

RESPONSES OF TEA TO ENVIRONMENT IN KENYA. 2. DRY MATTER PRODUCTION AND PARTITIONING

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SUMMARY

In a genotype × environment experiment at four sites with four tea (*Camellia sinensis*) clones in Kericho, Kenya, differences in ground cover and total dry matter production and partitioning were found between clones and between sites. The major contributor to these differences was the daily intercepted solar radiation that differed by as much as 30% between sites. Differences in radiation use efficiency (RUE) between the sites were small, but varied from 0.3 to 0.45 g MJ⁻¹ between the clones. The rate of dry matter production was affected by the prevailing weather conditions. During the dry seasons the rate of dry matter production differed between the sites and clones by a maximum of 2 g m⁻² d⁻¹. Harvest indices were found to vary between the sites and increased with time. Partitioning to harvested shoots ranged from 10% for clone TN14-3 to a maximum of 19% in clone S15/10 at site 4. Partitioning to roots showed distinct differences between clones, being least in clone S15/10 (10–20%) compared with 15–32% in other clones. Rooting depths were greatly influenced by the prevailing temperatures.

INTRODUCTION

The rate of dry matter (DM) production of tea (*Camellia sinensis*) depends on the incident solar energy, the canopy area available to intercept radiation, the availability of water and nutrients and the solar radiation conversion ratio (Squire, 1985). In total, the rates of net photosynthesis and assimilate translocation account for the productivity (annual and seasonal growth changes) of the bushes.

The mean daily total solar radiation at the Tea Research Foundation (site 1) (0° 22' S 35° 21' E) is about 18.4 MJ m⁻² d⁻¹ (Stephens *et al.*, 1992; Ng'etich *et al.*, 1995b). While the light saturation point for single leaves is about 300 W m⁻², it is about 600 W m⁻² for whole canopies (Squire, 1977; Sakai, 1975; Callander and Woodhead, 1981).

The relationship between DM and solar radiation can be expressed as:

$$DM = S_o \cdot f_s \cdot \epsilon_s \quad (1)$$

where DM = total dry matter (g m⁻²), S_o = incident solar radiation (MJ m⁻²), f_s

is the fractional radiation interception and ϵ_s = solar radiation conversion ratio (g MJ^{-1}), which is also termed Radiation Use Efficiency (RUE).

The RUE, ϵ_s , is defined as the ratio of dry matter produced per unit intercepted solar radiation.

$$\epsilon_s = \text{DM} / S_i \quad (2)$$

where S_i is the intercepted total solar radiation (MJ m^{-2}).

Reported values of RUE for tea range from 0.25 g MJ^{-1} to 0.55 g MJ^{-1} (Magambo and Cannell, 1981; Squire, 1985; Carr and Stephens, 1992; Burgess, 1992) which are low compared with 0.99 to 1.38 g MJ^{-1} for willow (Cannell *et al.*, 1987).

In tea, the harvest index (HI), defined as the fraction of the total DM partitioned to harvestable shoots, ranges from 7 to 24% (Magambo and Cannell, 1981; Murty and Sharma, 1986; Burgess, 1992, 1994). These values are small compared with forest trees whose HI's range from 40 to 85% (Cannell, 1985) and 42% for oil palm (Corley, 1983). Magambo and Waithaka (1983) reported that the HI of harvested tea decreased with age. This they attributed to the increase in the proportion of total DM accounted for by the wood in the frame of the bush.

Genotypic variations in total DM production and partitioning in tea have been found to be influenced by the above ground DM (Magambo and Waithaka, 1983) and Burgess (1992) reported clonal differences in DM partition in young tea with high-yielding clones partitioning the most to the top (and less to the roots).

The environmental variables found to have influence on partition of assimilate are temperature, photoperiod, water stress and nutrition. In coffee (*Coffea arabica*), seasonal changes in partitioning were ascribed to changes in air temperature and water stress between seasons (Cannell, 1985). These seasonal changes in partitioning may be caused by the changes in direction of movement of photosynthates as observed in tea, due to changes in season (Manivel and Hussain, 1982).

The limited information available on light interception, RUE and DM production in tea highlights the importance of further research on factors affecting the rate of canopy development and the radiation use efficiency.

DM partitioning can be a useful tool in clonal selection (Magambo and Waithaka, 1983; Burgess, 1992). An understanding of clonal differences (and locational differences) in partitioning to shoots (HI), therefore, is important to tea growers and scientists alike. Most studies, however, have concentrated on single locations (Magambo and Cannell, 1981; Burgess, 1992).

In the first paper in this series, large clonal interactions with environment were reported in total DM and yield (Ng'etich and Stephens, 2001a). This paper presents an analysis of the clonal differences observed and discusses the effects of environment on light interception and DM production and partitioning at four sites in Kericho.

METHODOLOGY

Details of the field experiment and genotypes are described in a previous paper (Ng'etich and Stephens, 2001a). The experiment was set up in 1991 at four sites in Kericho, Kenya, using four clones of scientific and commercial importance (S15/10; BB35; 6/8; and TN14-3). The sites chosen spanned an altitude range from 1800 to 2200 m asl with a mean air temperature difference between extreme sites of about 3 °C.

Ground cover

Ground cover (GC) was measured at 14-d intervals on representative plants selected in June 1992. One plant per clone was selected in each replicate and in the observation plot, giving a total of 20 plants. A grid measuring 1.2 x 0.8 m, with squares of 0.0036 m² was placed just above the canopy surface and the cover in each square was assessed from directly above. Following the method used by Burgess (1992), squares were recorded as fully covered (> 75% cover), half covered (25 – 75%) or empty (< 25% cover). The total number of squares counted was expressed as a fraction of the plant spacing. During whole plant harvests for total DM determination, the GC of the harvested plants was also measured.

Leaf area index (LAI)

During the first two harvests, in May and August 1992, the area of all leaves was measured using a leaf area meter (Model LI2005, LiCor, NE, USA). Thereafter, a leaf area card (Pethiyagoda and Ragendram, 1965; Ng'etich and Wachira, 1992) was used due to the large number of leaves to be measured. The total leaf area was divided by the measured GC to determine the LAI. During the harvests done in August and December 1993 and April 1994, the leaf area of 200 randomly selected leaves was determined from each sampled plant. The total leaf area was estimated from the total leaf dry mass and the leaf specific mass (kg m⁻²).

Whole plant harvests

Plants to be harvested were selected from the observation block of 80 plants of each clone situated to one side of the experimental area (Ng'etich and Stephens, 2001a). GC and stem diameters were used to select plants that were representative of the site mean for each clone. Between May 1992 and April 1993, three plants were harvested from each clone at the four sites. From August 1993, the number of harvested plants was increased to four per clone. Each plant was treated as a replicate.

To study the effect of seasons on DM production, whole plant harvests were done in May and August 1992, January, April, August and December 1993 and April 1994 to coincide with the major seasons in Kericho (Stephens *et al.*, 1992). The selected plants were cut at the base of the stem. All the leaves were stripped

off and the total leaf area was determined. Excavation of the roots was carried out on a rectangular area of 1.21 x 0.76 m centred on the stump of the cut plant. The area of excavation on the soil surface was equivalent to the plant spacing.

Dry matter partitioning

Between May 1992 and April 1994, DM partitioning was determined from the seven whole-plant harvests from the observation plots at each site. The same plants used for DM production were used in the analysis of partitioning.

An initial harvest on representative plants from the nursery was done in June 1991 before planting them out in the field. The first harvest after out-planting was during May 1992 when the plants were just over 10 months old. At each harvest, the sampled plants were separated into leaves, tender stems, woody stems, and coarse and fine roots. On a tea bush, tender stems (or branches) are usually those parts of branches that are still green, while woody stems are the hard, fibrous part of the stem or branches. Fine roots were taken as those with diameter < 1 mm, while coarse roots were those with diameters > 1 mm. These definitions of harvested parts closely follow those developed by Magambo and Cannell (1981) and Burgess (1992) in order to allow direct comparisons with their results in Kenya and southern Tanzania respectively.

RESULTS

Ground cover

At sites 1 and 4, the GC increased from a mean of 5% in July 1992 to 15% and 22% respectively by early September 1992. By April 1994, the mean GC had risen to 75% and 90% at sites 1 and 4 respectively. Clone TN14-3 had the greatest GC at three sites, while clones 6/8 and S15/10 had the least.

Over the period May 1992 to December 1993 there was a linear relationship between GC at each site and mean air temperature. Soil conditions at site 3 limited the potential growth and development of the tea (Ng'etich *et al.*, 1995a). Excluding this site from the analysis improved the regression fit ($r^2 = 99.9\%$), with a mean rate of change in GC with temperature of $3\% \text{ }^\circ\text{C}^{-1}$ (*s.e.* $0.04\% \text{ }^\circ\text{C}^{-1}$; $n = 3$) over the period considered. Clone BB35 had the largest slope of $3.5\% \text{ }^\circ\text{C}^{-1}$ (*s.e.* $0.42\% \text{ }^\circ\text{C}^{-1}$; $r^2 = 97\%$) and S15/10 the smallest $2.0\% \text{ }^\circ\text{C}^{-1}$ (*s.e.* $0.29\% \text{ }^\circ\text{C}^{-1}$; $r^2 = 96\%$), though this was not quite significantly different from the other clones (Fig. 1).

LAIs were calculated from individual leaf area values and the GC measured during whole-plant harvests. Differences between clones were not significant. Clone S15/10 and BB35, however, had lower LAIs than both clones 6/8 and TN14-3 (Table 1).

Light interception

Using measurements of GC and LAI, the clonal light interception at each site was calculated for all the whole-plant harvests. Since solar radiation was only

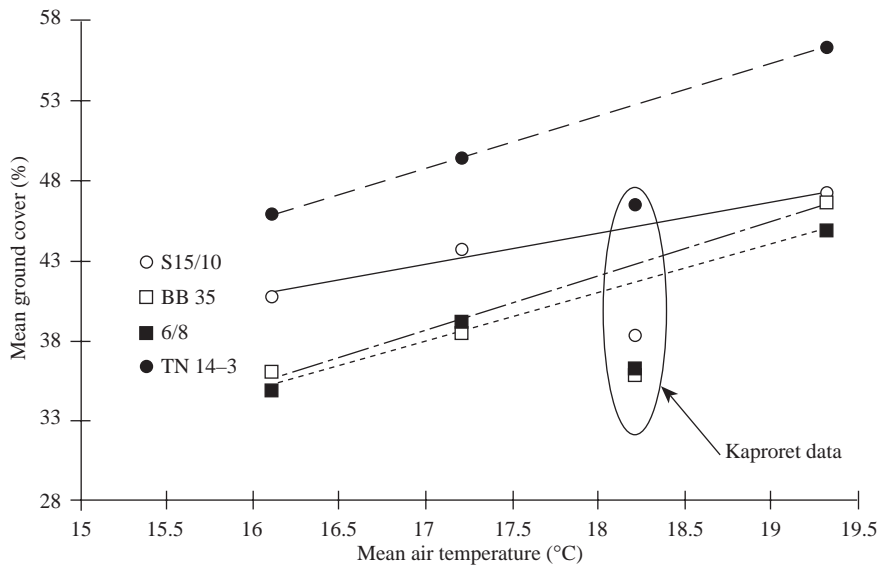


Fig. 1. Relationship between mean ground cover and air temperature at the four sites for each clone during the period May 1992 to April 1994.

Table 1. Mean green Leaf Area Indices (LAI) of clones S15/10 and TN14-3 at sites 1 and 4, during dry matter harvests.

Harvest date	Clone S15/10		Clone TN14-3	
	Site 1	Site 4	Site 1	Site 4
May 1992	2.2	2.5	2.4	2.5
August 1992	2.6	2.8	3.1	3.4
January 1993	3.0	3.1	3.8	4.3
April 1993	3.8	4.0	4.5	5.0
August 1993	4.5	4.3	5.2	5.4
December 1993	4.7	5.0	6.3	5.8
April 1994	5.2	5.4	6.1	5.8

measured at sites 1 and 4, light interception for sites 2 and 3 was calculated using incident solar radiation at sites 1 and 4 respectively. Sites 1 and 2 are only about 5 km apart, as are sites 4 and 3, and solar radiation was assumed to vary little over these distances. Though there could have been linear dependence of incident solar radiation with altitude (due to the cloud cover differences between sites) this could not be determined in this study.

Total dry matter production

In the 34 months to April 1994, clone TN14-3 produced the most DM at each site ($p \leq 0.001$) (Table 2). At site 4 all clones produced more ($p \leq 0.01$) DM than at

Table 2. Total dry matter (t ha^{-1}) for 34-month-old plants of four clones at four sites in Kericho, Kenya: April 1994.

Clone	S15/10	BB35	6/8	TN14-3	Mean	<i>s.e.</i> sites
Site 1	14.7	15.4	20.4	21.5	18.0	
Site 2	15.4	16.1	17.4	21.5	17.6	
Site 3	15.1	16.7	19.4	19.6	19.2	
Site 4	18.0	20.3	21.4	29.0	22.2	
Mean	15.8	17.1	19.7	22.9		
<i>s.e.</i>		0.47				0.47

s.e. interactions = 0.93; n = 4

the other sites. Clone S15/10 produced the least ($p \leq 0.05$) DM at all the sites. At site 4 there were differences between all the clones, while at site 3, clones 6/8 and TN14-3 were similar ($p \leq 0.05$). At both sites 2 and 1, clones S15/10 and BB35 were not significantly different ($p \leq 0.05$).

The total DM increased from a mean of 4 g per plant (0.044 t ha^{-1}) at planting to a mean of 0.48 t ha^{-1} in May 1992. By April 1994, the mean total plant DM had reached 18 t ha^{-1} at site 1 and 22 t ha^{-1} at site 4.

Overall responses of total dry matter (TDM) to mean air temperature (T) during the period of observation were linear:

$$\text{TDM} = 0.485T + 8.24, r^2 = 78\% \quad (3)$$

While there were no significant responses of clones TN14-3 and 6/8, clones S15/10 and BB35 were highly responsive to temperature, with slopes of 1.06 and $1.59 \text{ t ha}^{-1} \text{ }^\circ\text{C}^{-1}$ respectively.

Rate of dry matter production

In clone S15/10 the rate of DM production rose, from $0.5 \text{ g m}^{-2} \text{ d}^{-1}$ in May 1992 during the cool and wet season to reach a maximum of $3.5 \text{ g m}^{-2} \text{ d}^{-1}$ during the period August to December 1993 (Fig. 2), as the plants grew and intercepted more radiation. By comparison, the rate in clone TN14-3 rose from $0.6 \text{ g m}^{-2} \text{ d}^{-1}$ to $5.5 \text{ g m}^{-2} \text{ d}^{-1}$ during the same period.

The growth rate of all clones was greater at site 4 than at the other sites. The rate of DM production generally was lower during periods of drought, with the largest reduction occurring during the period December 1993 to April 1994 when there was a 58% drop in the rate of DM production at site 4. By contrast the rate increased by 4% at site 1.

During the period January to April 1994, the rate of DM production at site 1 was the largest ($3.8 \text{ g m}^{-2} \text{ d}^{-1}$), while the lowest rate ($2.3 \text{ g m}^{-2} \text{ d}^{-1}$) was at site 2. The mean rate during this period ($3.0 \text{ g m}^{-2} \text{ d}^{-1}$) was lower than for the period August to December 1993 ($4.8 \text{ g m}^{-2} \text{ d}^{-1}$).

Response to air temperature seemed to have been influenced by other factors. The largest slope of response was shown in harvests immediately after a cool wet

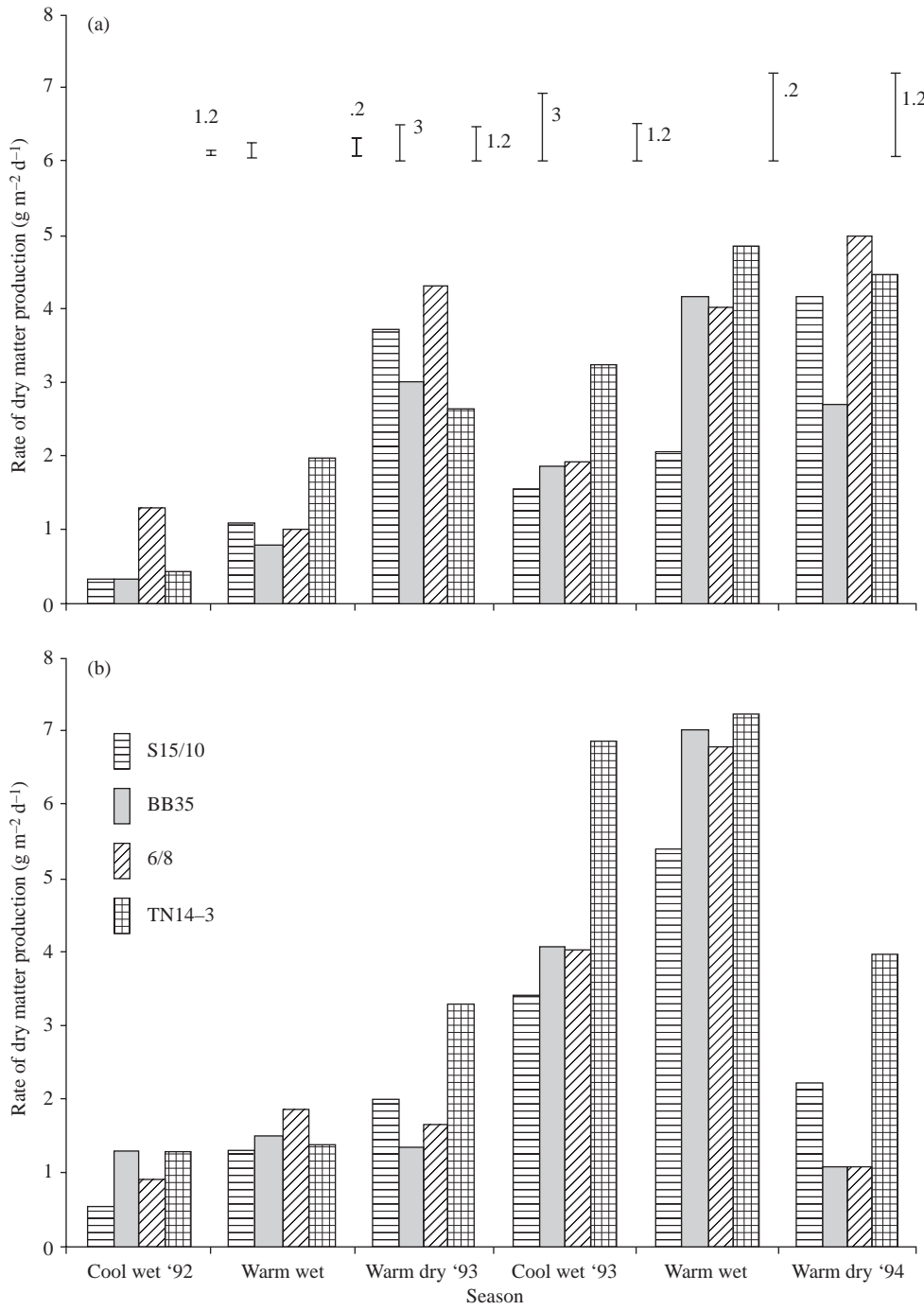


Fig. 2. Variation in rates of dry matter production of four tea clones at a) site 1 and b) site 4. The bars are s.e.d. between: 1 = sites; 2 = clones; 3 = clone x site interactions.

Table 3. Differences in partial slopes of relationships between mean air temperature, time since planting and rate of dry matter production at four sites. Figures in parentheses are *s.e.* of the coefficients: n=24.

Clone	Temperature	Time	Intercept	r^2
	($\text{g m}^{-2} \text{d}^{-1} \text{ } ^\circ\text{C}^{-1}$)	($\text{g m}^{-2} \text{d}^{-1} \text{ a}^{-1}$)	($\text{g m}^{-2} \text{d}^{-1}$)	
S15/10	-0.014 (0.224)	2.044 (0.438)	-1.35 (3.71)	43.5
BB35	0.138 (0.202)	1.606 (0.402)	-3.25 (3.35)	45.4
6/8	0.063 (0.213)	2.008 (0.402)	-2.35 (3.54)	52.4
TN14-3	-0.140 (0.324)	2.446 (0.402)	0.33 (5.38)	38.7

period (August 1992 and 1993), while the least was after the warm dry and warm wet seasons. There were clonal differences in these responses, clone BB35 having the greatest and 6/8 the least (Table 3). During periods of drought, the responses of clones TN14-3 and 6/8 to temperature were not significant.

Radiation use efficiency

The seasonal changes in RUEs are shown in Fig. 3. These varied from a minimum of 0.1 g MJ^{-1} to a maximum of 0.56 g MJ^{-1} during the period May 1992 to April 1994. The smallest recorded RUEs occurred during January to April in 1993 and 1994. During these periods, ϵ_s was less at site 4 than at site 1 (Fig. 3). There were clonal differences in the values of ϵ_s though most of these were not significant. Clones TN14-3 and 6/8 nearly always had greater RUEs than BB35. These rankings appeared to change at site 4, where the RUE for clone BB35 was more than for the other clones when available water depletion was below 45% (Fig. 3).

On the other hand, ϵ_s was not always greatest at the warmer sites particularly during the dry seasons. Clonal differences were at their minimum during the cool wet or warm wet seasons and maximum during the warm dry season, though linear relationships with mean air temperature were not significant. The drop in ϵ_s during dry periods was more pronounced during the December 1993 to April 1994 period when the soil water deficits were greatest (Ng'etich *et al.*, 1995b).

Mean values of ϵ_s during the period May 1992 to April 1994 were not significantly different between the clones or sites, though they were lowest at site 3 (0.31 g MJ^{-1}). The greatest value was 0.45 g MJ^{-1} for clone BB35 at site 2. Mean RUEs at each site, excluding site 3, were similar (0.39, 0.41 and 0.4 at sites 1, 2 and 4 respectively).

Dry matter partitioning

Harvested shoots. The rate at which DM was partitioned to shoots differed significantly between clones ($p \leq 0.05$) and between locations ($p \leq 0.01$), while there were also significant interactions during some of the harvests. The mean values ranged from $0.03 \text{ g m}^{-2} \text{ d}^{-1}$ for clones TN14-3 and 6/8 to $0.05 \text{ g m}^{-2} \text{ d}^{-1}$ for clone S15/10 during the initial harvest in May 1992. By August 1993, the

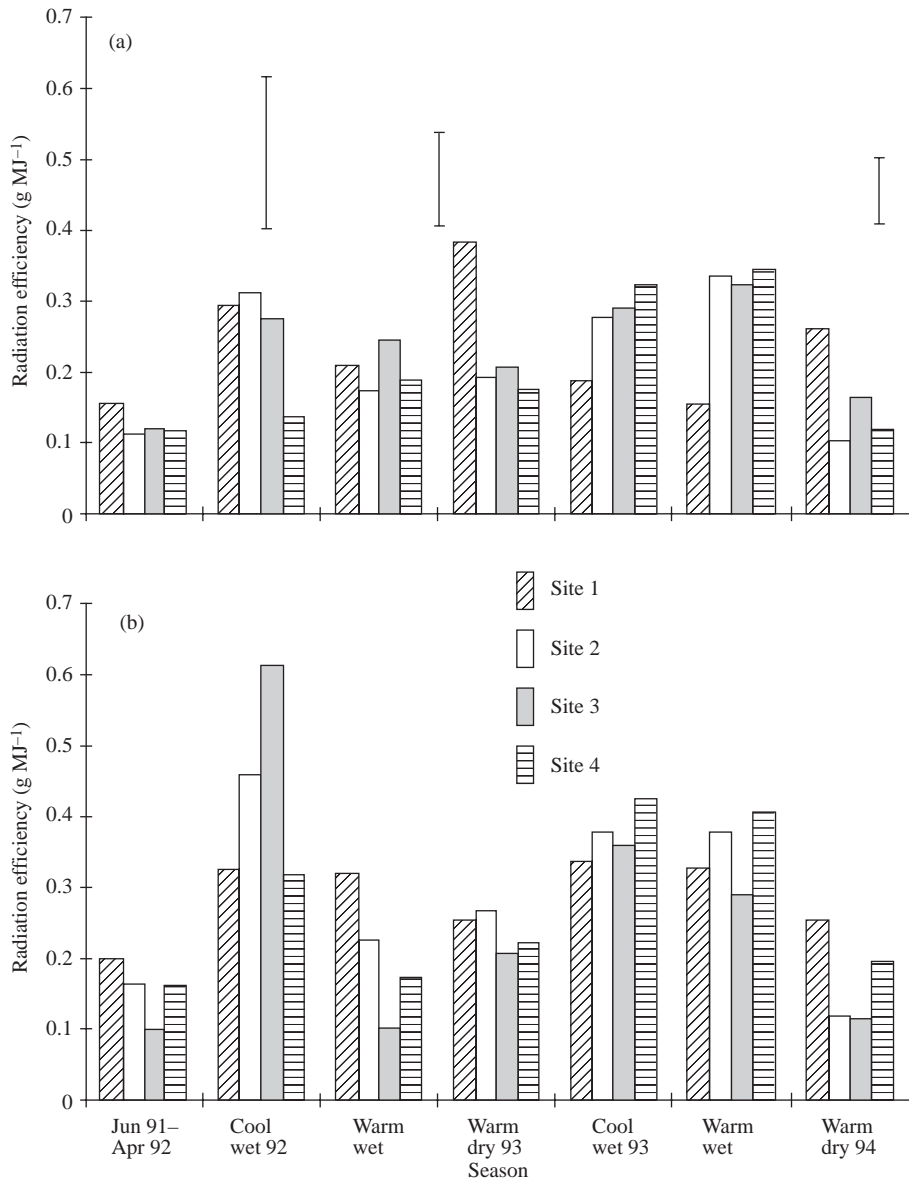


Fig. 3. Changes in radiation use efficiency of a) S15/10 and b) TN14-3 at four sites in Kericho, Kenya. The bars are s.e.d. between sites.

partition to shoots had increased to 1.18 g m⁻² d⁻¹ for clone S15/10 at site 4. During August 1993, after a cool wet period, clone S15/10 partitioned more to leaves and shoots at all the locations ($p \leq 0.05$).

During the harvest in December 1993 after a period of warm weather, partitioning to shoots increased to 10% (clone TN14-3) and 16% (clone S15/10) of the total DM. The increase in HI during the period December 1993 to April

1994 was less than that of the previous period (August to December 1993) at all the locations. This difference was more marked at site 4 (59%) while it was the least at site 3 (43%). The drop at sites 2 and 1 were similar to that of site 3 (44 and 45% respectively).

Linear relationships between seasonal changes in HIs and mean air temperature were not significant for most of the seasons except for clone BB35 during the warm dry period January to April 1993. During this period, the HI of clone BB35 increased by 0.061 (*s.e.* 0.006) $^{\circ}\text{C}^{-1}$ ($r^2 = 99.8\%$).

The changes in ratios of harvested shoots to total DM with time on total DM are shown in Fig. 4. The increases appear to follow a logistic growth curve. Though the parameters for these curves were not characteristic of site, the time taken to reach the point of maximum increase in HI differed between sites (about 700 d at higher altitudes compared with 500 d at lower altitudes).

Partitioning to frame. Partitioning to tender stems accounted for less than 25% of the total biomass of the plant in most clones. There were differences between the locations in partition to tender stems, though the ranking varied with season. After a cool wet season in 1992 (April to August), the proportion of DM partitioned to tender stems was largest (22%) at site 3 ($p \leq 0.05$) and least at site 4. Clone BB35 had the highest proportion of tender stem while clone 6/8 had the lowest ($p \leq 0.05$). By contrast, in the 1993 warm dry season, partitioning to tender stems was greatest at site 1 ($p \leq 0.05$) and least at site 3. In this particular harvest, clone BB35 again had the most ($p \leq 0.05$) DM partitioned to tender stems. This, however, changed during the harvest in April 1994 when partitioning to tender stems was lower than during December 1993 in all the locations (Fig. 5).

Partitioning to wood during August 1992 and January and August 1993 was significantly higher in clone TN14-3 than in BB35 ($p \leq 0.05$) and was highest at site 4 ($p \leq 0.05$) during April 1993 while it was lowest at site 3 (Fig. 5).

Partitioning to roots. This accounted for 10 to 20% of clone S15/10 total DM, while it ranged from 15 to 32% for the other clones. There were also differences between the locations, site 4 having the largest proportion of DM partitioned to roots (up to 25%) while site 1 had the lowest (20%; Fig. 5).

Clone 6/8 partitioned most to coarse roots in all the locations ($p \leq 0.05$), while clone S15/10 partitioned the least. Only clone TN14-3 partitioned significantly more to fine roots than the other clones at all locations.

Seasonal changes in partitioning to roots were also evident. During the first field harvest in May 1992, clone 6/8 partitioned more to the roots than clones BB35 and S15/10 ($p \leq 0.05$), but was not significantly different from clone TN14-3. At this harvest partitioning to fine roots was greatest at site 1 (5%) and least at site 4 (3%; $p \leq 0.05$). In the subsequent harvests, however, the proportion of DM partitioned to fine roots was more at site 3 than at any other site.

During the warm dry periods (January to April 1993 and 1994) the proportion of DM partitioned to roots increased at each site, though clonal increases were

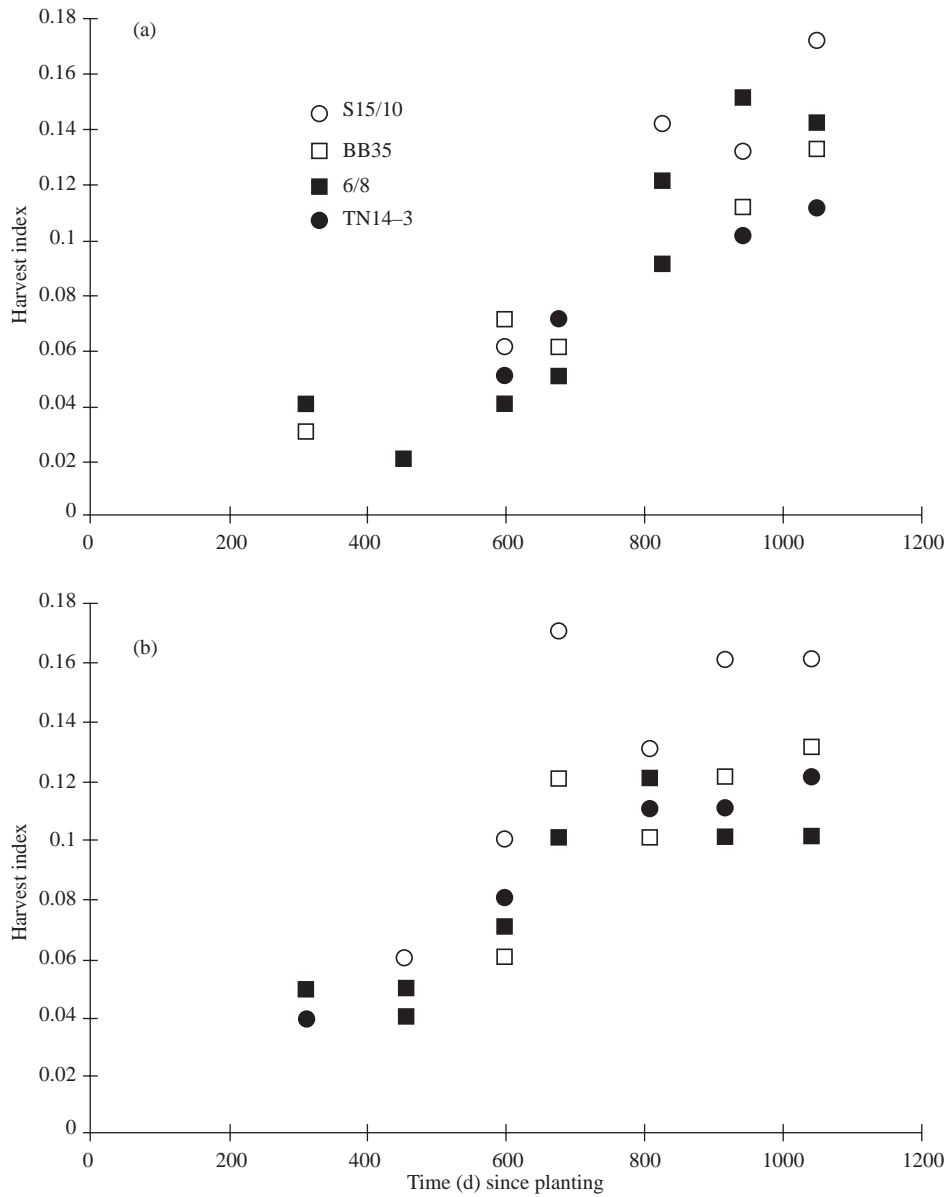


Fig. 4. Changes in harvest index of four tea clones with time, from May 1992 to April 1994 at a) site 1 and b) site 4 in Kericho, Kenya.

not consistent. The largest change was that of clone 6/8 at site 4 (45% increase) during the period January to April 1994, while partitioning to roots was least in clone S15/10 (less than 5% increase) at site 1.

Rooting depth

There were site variations in final root depth measured during the whole-plant

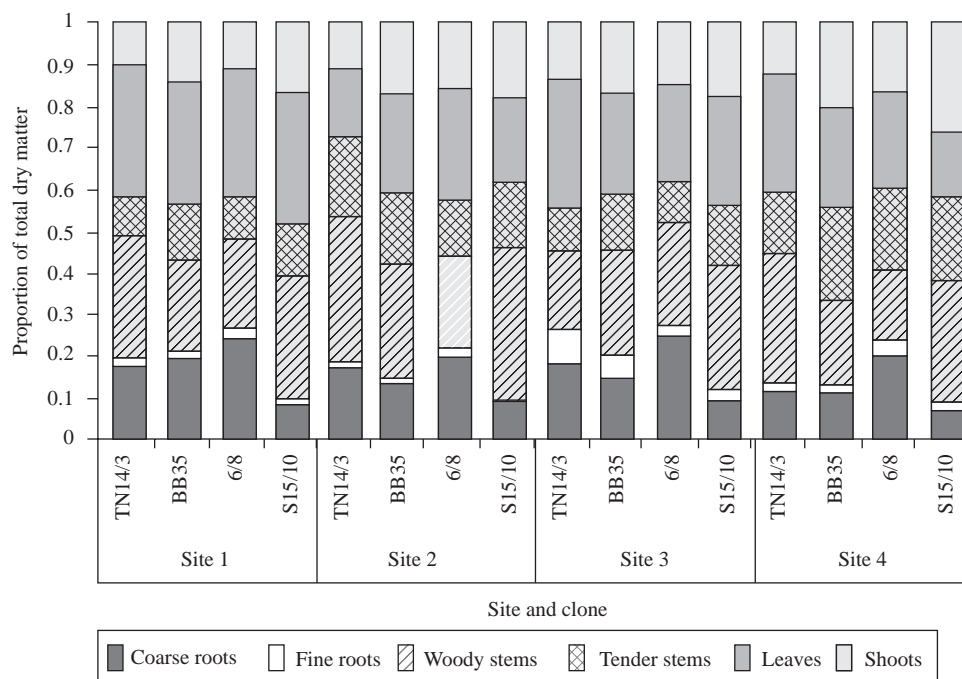


Fig. 5. Proportional partitioning of total dry matter of four clones at four sites during the period April 1993 to April 1994.

harvest in April 1994. Tea plants at site 4 had the deepest roots (1.4 m; $p \leq 0.01$), while those at site 3 were shallow. There were no significant differences in mean root depths between sites 3 and 1.

Clonal differences in root depths at the end of the experimental period were also significant (Fig. 6). Clone S15/10 had the shallowest roots at each site and both clones 6/8 and TN14-3 had the deepest ($p \leq 0.05$) except at site 3 where the roots of clone TN14-3 were shallower than clone 6/8 ($p \leq 0.05$).

The increase in root depth was modelled using an exponential equation of the form:

$$d_t = d_o \cdot e^{k_r t} \quad (4)$$

where d_t = the root depth at time t (d) since planting, d_o = the initial depth (m) and k_r = the relative root extension rate ($\text{m m}^{-1} \text{d}^{-1}$). This relationship was found to account for more than 90% of the variance in all the locations. The mean relative rate of downward root extension was greater at site 4 ($0.0017 \text{ m m}^{-1} \text{d}^{-1}$) than at all the other locations, while site 1 had the least (Table 4). Differences between clones were also significant. Clone TN14-3 at site 4 had the largest relative rate of downward extension ($0.00216 \text{ m m}^{-1} \text{d}^{-1}$), while the least was clone S15/10 at site 1 ($0.00135 \text{ m m}^{-1} \text{d}^{-1}$).

There were significant $G \times E$ interactions in maximum root depths recorded

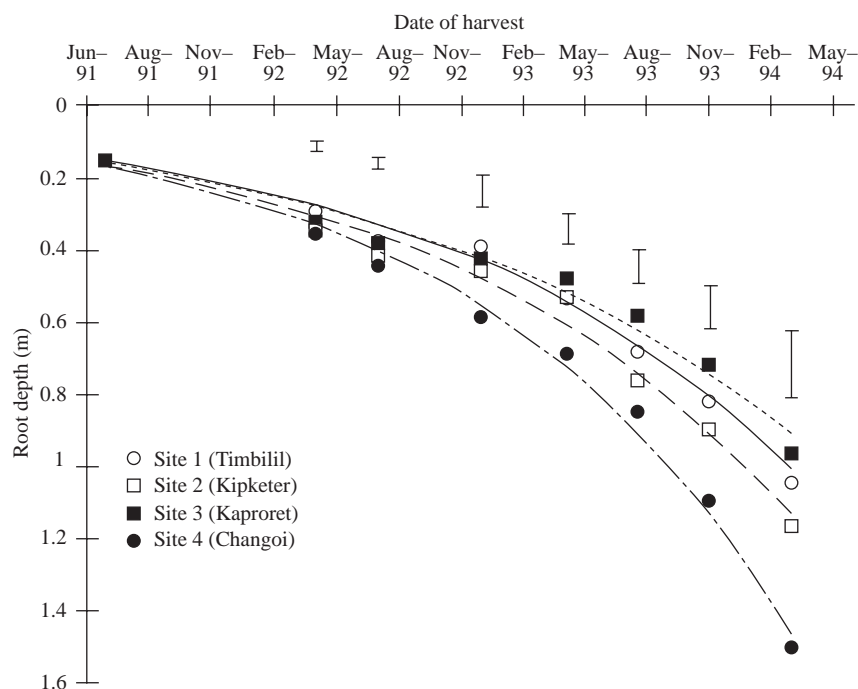


Fig. 6. Mean root depths during each total plant harvest at the four sites. The curves are fitted with an exponential equation (Eq. 4). Error bars indicate the s.e.d. between means for each dry matter harvest.

during the experimental period. These interactions were analysed in terms of response to mean air temperature (Fig. 7).

Clones TN14-3 and 6/8 had the greatest response to mean air temperature, though there were no significant differences between their slopes (0.163, *s.e.* 0.013, and 0.169, *s.e.* 0.0266, $m\ ^\circ C^{-1}$ respectively; $n = 3$). Clone S15/10 had the least response to temperature with a slope of 0.112, *s.e.* 0.0201, ($r^2 = 97\%$), while BB35 had a slope mid-way between these two extremes. Only the slope of TN14-3 was significantly different ($p \leq 0.05$) from zero.

Table 4. Changes in the relative root extension rates with mean air temperatures between May 1992 and April 1994.

	Site 1	Site 2	Site 3	Site 4
Mean air temp ($^\circ C$)	16.1	17.2	18.1	19.3
Mean k_r ($m\ m^{-1}d^{-1}$)	0.00148	0.00153	0.00133	0.00170
<i>s.e.</i> of coefficient	8.02×10^{-5}	9.35×10^{-5}	8.97×10^{-5}	8.54×10^{-5}
Maximum SWD (mm)	91	95	116	134

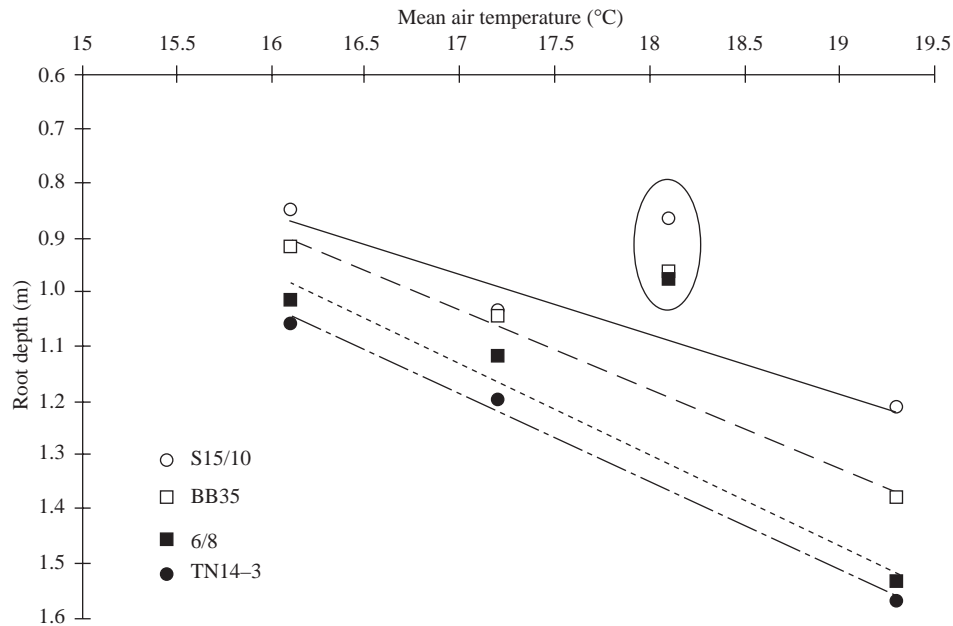


Fig. 7. Relationships between mean air temperatures and maximum root depths at April 1994 for four clones. The fitted linear regression lines exclude site 3 data (circled).

DISCUSSION

Rate of canopy development

The mean GC was greater at lower altitudes due to the higher temperatures during the cool wet season May to August 1992 and warm wet season September to November 1992. The slow increase in GC at higher altitudes (sites 1 and 2) was strongly correlated to effects of the lower temperatures experienced at these sites. Burgess (1992) reported slow development of GC during the cool season in Tanzania, when temperatures are known to restrict shoot extension (Stephens and Carr, 1990).

When site 3 was excluded, the relationship between mean ground cover and mean air temperature at each site was linear. This suggests that the rate of increase in GC could be influenced more by long-term effects of air temperature than short term ones experienced during seasonal changes. The slow development of GC at site 3 indicates the extent to which poor site conditions can restrict growth below the potential. In this case high pH (>5.6) and compact soils ($1.2\text{--}1.4 \times 10^3 \text{ kg m}^{-3}$) resulting from previous land use (Ng'etich *et al.*, 1995a) were both contributory factors.

Intercepted solar radiation

The greater intercepted radiation in Kericho than in southern Tanzania (Burgess, 1992) was due to the difference in incident solar radiation at these two

experimental areas. The clonal differences in intercepted radiation are attributable to GC and incident solar radiation, since extinction coefficients were similar. Slow development of GC at site 1 meant lower interception values, and hence lower DM production.

Dry matter production

The increases in rate of DM production with time were similar to those reported for clones S15/10, BB35 and 6/8 in Tanzania (Burgess, 1992). The seasonal changes in rates of DM production may have been due to environmental factors during these seasons. When the preceding period was a cool wet or warm wet season, the relationships between rate of DM production and mean air temperature were positive and linear. The rate of increase in DM production with temperature, however, varied with season and was greatest during the warm wet season. Inclusion of the age of the plants in the stepwise regression improved the fit considerably. This implies that though water stress reduced the rate of DM production (January to April 1994), these effects were masked by the increase in plant DM with time.

The changes in relative positions of sites 4 and 1 in rates of DM production during the warm dry periods (January to April 1993 and December to April 1994) may have been due to limiting soil moisture. Since water stress was not a treatment, direct relationships between rate of DM production from whole-plant harvests and soil water deficits could not be attempted in this study. The reduction in rates of DM production during the 1994 dry season reported in this experiment, however, are similar to those reported by Burgess (1992) for clones S15/10, BB35 and 6/8.

Radiation use efficiency

The values of RUE (ϵ_s) found in this study are higher than those reported by Magambo and Cannell (1981) in this same location but similar to those reported by Burgess (1992) in Tanzania. Though no effect of temperature could be determined in this study, the negative correlation with mean air temperatures during dry seasons implies greater control by water stress. Marshall *et al.* (1992) also reported that ϵ_s was not strongly affected by temperature in a stand of groundnut.

The low ϵ_s determined for the warm dry period in 1994 may have been due to a decrease in soil moisture that restricted growth even though solar radiation was not limiting. On the other hand, total incident solar radiation during this period was higher than in the previous period, which, if the tea bush canopies were already light-saturated, may have resulted in lower values of ϵ_s being calculated. The variations in RUE during periods of water stress could be related to changes in available soil water capacity as the depth increased.

Total dry matter production.

The total DM production at site 4 was comparable with that of similarly aged

plants of clones S15/10, BB35 and 6/8 in Tanzania (Burgess, 1992). The relationships between mean air temperature during the period June 1991 to April 1994 and total DM production at each site were linear (though not significant, $r^2 = 77\%$). The lack of a significant relationship with air temperature could have been due to effects of soil water stress during the dry season. The low soil temperatures recorded at site 1 (Ng'etich *et al.*, 1995b) could have been a limitation to total plant DM mass, while the larger values of DM recorded at site 4 may have due to more intercepted radiation causing a positive feedback.

Dry matter partitioning

Harvest index. The values of HI reported in this study were found to range from 9 to 19%. Burgess (1992) reported similar results from young tea plants in Tanzania. The findings in this study are in sharp contrast to earlier reports from site 1 on mature 6/8 as having a HI of 8% (Magambo and Cannell, 1981). By contrast, in Tanzania HIs of up to 24% have been reported for irrigated clone 6/8 (Burgess, 1994). These results seem to suggest that the HI of tea will continue to rise with bush age and as harvesting techniques are improved. The differences in clonal increase in HI with time in this study partly confirm this assertion. Though the maximum point of HI may not have been reached by the close of this study, there are indications that the increase in HI is of a logistic form. Such analyses using logistic functions also indicate that maximum HI may be reached much earlier at lower altitudes than at higher altitudes. The yield of 11000 kg ha⁻¹ reported by Oyamo (1992) for 16-year-old S15/10 probably reflects this increasing HI and, assuming more than 95% light interception and a RUE of 0.4 g MJ⁻¹, gives an estimated HI of 37%.

The changes in partitioning between shoots and roots during the dry season are similar to other reports on tea (Othieno, 1982b; Burgess, 1992) and in other tree species (Linder and Rook, 1984).

Rooting depths

Variation in final root depths between locations was mainly due to differences in soil temperature and soil water deficits. The low temperatures recorded at site 1 may also have contributed to the differential increase in root depth between locations. Carr (1971) and Fordham (1972) reporting results from Tanzania and Malawi respectively, showed that root growth was greater in cool seasons. In the more even climate at Kericho, the linear response of root depths to mean air temperature was more dominant than any seasonal fluctuations in root growth. Interestingly, root growth appears to be less affected by temperature than shoot growth; clones S15/10, BB35 and TN14-3 all partitioned a greater proportion of DM to roots at higher altitudes.

Recent droughts in Kericho have had the greatest effects on 3- to 4-year-old clones. These clones tend to be high-yielding genotypes that partition more DM to shoot growth. This experiment has shown that, although root growth in the warmer areas is greater than at high altitudes, there is considerable genotypic

variation in the rate of development and the highest yielding clone, S15/10, had 30% less rooted volume than TN14-3 and 6/8. Since LAIs had reached 5.6 on average by three years after planting, the evaporative demand would be similar to that from mature tea that would commonly have 5–6 m deep roots (Cooper, 1979; Stephens and Carr, 1991) allowing the crop access to about five times as much water. The recent spate of droughts, together with the drive by estates to increase their yields by planting high yielding clones, suggests that there should be cause for concern if there are insufficient water resources to irrigate the young tea in dry periods.

Effects of soil conditions

The performance of all clones was relatively poor at site 3, which was identified as having poor soil conditions with high bulk densities and soil pH. At this site, solar radiation interception was almost 20% less than would have been predicted on the basis of temperature alone. Consequently, total DM production was lower than expected with the most noticeable effect on TN14-3, which had the most rapid canopy expansion and the largest DM production overall. This clone is used often on commercial estates as an infill in areas with high soil pH, but it produced about 30% less DM than at site 4.

The key factor leading to reduced growth was probably root development. At site 3, roots of all clones penetrated less deep than at any other site but had a larger proportion of fine roots, presumably with an attendant increase in fine root turnover. The plant-available water would have been lower and the plants, therefore, would have been under greater water stress. This example is interesting in that it highlights the importance of ensuring appropriate soil conditions before planting, even when the climate is favourable. The extent of such soil conditions in tea growing areas needs assessment so that remedial action can be taken if appropriate.

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