$$

Likewise LAR and SLA (Given curves for Leaf Dry Weight) may also be obtained.

TABLE 1 — *Statistics of Polynomial Regressions*

PHASE 3 — Treatment TRI 2025 - Dry Weight (g)

Source of variation	*Regression of Degree 1*				*Regression of Degree 2*				*Regression of Degree 3*				*Regression of Degree 4*			
	SS[1]	*DF*[2]	*MS*[3]	*F-Ratio*	*SS*	*DF*	*MS*	*F-Ratio*	*SS*	*DF*	*MS*	*F-Ratio*	*SS*	*DF*	*MS*	*F-Ratio*
Times	22.69	15	—	—	22.69	15	—	—	22.69	15	—	—	22.69	15	—	—
Regression	16.40	1	16.40	160.78*	19.58	2	9.79	95.98*	21.66	3	7.22	70.78*	22.06	4	5.52	54.12*
Over the previous one	—	—	—	—	3.18	1	3.18	31.18*	2.08	1	2.08	20.39*	0.404	1	.404	3.96
Deviation from this Regression	6.29	14	.450	4.41*	3.11	13	0.239	2.34*	1.03	12	0.086	0.843	0.630	11	.057	.559
Error	4.87	48	.102	—	4.87	48	0.102	—	4.87	48	0.102	—	4.87	48	.102	—
TOTAL	27.56	63	—	—	27.56	63	—	—	27.56	63	—	—	27.56	63	—	—

*Significant at ≤ P 0.05 1 SS = Sum of Squares 2 DF = Degree of Freedom 3 MS = Mean Sum of Squares

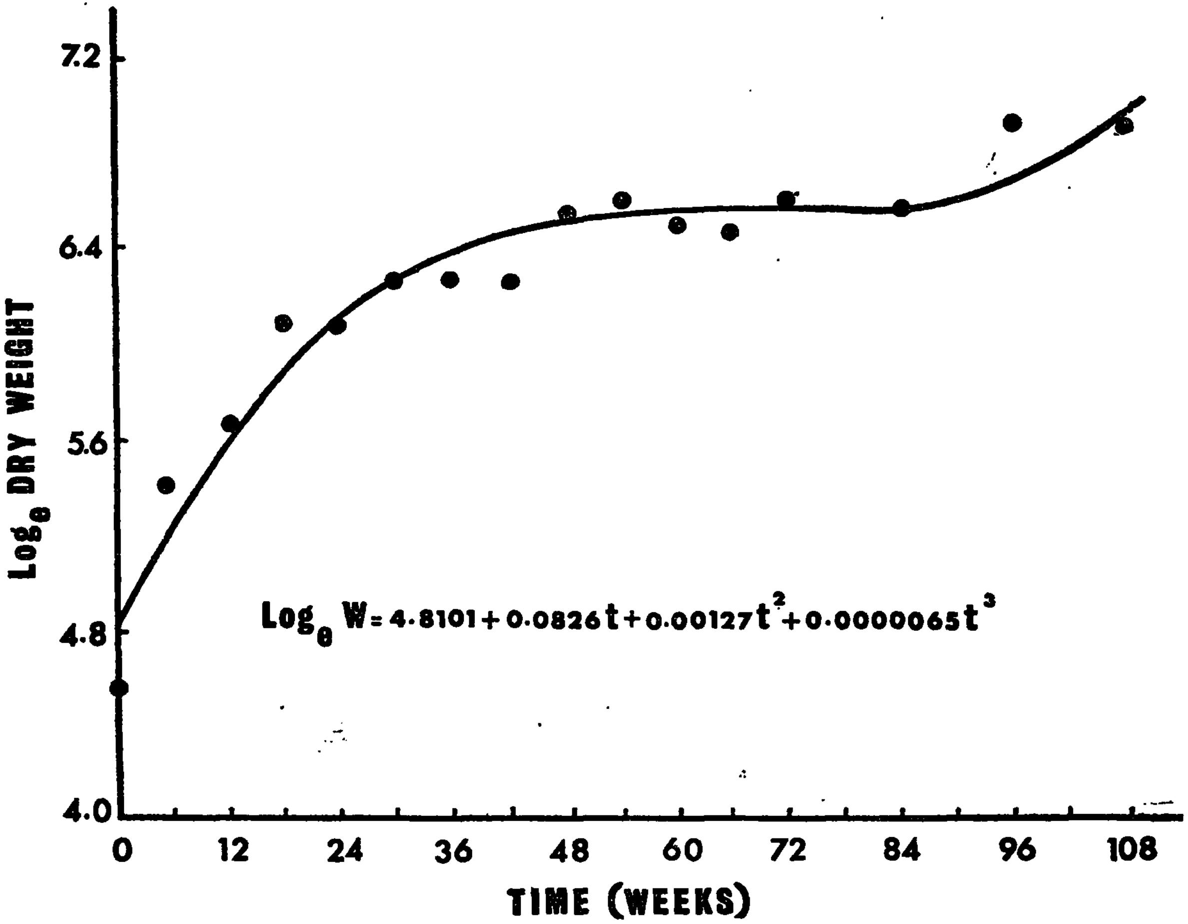

Fig. 1 — An example of application of curve fitting technique Phase 3. Dry weight of TRI 2025.
⊗ raw data, — fitted curve.

Total Dry Weight, Leaf Area and Leaf Dry Weight

Except for the dry weights of clone DN during Phase 1, (which gave a quadratic curve) the total dry weights, leaf areas and leaf dry weights showed linear relationships with time in both Phases 1 and 2 (Table 2). The best performance was observed from clone TRI 2025 and the poorest from DN (Table 3). The growth of clone TRI 2023 was poor in Phase 1, but markedly increased during Phase 2. This was especially evident from leaf area. In Phase 3, all the clones showed a similar and very close trend in dry weights (Table 3) but, were different for leaf area and leaf dry weight. Although TRI 2023 gave the highest total dry weight in Phase 3, its leaf area and leaf dry weight were smaller than TRI 2026 and TRI 2025. Further, the leaf area of TRI 2023, remained at a fairly constant level throughout Phase 3. In fact, the correlation of LA with time was not significant (Table 2).

TABLE 2 — *Best Fitting Correlation Co-efficients*

		TREATMENT				
		TRI 2026	*TRI 2023*	*TRI 2025*	*DN*	
PHASE 1						
Dry Weight	— Linear	.8606**	.9051**	.9599**		
	— Quadratic				.7819**	
Leaf Dry Weight	— Linear	.8358**	.8000**	.9564**	.9586**	**$P \leq 0.01$
Leaf Area	— Linear	.8118**	.6207**	.9383**	.8099**	
PHASE 2						
Dry Weight	— Linear	.8512**	.9695**	.9052**	.7530**	*$P \leq 0.05$
Leaf Dry Weight	— Linear	.9553**	.9691**	.9256**	.7880**	
Leaf Area	— Linear	.9686**	.9233**	.7509**	.7171*	
PHASE 3						
Dry Weight	— Cubic	.9715**	.9765**	.9544**	.9738**	NS— Not Significant
Leaf Dry Weight	— Cubic	.8207**	.8338**	.8893**	.8417**	
Leaf Area	— Linear	—	.3879^{NS}	—	—	
	— Cubic	.7966**	—	.8366**	.5807*	

TABLE 3 — *Values of Total Dry Weight, Leaf Area and Leaf Dry weight at the end of each growth phase*

Treatment	*TOTAL DRY WEIGHT (g)*			*LEAF AREA — (dm^2)*			*LEAF DRY WEIGHT (g)*		
	Phase 1	*Phase 2*	*Phase 3*	*Phase 1*	*Phase 2*	*Phase 3*	*Phase 1*	*Phase 2*	*Phase 3*
TRI 2026	116.14	166.35	1158.75	32.55	58.94	151.09	32.54	58.02	245.35
TRI 2023	72.13	215.40	1211.60	29.39	80.74	134.29	25.07	88.06	224.35
TRI 2025	116.14	240.30	1087.79	42.70	95.03	135.69	52.97	111.40	321.63
DN	67.62	117.94	799.27	23.07	36.40	73.91	28.39	44.21	156.85

Relative Growth Rate

The overall RGR was higher in Phase 1 than in Phase 2 except for clone TRI 2023(Table 4). This may have been due to an increase in non-photosynthetic plant materials. This was further evident in Phase 3, in which the RGR of all the clones fell to very low levels (Fig. 2). The very high RGR in clone TRI 2025 and DN

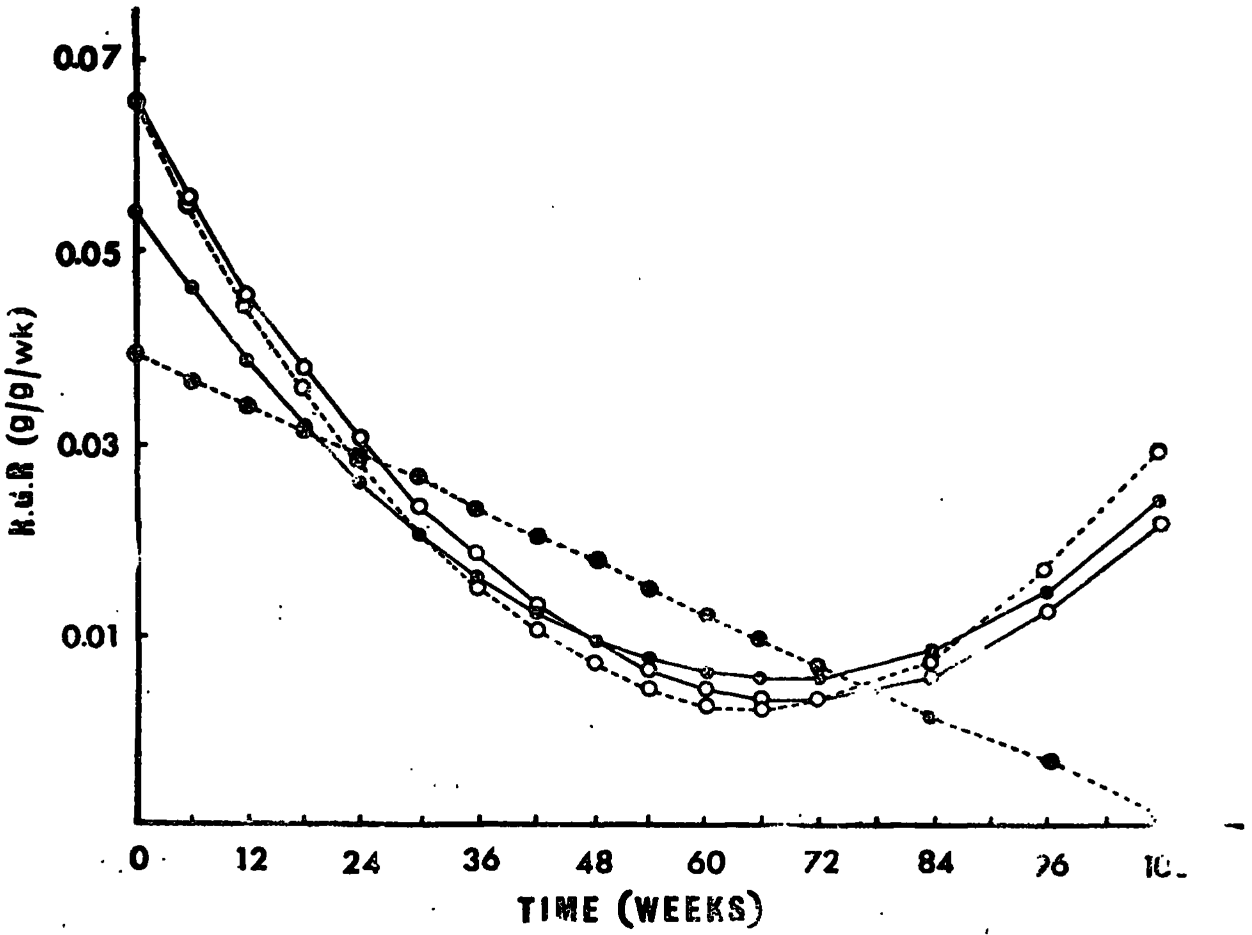

Fig. 2. — Expected curves for Relative Growth Rates (RGR) of Phase 3.

○—○ TRI 2026 ●—● TRI 2023 ●..● TRI 2025 ○..○ DN in Phase 1 reflects their ability to establish well after transplanting. In clone TRI 2023, RGR increased from 0.0482 in Phase 1 to 0.0959 g/g/wk in Phase 2. This clone takes a relatively longer time to establish, but subsequently grows vigorously. Its very high RGR in Phase 2, may have been the result of a relatively higher proportion of leaf material. In Phase 3, RGR declined to about 0.0091 g/g/wk in all clones and then increased to about 0.03 g/g/wk in clones TRI 2023, TRI 2026 and DN (Fig 2); clone TRI 2025 differed however in that it's RGR continued to decline. By this time, this clone had possibly produced a fully grown canopy which restricted further growth. The dry matter produced may have been utilized for the maintenance of the bush, replacements of dead organs and the production of flush (i.e. yield), which was not included in these calculations.

Net Assimilation Rate

Differences in NAR between clones were not evident until the 12th week of Phase 1 (Fig. 3a). Clones TRI 2023 and TRI 2026 maintained NAR's at a uniformly low level, whilst those of TRI 2025 and DN increased. Immediately after the cut given at the end of Phase 1, the NAR of clone TRI 2023, increased to a very high level (0.80 g/dm^2/wk), but then declined to about 0.3 g/dm^2/wk during the course of Phase 2 (Fig. 3b). In all the other clones NAR's were maintained at relatively low levels with DN being the lowest. The effect of water stress on NAR was clearly evident in Phase 3, in which the values in all the clones tested declined during the drought period (24 to 48 weeks) - (Fig. 3c). Clone TRI 2025 was the least affected. Towards the end of Phase 3, NAR increased to higher levels except in clone TRI 2025, in which it declined apparently to negative values. The dense, thick canopy of TRI 2025 at this stage with large horizontal leaves may reduce the light penetration into the bush. Therefore, the lower layers of the canopy might have been partially or completely shaded, resulting in low values of NAR.

TABLE 4 — *Expected Relative Growth Rates (g/g/wk)*

TREATMENT	*Phase 1*	*Phase 2*
TRI 2026	0.0655	0.0533
TRI 2023	0.0482	0.0858
TRI 2025	0.0875	0.0508
DN	0.0809	0.0337

Leaf Area Ratio

Towards the end of Phase 1, whilst LAR increased in TRI 2026 and TRI 2023, in clones TRI 2025 and DN it declined (Fig. 4a). This shows that in high-yielding clones, such as TRI 2023 and TRI 2026, more of the dry matter produced was utilized for the production of leaves than for the production of roots and stems, whereas in drought tolerant clones, such as, TRI 2025 and DN, there was an opposite trend, especially during the early stages of growth. This was further evident in Phase 2, in which DN maintained its LAR almost at a constant level, whilst those of TRI 2023 and TRI 2026 increased continuously (Fig. 4b). Very low LAR towards the end of Phase 3, may suggest that the production of canopy leaves was restricted at this stage (Fig. 4c).

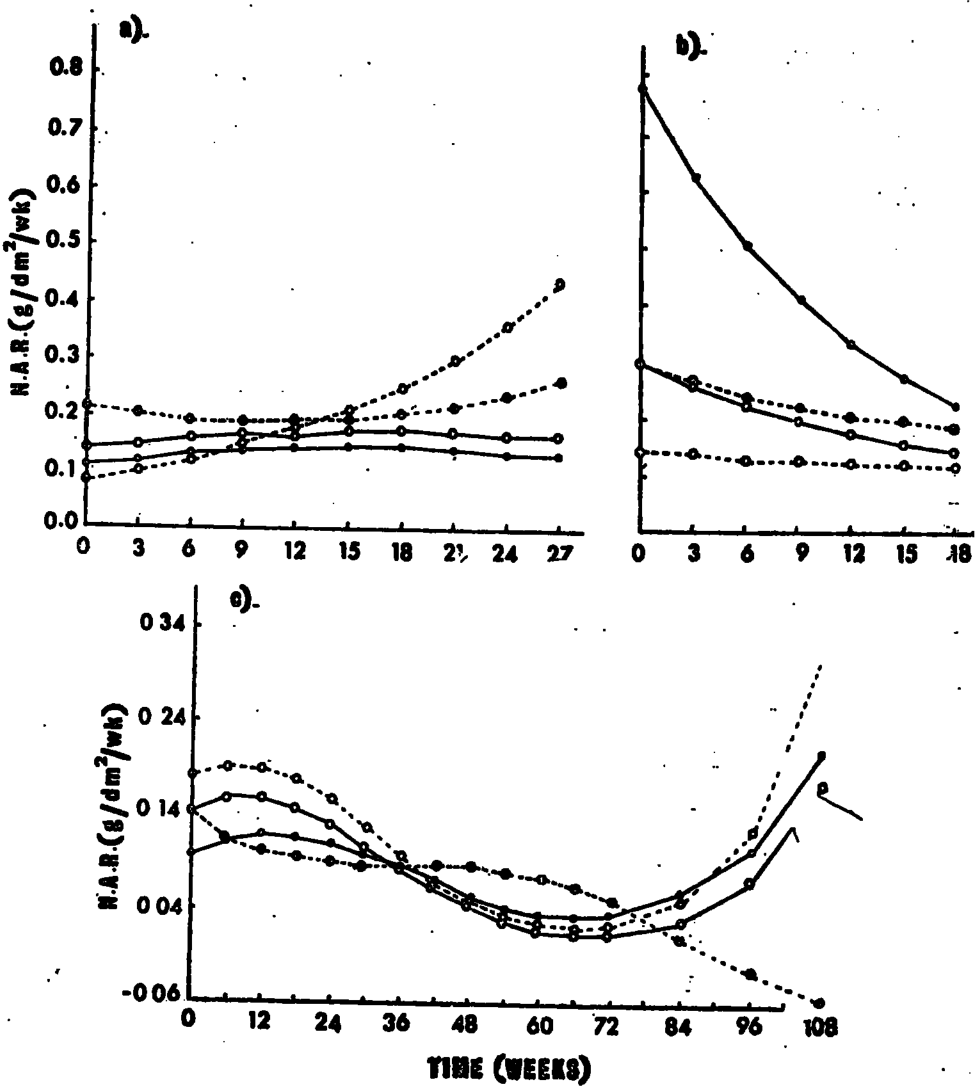

Fig. 3. — Expected curves for Net Assimilation Rates (NAR)

(*a*) *Phase 1* (*b*) *Phase 2* (*c*) *Phase 3*

○——○ TRI 2026 ●——● TRI 2023 ⊕....● TRI 2025 ○....○ DN

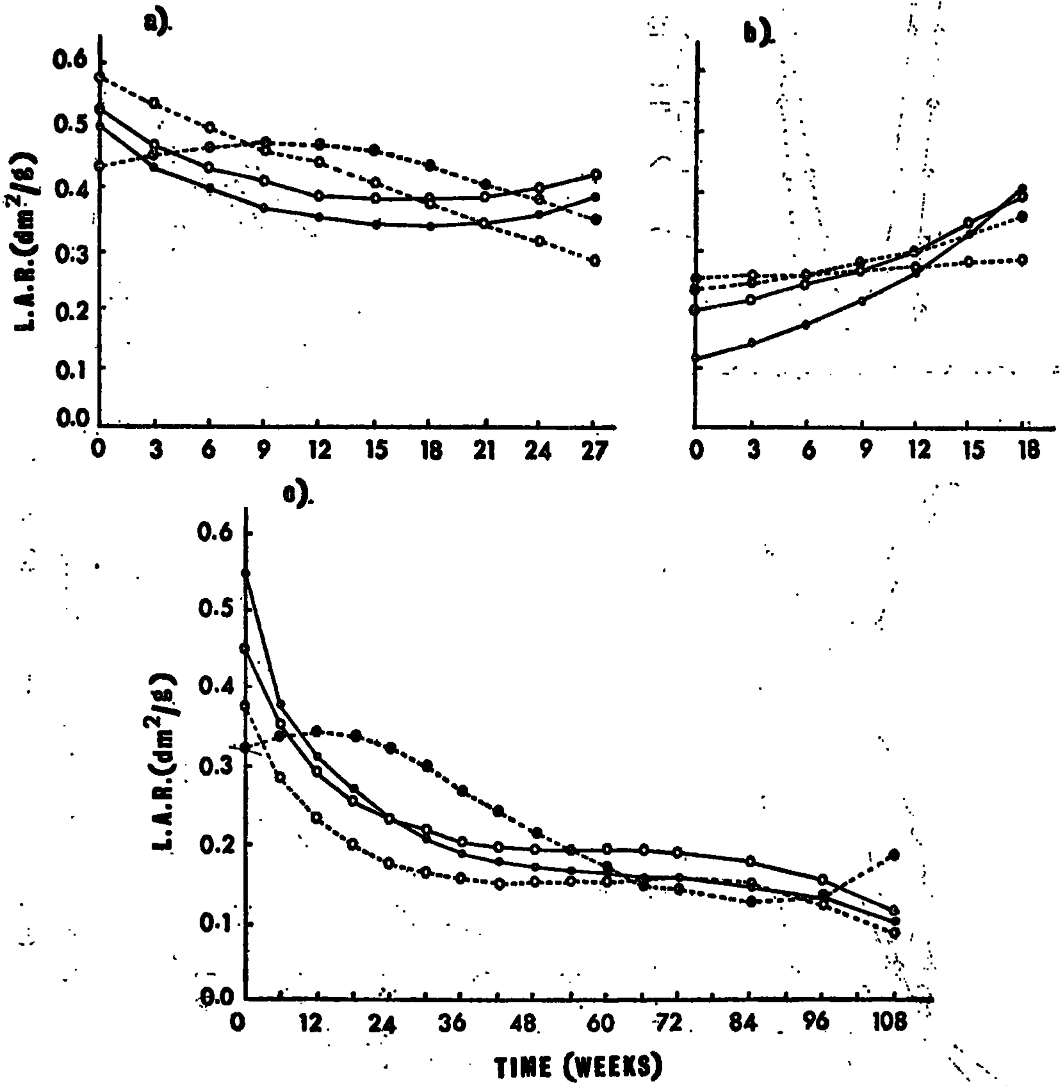

Fig. 4. — Expected curves for Leaf Area Ratios (LAR)

(a) Phase 1 *(b) Phase 2* *(c) Phase 3*

○——○ TRI 2026 ●——● TRI 2023 ●....● TRI 2025 ○....○ DN

Specific Leaf Area

The low SLA's of DN and TRI 2025 in all three phases support the view that these two clones possess relatively thick leaves (Fig. 5a - 5c). In Phase 3, SLA's in all four clones declined sharply until the commencement of the drought period (around 24th week) and then began to increase (Fig. 5c). This may imply that, during water stress tea leaves reduce their thickness.

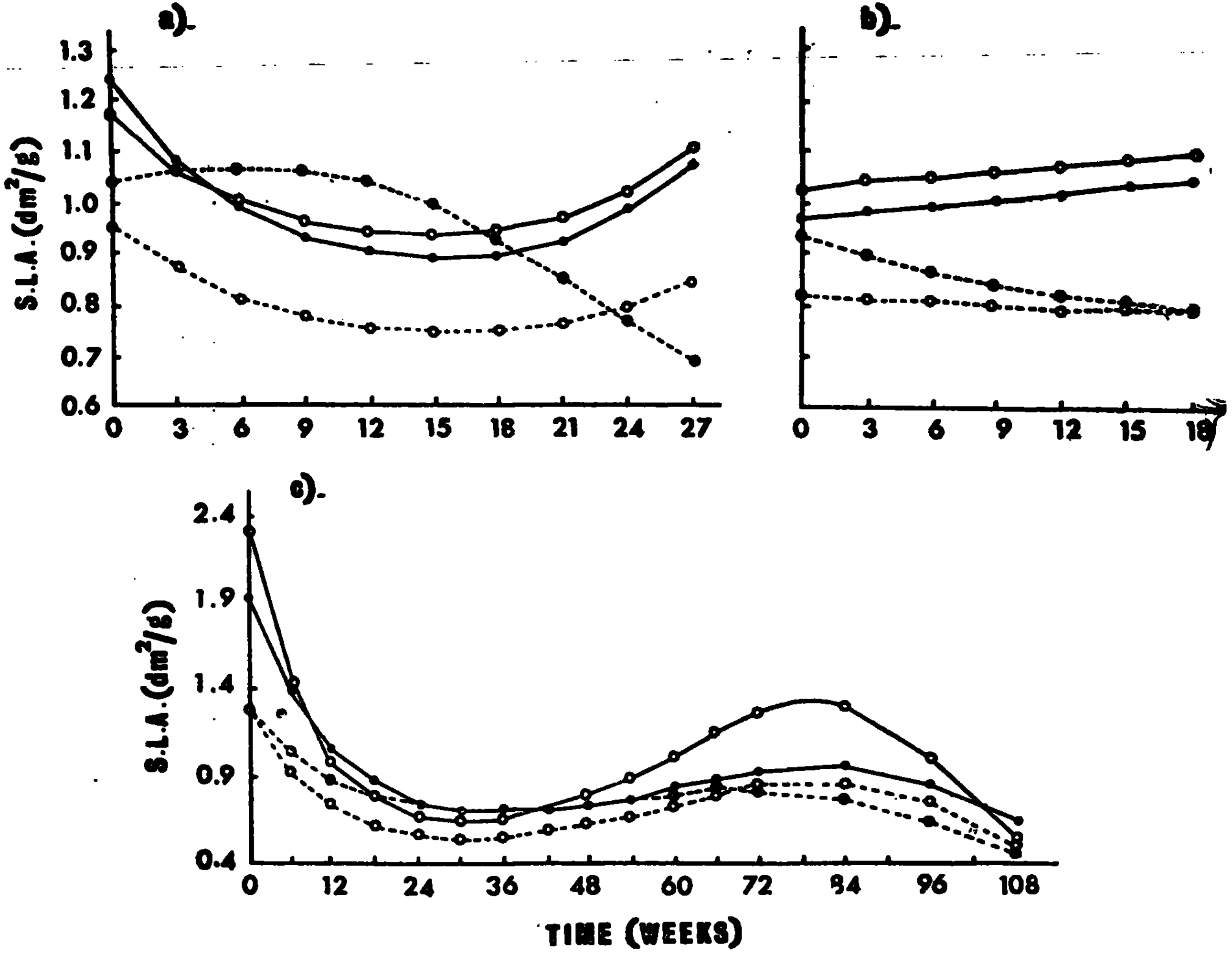

Fig. 5. — Expected curves for Specific Leaf Area (SLA)

(a) Phase 1 (b) Phase 2 (c) Phase 3

○—○ TRI 2026 ● - - ● TRI 2023 ●....● TRI 2025 ○....○ DN

DISCUSSION

The use of polynomial regression to decide the best fitting growth curves for plant growth analysis studies is becoming a very useful technique. This is specially true in the case of woody perennials where high variability in data is unavoidable. Large samples are extremely difficult to handle and it is a time and labour consuming operation. There is always a risk of losing plant material during harvesting, especially during the excavation of roots. Normally, in a population, plants are not strictly uniform, even when they are vegetatively propagated. Therefore, to minimize variability between samples, it is necessary to harvest a large number of plants on each occasion. Due to the large amount of labour involved, experimenters are usually compelled to choose a minimum sample size and/or to harvest at longer intervals. This, not only increases experimental error, but also creates the possibility of losing some valuable information during sampling intervals.

On the other hand, the curve fitting technique used in this study allows for more frequent but smaller samples to be taken. This results in an even distribution of the workload throughout the experimental period, and also gives more information on time trend. The only assumption, which is necessary for the adoption of this approach, is that fitted growth curves adequately describe the trend in the raw data.

Clonal selection of tea has been practised in the past purely on the basis of yield. Yield however may be influenced by many factors, mainly weather and soil so that yield in a single environment is not a good criterion for selecting clones. An understanding of the growth and behaviour of different clones could be very useful in selecting and improving clonal tea. Clones have been shown to differ in their physiology and/or morphology, *eg.* photosynthetic ability (Shatilow and Alchivieldiani, 1980; Kathiravetpillai and Kulasegaram 1981) or dry matter partitioning (Magambo, 1978; Kathiravetpillai and Kulasegaram 1981). Nevertheless, only very limited studies have been made on the growth and behaviour of the tea plant. The growth analysis experiments carried out in this study, were mainly aimed at explaining the growth and behaviour of our popular tea clones in growth analytical terms.

Clone TRI 2023 has been recognized as the highest yielder among the four clones, but it is susceptible to drought. The factors which determine this response can be clearly identified by growth analysis. Once established, this clone diverted the majority of its assimilates to leaf production, whilst the dry matter distributions to the root was relatively low, resulting in a small root system, exploring a small soil volume and thus explaining its susceptibility to drought.

The other remarkable feature of clone TRI 2023 was its marked response to the cutting back of vegetative portions of the canopy. The NAR was increased to very high level (0.8 g/dm^2/wk) immediately after the cut given at the end of Phase 1 (Fig. 3b). This may have been due to the exposure of canopy leaves to full light, and or possibly due to induction of new growth. This response was less evident at the change between growth Phase 2 and 3. During Phase 3, the dry matter production was mainly translocated to the new flush, which was being continuously removed. If this yield data had been included in the calculations, the NAR would have been much higher. The growth promoting effect of cutting as demonstrated in clone TRI 2023 is worth investigating further, because even the plucking operations could induce the production of new shoots and the magnitude of this effect could vary from clone to clone.

The total dry weight and leaf area of clone TRI 2023 during Phase 3 (Table 3) shows that although it produced the heaviest bush, its canopy was smaller than those of TRI 2026 and TRI 2025. This clone carries a fairly tall main stem, before branching out, which leads to a small canopy after the cut.

The evidence suggests, that NAR is not a constant characteristic of the tea leaf, but varies depending upon the situation. Clones, such as, TRI 2023 and DN gives high NAR's, mainly due to their leaf and canopy characteristics. It is a common observation that these clones produce well spread, small canopies with narrow, erect leaves, which may allow more light penetration into the bush. In TRI 2023 this results in a higher dry matter production. In clone DN however, the efficient canopy structure is counteracted by the reduced leaf area caused by the distribution of dry matter mainly to stems and roots and the result is poor yield.

The rapid decline in LAR in clones such as TRI 2023 during Phase 3 shows that dry weight was being diverted to stem thickening (as well as to the production of new flushes which were then harvested and have not been included in these analyses).

The growth performance of TRI 2026 followed closely that of TRI 2023. This clone established better after transplanting, but its subsequent growth was inferior to TRI 2023. It produced a large canopy, which may have resulted in some mutual shading of the lower layers, so reducing their photosynthetic capacity. Clone TRI 2025 produced the greatest amount of dry matter among the clones studied during Phase 1 and 2 but not in Phase 3. This clone established well within a very short period of time and grew very vigorously, resulting in a bush with a large root system and a large leaf canopy. This large canopy with its large, thick and horizontal leaves may have reduced light penetration, so limiting photosynthetic capacity of the bush. The reduction of NAR and RGR even to negative values at the end of Growth Phase 3, suggests that the growth of the bush had completely stopped and that the lower layers of the canopy were not only unproductive, but might also have been parasitic. It must, however, be emphasised once again that the estimates of NAR and RGR given here are under-estimates due to the non-inclusion of dry weight of the harvested crop.

All four clones, responded to the drought period in Phase 3. NAR declined and recovered again with the onset of wet weather. TRI 2025 was the least affected. In this clone NAR was maintained at a moderate level throughout the dry spell, but began to decline after that, possibly as a result of its dense canopy. Reduction in LWR with the onset of dry weather may have been due to the restricted production of new leaves and shedding of some older leaves. The simultaneous increase in SLA may indicate that the leaves become comparatively thin, during water stress, perhaps by the loss of some storage materials or water.

ACKNOWLEDGEMENTS

We wish to express our sincere thanks to Mr C. Gunasekera of the Tea Research Institute of Sri Lanka, Ratnapura, and Messrs D. G. Kulasinghe and K. D. Dahanayake of the National Apprenticeship Board, for their assistance in carrying out the tedious growth assessments cheerfully. We are grateful to Dr W. E. Peat of Wye College, University of London, for the statistical advice and computor programmes, and to Dr S. Sandanam of the Tea Research Institute of Sri Lanka, Talawakele, for his comments and reading the manuscript. Thanks are also due to Mr D. J. M. Hettiarachchi for the photographs and Mr Thambimuttu for typing the manuscript.

REFERENCES

Avery, D. J. (1969). Comparison of fruiting and de-blossomed maiden apple trees and of non-fruiting trees on a dwarfing and an invigorating root stock. *New Phytologist* **68**, 323-326.

Avery, D. J. (1970). Effects of fruiting on the growth of apple trees on four root stock varieties. *New Phytologist* 69, 19-30.

Barua, D. N. (1960). Effects of age and CO_2 concentration on assimilation by detached leaves of tea and sun flower. Journal of Agricultural Science, Cambridge **55**, 413-421.

Barua, D. N. (1970). Light as a factor in metabolism of the tea plant. Physiology of Tree Crops, Ed. Luckwill & Cutting, 307-321.

Blackman, V. H. (1919). The compound interest law and plant growth. *Annals of Botany* **33**, 353-360.

Briggs, G. E., Kidd, F. & West, C. (1920). A quantative analysis of plant growth. *Annals of Applied Biology* **7**, Pts. I & II, 103-123 & 202-223.

Dudney, P. J. (1973). An approach to the Growth Analysis of perennial plants. Proceeding of Royal Society, London B. **184**, 217-220.

Dudney, P. J. (1974). An analysis of Growth Rates in the early life of apple trees. *Annals of Botany* **38**, 647-656.

Gregory, F. G. (1918). Physiological conditions in cucumber houses. Report of the Experimental Research Station, Chestnut, England. **3**, 19-20.

Holland, D. A. (1967). The estimation of total leaf area on a tree. Report of East Malling Research Station, 101-104.

Hunt, R. (1978). Plant Growth Analysis. Studies in Biology No. 96. Edward Arnold (Publishers) Ltd., London.

Hunt, R. and Parsons, S. T. (1974). A comparison programme for deriving growth functions in Plant Growth Analysis. *Journal of Applied Ecology* **11**, 297-307.

Huges, A. P. and Freeman, P. R. (1967). Growth Analysis using frequent small harvests. *Journal of Applied Ecology* **4**, 553-560.

Huxely, P. (1975). Tea Growing. Tea in East Africa **15**, No. 2, 13-17.

Kathiravetpillai, A. and Kulasegaram, S. (1981). A quantitative study of the early growth of cuttings of tea (*Camellia sinensis* (*L.*) O. Kuntze). *Tea Q.* **50**, 61-70.

Magambo, M. J. S. (1975). Some observation on growth of tea shoot. Tea in East Africa **15**, No. 2, 7.

Magambo, M. J. S. (1978). Crop Physiology. Tea in East Africa 18, No. 1, 8-10.

Magambo, M. J. S. (1978). Dry matter production of plucked and unplucked bushes. Tea in East Africa **18**, No. 2, 5-7.

Maggs, D. H. (1959). The pruning response of one year apple trees. *Annals of Botany* **23**, 319-330.

Maggs, D. H. (1964). Growth rates in relation to assimilate supply and demand — I. Leaves and roots as limiting regions. *Journal of Experimental Botany* **15**, 574-583.

Maggs, D. H. (1965). Growth rates in relation to assimilate supply and demand — II. The effect of particular leaves and growing regions in determining the dry matter distribution in apple trees. *Journal of Experimental Botany* **16**, 387-404.

Nathaniel, R. K. (1976). Some observations on the growth of clonal tea under Low-country conditions in Sri Lanka. Proceeding of 22nd Science Conference. UPASI 173-183.

Nicholas, A. O. and Calder. D. M. (1973). Comments on the use of regression analysis for the study of plant growth. *New Phytologist* **72**, 571-581.

Pethiyagoda, U, and Rajendram, N. S. (1965). The determination of leaf areas in tea. *Tea Q.* **36**, 48-58.

Rees, A. R. (1963). Relation between crop growth and leaf area index in the Oil Palm. Nature **197**, 63.

REES, A. R. and CHAPAS, L. C. (1963). An analysis of growth of Oil Palms under nursery conditions — I. Establishment and growth in the wet zone. *Annals of Botany* 27, 607-614.

SHATILOW, I. S. and ALCHIVIELDIANI, N. S. (1980). Photosynethetic productivity of different tea cultivars and its role in the formation of highly productive tea plantations. Selskokhozyaistvennaya Biologia No. 4, 534-538.

TANTON, T. W. (1977). Why tea yields are so low. Tea Research Foundation of Central Africa Quarterly News Letter No. 48, 4-6.

TEMPLETON, J. K. (1968). Growth studies in H. Brasiliencies — I. Growth analysis up to seven years after bud grafting. *Journal of Rubber Research Institute*, Malaysia 20, Pt. 3, 136-146.

VERNON, A. J. and ALISON, J. C. S. (1963). A method of calculating NAR. Nature **200**, 814.

VYVYAN, M. C. (1957). Analysis of growth and of form in young apple trees. *Annals of Botany* 21, 479-497.