

Responses of composite tea to progressive drought

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ABSTRACT: An experiment was done on potted grafted tea under a polyethylene tent to quantify the effects of reducing soil moisture content on key physiological factors affecting diurnal and physiological responses of grafted tea clones subjected to varying water levels. The reduced soil moisture content reduced the leaf water potential in all the clones. The diurnal differences in leaf water potential were more pronounced at the 12.5% v/v soil moisture content. Generally, the mean leaf water potential increased with a decline in soil moisture content. Based on this study, the minimum moisture level below which composite tea plants might suffer water stress is below 30% v/v, and the exposure period should be short. Rootstocks identified as being potential for commercialisation are TRFK 57/15, TRFK 8/112, TRFCA SFS 150 and EPK TN 14-3. Among the scions, AHP S15/10 was found to be more susceptible to water stress. Relative water content declined with decrease in soil moisture content ($R^2 = 0.9915$, $P < 0.001$) in all the scions. The total chlorophyll content varied between clones and decreased significantly ($P < 0.05$) with increase in soil moisture content. Rootstocks did not affect the chlorophyll content. Based on the studied parameters of leaf water potentials, relative water content and chlorophyll contents, the rootstocks identified for potential commercialization were TRFK 57/15, TRFK 8/112, TRFCA SFS 150 and EPK TN 14-3.

KEYWORDS: *Camellia sinensis*, Progressive drought, rootstocks, scions, soil moisture content

Introduction

Tea growth and productivity is mainly controlled by water availability, which is a primary factor that controls plant growth processes (Hsiao, 1973; Kramer and Kozlowski, 1979). The physiological and morphological adjustment that takes place in a plant during a water deficit situation can have either short or long term responses. These responses and their influences affect general field performances, and are either genetically or environmentally controlled (Jones, 1980). Plants adapt to drought by improving their water uptake, reducing water loss or by maintaining large internal storage of water (Larcher, 1983).

Adaptations are heritable changes in plants that help them survive in their environments. These heritable changes impose limits in environments, and together with other factors including; precipitation, soil water storage, temperature and others that affect transpiration and other processes influence physiological processes (Kramer, 1980). Physiological processes include plant water tolerance, water absorption, stomatal opening, cell enlargement, photosynthesis, carbohydrate and nitrogen metabolism, and they significantly influence plant partitioning and economic yield.

Drought tolerance refers to all the mechanisms that maintain the plant survival or productivity during drought and a number of adaptations that have developed

in plants confer selective advantage to survival for example; avoidance of plant water deficits, and tolerance of plant water deficits and efficiency mechanisms (Jones, 1992). Two types of water use behaviour, eg prodigal use where the plant is not in serious danger of desiccation despite fast water use (Passioura, 1982) is common where the water supply is interrupted by short dry spell. High stomatal conductance that decreases instantaneous water use efficiency is typical of this prodigal behaviour.

Many woody plant species respond to water deficits by changing their assimilate partitioning in favour of expansive root system that involve in water uptake, transport and by an increase in water use efficiency (Li *et al.*, 2000; Zhang *et al.*, 1996).

In Kenya, tea is generally grown as a rain fed perennial crop, at altitudes ranging from 1500 to 2700 m amsl. It requires a minimum annual rainfall of 1200mm although amounts ranging from 2500 – 3000mm are considered optimum (Callander and Woodhead, 1981; Carr, 1972). Average rainfall in Kenya in most tea growing areas is about 1000mm/year. However, the distribution is bi-modal with long rains falling within March - May, and short in October - November. Consequently, some tea growing areas experience drought periods of 2 - 3 months annually, and during this period tea yields are reduced. The existence of high transpiration rates from tea canopies cause significant soil water deficits, which decrease leaf expansion rates (Stephen and Carr, 1993; Squire, 1990). Sometimes when the soil is wet, excess transpiration at midday could cause transient water deficits within the plant (Smith *et al.*, 1994).

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Soil moisture regimes negatively affect physiological responses through decreased chlorophyll content and stomatal limitation leading to reduce photosynthetic capacity. Drought stress in tea minimally affects photosynthesis than in other crops by 13% (Smith *et al.*, 1993), although Squire (1977) reported a value of 30% in a dry season, compared to a wet season. Damages to photosynthetic apparatus may impose additional non-stomatal limitation to photosynthesis under water deficit (Souza *et al.*, 2004).

Through quantifying the effects of soil water deficits on key physiological factors affecting growth and development, we attempt to predict the performance of clonal teas in the tea growing environments, which are often characterized by a long dry season and short drought spells. Studies on water relations and responses of plants to drought are becoming important because the frequency of water deficits are expected to increase in future due to global environmental changes (Chaves *et al.*, 2003). This study was conducted to determine diurnal physiological behaviour of tea on the basis of water relations, to compare and understand the physiological behaviour and survival of *Camellia sinensis* composites under semi-controlled conditions.

Materials and Methods

Plant material and experimental site

The study was conducted on two year old composite tea plants containing scion clones TRFK303/577, TRFK31/8; TRFK6/8 and AHPS15/10 grafted on rootstocks; TRFCA SFS150; EPK TN14-3; TRFK8/112; TRFK57/15. The composites were developed, grafted and allowed to undergo a nursery period of 18 months and hardened before transplanting (Anonymous, 2002). The plants were potted in 4.8 litre (28 x 10 cm) polyethylene pots and placed in a rain out shelter constructed with poles. The roof was covered with an ultra violet treated 200-micron film clear polyethylene sheet (Sunselector AD – IR 504) which transmits 82% of photosynthetically active radiation (PAR), 65% of diffused light and with 88% thermicity. The rain out shelter structure was oriented at East - West aspect. The plants received adequate watering as they acclimatized before treatment applications. The experimental site was located at TRFK; altitude 2178 m amsl, Latitude 0° 22' S, Longitude 35° 21' E.

Plant and soil water status

The plants were arranged in a complete randomized block design, with main plots being four soil moisture

contents of field capacity (FC) (75% FC; 50%FC; 25%FC and 12.5% FC equivalent to TDR values of 40%v/v, 30%v/v, 20%v/v, and 12.5%v/v) (+/- 2%) and subplots being four rootstocks; replicated three times. The plants were all irrigated to field capacity, and allowed to dry to respective soil moisture contents. Their respective soil moisture contents were maintained at their desired levels by adding water and soil moisture determined by use of a Time Domain Reflectometer (TDR) (TRIME-FM, Eijkelkamp, The Netherlands). Shoot water potential was measured by cutting shoots from each treatment (n=24) and measured three times a day; early morning, midday and late afternoon using a pressure chamber (PMS Instruments, Co., Corvallis, OR., USA).

Relative water content

Relative water content of fully developed young tea leaves was calculated from the same shoots (n=24):

$$\text{RWC (\%)} = (\text{FW} - \text{DW}) / (\text{SFW} - \text{DW}) * 100 \quad 1$$

where FW is fresh weight, DW is dry weight, and SFW is saturated fresh weight of leaves after re-hydrating samples for 24 hours (Turner, 1981).

Determination of chlorophyll and SPAD calibration

Determination of gas exchange parameters and comparison of the data obtained may provide mechanistic information regarding the causes of differences species in photosynthetic activity and growth rates. A possible source of interspecific variation in photosynthetic activity may be differences in the constitution of the photosynthetic apparatus, particularly chlorophyll content. It was therefore considered essential to relate water stress parameters to concurrent estimates of leaf greenness in the form of SPAD readings to establish the relationship between the variables in all the tested clones. SPAD values is a measure of absorbance of the leaf in the red and near infra-red regions. Using the two absorbances, the meter calculates a numerical SPAD value which is proportional to the amount of chlorophyll present in the leaf.

SPAD measurements are commonly made and a link between them and chlorophyll content is species dependent (Marquard and Tipton, 1987) and therefore specific calibration is necessary.

SPAD measurements

Chlorophyll content was determined non-destructively using N-tester (Hydro International, Hydro Agri Deutschland GmbH, Hanninghof 35, D-48249 Dulmen).

The third leaf was used to quantify SPAD values in each clone under the four water treatments as outlined by Wanyoko *et al.*, (2000). Determination was done once a day for two days. The measurements provide numerical values related to chlorophyll content (Lawson, *et al.*, 2001). Close linear correlation between SPAD values and extractable chlorophyll content has been reported for a wide range of plant species (Marquard and Tipton, 1987; Finnan, *et al.*, 1998).

SPAD calibration

In order to derive the estimates of chlorophyll content from SPAD values, it was necessary to construct a calibration curve. Leaves from 18 month old composite tea were sampled to represent a range of colour extending one mature leaf and an immature bud to three mature leaves and an immature bud. Three SPAD measurements were made from the selected leaves. The leaves were immediately sealed in labelled polyethylene bags and either stored in a refrigerator or analysed immediately.

Chlorophyll determination was done by spectrophotometric analysis following extraction in acetone (Lee-good, 1993). One gram fresh weight sub-sample from the sampled leaves were ground with a pestle using a mortar and pure quartz and 40ml of 80% acetone as the extraction solvent. The resulting suspension was diluted to 100ml using 80% acetone. Absorbance was read and recorded using a 10ml aliquot placed in a quartz cuvette using a digital grating spectrophotometer (Cecil CE: 393) set at 470nm, 653nm and 666nm using methanol as a blank.

Chlorophyll *a*, *b*, and total chlorophyll contents ($\mu\text{g g}^{-1}$ tissue) were determined using Taylors (1994) equations as follows:

$$\text{Chlorophyll } a = 15.65A_{666} - 7.34A_{653} \quad 2$$

$$\text{Chlorophyll } b = 27.05A_{653} - 11.21A_{666} \quad 3$$

$$\text{Total chlorophyll} = \text{Chlorophyll } a + \text{Chlorophyll } b \quad 4$$

Where A represents absorbance.

The values obtained were used to construct a calibration curve relating the SPAD values and their chlorophyll content. This calibration was used to convert SPAD values to the corresponding chlorophyll contents.

Data analysis

The recorded data were subjected to statistical analyses using an M-STAT-C package. In the text, the means are considered significant at $P < 0.05$. These means were separated using Least Significant Differences (LSD).

Results and Discussions

Shoot water potential

The results of the shoot water potential indicated that, it varied with varieties and the prevailing soil moisture contents. The reduced soil moisture content reduced the shoot water potential of all the plants (Figure 1). There were diurnal differences in different soil moisture regimes. Generally, the morning water potential values were more negative (lower) under low soil moisture levels than were in high moisture regimes. During periods of water stress, midday depression of leaf water potential occurred after the morning maximum (Correia *et al.*, 1995; Grelle *et al.*, 1999) and other factors such as radiation and vapour pressure deficit are the most important factors when soil water is not limiting.

Water availability is a primary factor that controls plant growth processes (Hsiao, 1973; Kramer and Kozłowski, 1979) and during drought, plants adapt by improving their water uptake, reducing water loss or by maintaining large internal storage of water (Larcher, 1983). The minimum values were observed at solar noon and the differences in values observed at this

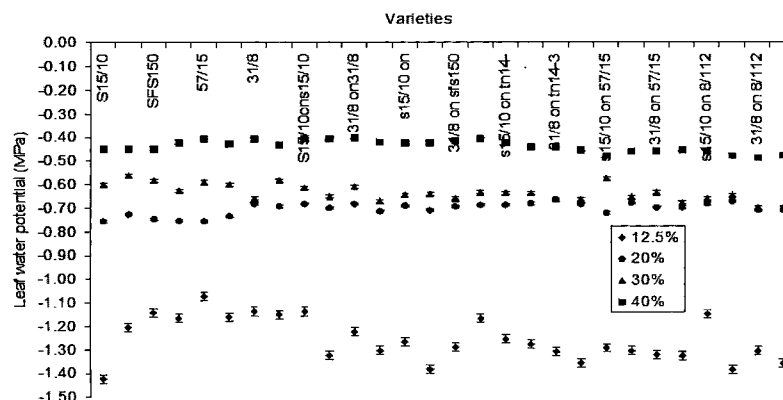


Fig. 1: Mean shoot water potential (MPa) of all composite tea grown under four different soil moisture content (%v/v) at Kericho. Vertical bars indicate standard error.

time between the water treatments were as high as 0.1 MPa and similar results were reported by Olufayo *et al.*, (1993). Moreshet *et al.*, (1996) observed that afternoon leaf water potential values were below those of morning, suggesting a lowering of the soil water potential near the roots. Similar results on instantaneous water-use efficiency showed that higher in drought stressed plants during the early morning and late evening while in the middle of the day water use efficiency values were similar to those of irrigated plants (Vadellet *et al.*, 1995). Due to morphological changes arising from acclimation to progressive drought, there were modifications of diurnal patterns suggesting they improved water-use efficiency, especially at periods with high humidity in the mornings.

Midday leaf water potential values presented large diurnal variations and low values independent of treatments. The low leaf water potentials in some composites during low soil water content suggest that this parameter may be related to the evaporative demand (Correia *et al.*, 1995). There were significant ($P < 0.05$) varietal differences in leaf water potentials in the low soil moisture regimes as compared to high soil water contents. AHPS15/10 was the worst affected by the low soil water content as it closed in towards the wilting point of -1.5

MPa, indicating that its survival is threatened under low soil water content (Figure 3).

There was a high significant relationship ($R^2 = 0.9619$, $P < 0.001$) between varietal soil moisture content and the reduced water potential indicating that reduced water content in the soil resulted in plants exerting more force to extract any available water. All the scions had similar low water potentials in the morning, increased in mid afternoon and later declined in late afternoon suggesting that severe drought effect is felt at midday. Lower leaf water potential (more negative), indicating a steeper water-potential gradient between the leaves and soil hence faster water-uptake on a daily basis. It is possible that diverse behaviour in diurnal leaf water potential among tea varieties was attributed to differences in stomatal conductance where some varieties maintain higher leaf water potential by keeping stomata less open than others (Tuomela, 1997).

The rootstocks, soil moisture and their interactions had significant ($P < 0.05$) diurnal leaf water potentials. There was an increase in leaf water potential with a decrease in soil moisture content. The high moisture content of 40% (v/v) had low values, followed by 30, 20 and 12.5% (v/v) with 0.439; 0.635; 0.701 and 1.315 MPa (Figure 2 a-d).

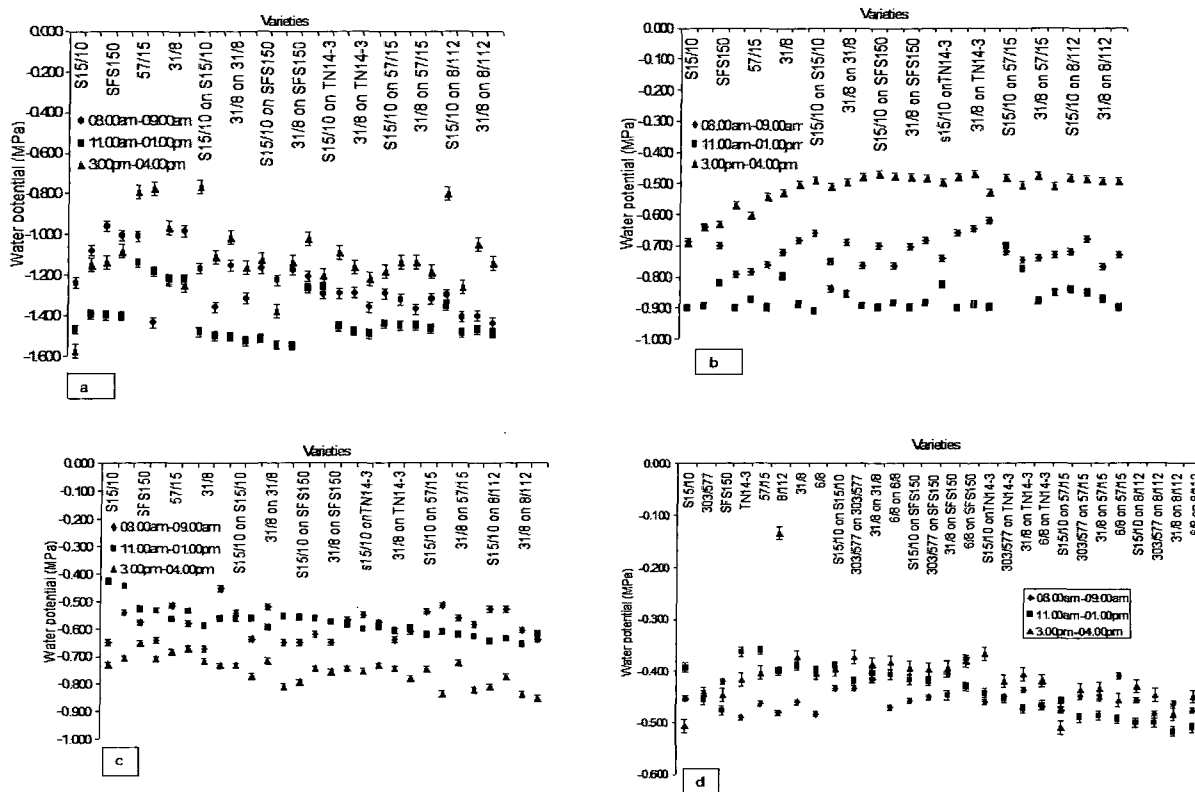


Fig. 2: Changes in composite tea leaf water potential (MPa) values in response to (a) 12.5% (v/v), (b) 20% (v/v), (c) 30% (v/v), and (d) 40% (v/v) soil moisture content. Vertical bars indicate standard error.

The materials had significantly low water potentials in the morning hours and increased by midday, and further reduced between 3.00 - 4.00pm to slightly lower values than the morning values (Figure 3). Diurnal changes in leaf water potentials begun at 11.00 hours and declined to lowest levels by 13.00 hours and again increased from 14.00 hours. The reductions in the leaf water potential declined much earlier from 14.00 hours regardless of the soil water content, suggesting that it was influenced by temperatures which were higher from around midday and persisted till 16.00 hours when it declined. The leaf water potential was lower throughout the day for well-watered plants. However, mid-morning and mid-afternoon values of leaf water potential were slightly lower for stressed plants (Eamus *et al.*, 1995). These values depended on the soil moisture level in the ascending order of 40% > 30% > 20% and 12.5%, respectively.

The rootstocks had significant differences of mean water potentials as shown in Table 1. Both own rootstocks and TRFCA SFS150 were similar but different

from TRFK 57/15 and 8/112, which were intermediate. The ungrafted clones had lower water potential, indicated that grafting selected scions improved water potentials. The lowest water potentials were achieved at high soil moisture levels with a mean of -0.439 MPa, while low water potential of -1.315 MPa closer to wilting point.

The mean water potential significantly ($R^2=0.99$, $P<0.001$) increased with a decline in soil moisture content suggesting that the composite tea plants that were subjected to low soil moisture levels below 20% v/v were likely to suffer moisture stress depending on the variety and duration of exposure. The results indicated that, the critical soil moisture content lied between 20 and 30% v/v for the tested clones.

Although all the rootstock had variable response on the scion clones, they were within the same range of water potential (0.755 - 0.7770 MPa). AHP S15/10 had an outstanding performance on all the rootstocks, followed by TRFK 6/8 (Table 2). Assessment of

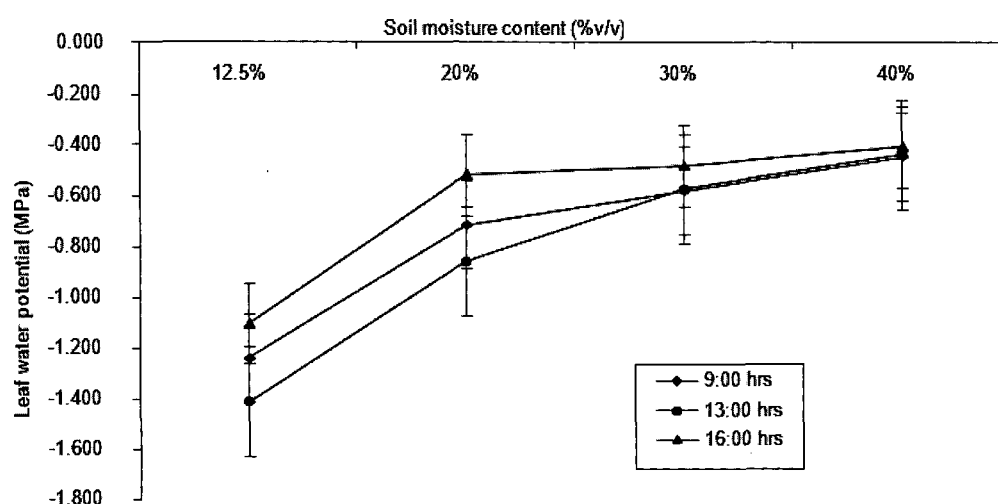


Fig. 3: Relationship between diurnal changes of mean water potential (MPa) and mean soil water content (%v/v) by composite tea plants at Tea Research Foundation, Kericho-Kenya. Vertical bars indicate standard error.

Table 1: Water potential (MPa) values of rootstocks subjected to varying soil moisture content (%v/v)

Soil moisture (%v/v)	Rootstocks						Mean
	Ungrafted	Own	SFS 150	TN 14-3	57/15	8/112	
40	0.434	0.49	0.417	0.439	0.462	0.475	0.439
30	0.572	0.636	0.645	0.650	0.634	0.675	0.635
20	0.761	0.695	0.695	0.679	0.698	0.694	0.704
12.5	1.434	1.247	1.275	1.298	1.309	1.328	1.315
Mean	0.8002	0.747	0.758	0.767	0.776	0.793	

CV (%) 2.15

LSD ($P<0.05$) Rootstocks 0.0137; Soil Moisture 0.0112; Interaction 0.0274

rootstocks potential to withstand water stress based on their own, the pooled soil moisture levels revealed that the order in terms of varietal performance was; TRFK 57/15>8/112>TRFCA SFS 150>EPK TN14-3 with values of 0.706, 0.730, 0.731 >0.743 MPa, respectively, while the scion varieties showed an ascending order of TRFK 6/8>31/8>303/577>AHP S15/10 (Table 3).

The grafted combinations with all scion across all soil moisture levels indicated the following order; own rootstocks>TRFCA SFS 150> EPK TN 14-3 > TRFK 57/15> TRFK8/112 with water potential values of 0.746, 0.758, 0.766, 0.7776, and 0.784 MPa, respectively (Table 4). Conclusively, other varietal attributes held constant, it would be prudent to plant clone TRFK57/15,

Table 2: Mean leaf water potential (MPa) values of scion clones grafted on rootstocks

Scions	Rootstocks						Mean
	Ungrafted	Own	SFS 150	TN 14-3	57/15	8/112	
S15/10	0.808	0.710	0.756	0.750	0.765	0.737	0.755
303/577	0.735	0.770	0.788	0.759	0.774	0.793	0.770
6/8	0.722	0.729	0.763	0.768	0.777	0.799	0.760
31/8	0.715	0.777	0.724	0.789	0.788	0.809	0.761
Mean	0.745	0.747	0.758	0.767	0.776	0.785	
CV (%) 2.25							

LSD (P<0.05) Rootstocks 0.0141; Clones0.0115; Interaction 0.028

Table 3: Changes of leaf water potential (MPa) values of rootstocks at different soil moisture (%v/v) contents during the day at different hours (a) 8.00-9.00am, (b) 11.00-01.00pm, and (c) 3.00-4.00pm)

Soil moisture (%v/v)	Rootstocks						Mean
	ungrafted	Own	SFS150	TN 14-3	57/15	8/112	
40	0.452	0.472	0.439	0.422	0.454	0.448	0.448
30	0.603	0.556	0.587	0.622	0.594	0.549	0.585
20	0.704	0.738	0.738	0.713	0.667	0.734	0.715
12.5	1.069	1.161	1.246	1.193	1.307	1.324	1.217
Mean	0.707	0.731	0.752	0.737	0.756	0.764	
CV (%) 3.88							

LSD (P ≤ 0.05) Rootstocks 0.024; Soil moisture 0.019; Interaction 0.047

40	0.423	0.388	0.405	0.429	0.459	0.483	0.431
30	0.483	0.561	0.568	0.569	0.598	0.620	0.566
20	0.878	0.864	0.852	0.890	0.877	0.800	0.860
12.5	1.414	1.188	1.503	1.468	1.419	1.451	1.407
Mean	0.799	0.750	0.832	0.839	0.838	0.839	
CV (%) 2.87							

LSD (P ≤ 0.05) Rootstocks 0.019; Soil moisture 0.016; Interaction 0.039

40	0.454	0.329	0.385	0.391	0.404	0.459	0.404
30	0.700	0.701	0.759	0.760	0.753	0.782	0.742
20	0.635	0.545	0.494	0.478	0.494	0.494	0.524
12.5	1.234	0.944	1.011	1.164	1.167	1.158	1.113
Mean	0.756	0.630	0.662	0.698	0.704	0.723	
CV (%) 6.97							

LSD (P ≤ 0.05) Rootstocks 0.040; Soil moisture 0.033; Interaction 0.080

Table 4: Changes of diurnal water potential (MPa) of scions grafted on different rootstocks determined at different hours of the day ((a) 8.00-9.00am, (b) 11.00-01.00pm, and (c) 3.00-4.00pm)

Scions	Rootstocks						Mean
	ungrafted	Own	SFS150	TN 14-3	57/15	8/112	
S 15/10	0.757	0.692	0.699	0.743	0.761	0.756	0.735
303/577	0.675	0.814	0.816	0.764	0.745	0.758	0.762
6/8	0.664	0.769	0.694	0.734	0.753	0.780	0.732
31/8	0.732	0.650	0.799	0.708	0.765	0.760	0.736
Mean	0.707	0.731	0.752	0.737	0.756	0.764	
CV (%) 2.06							
LSD (P=0.001) Rootstocks 0.022; Scions 0.018; Interaction 0.044							
S15/10	0.797	0.734	0.836	0.846	0.781	0.805	0.799
303/577	0.797	0.753	0.808	0.852	0.849	0.831	0.815
6/8	0.804	0.748	0.838	0.867	0.861	0.859	0.829
31/8	0.799	0.766	0.845	0.790	0.862	0.859	0.820
Mean	0.799	0.750	0.832	0.839	0.838	0.838	
CV (%) 3.00							
LSD (P< 0.05) Rootstocks 0.020; Scions 0.017; Interaction 0.040							
S15/10	0.876	0.620	0.596	0.695	0.705	0.730	0.704
303/577	0.735	0.530	0.691	0.748	0.680	0.729	0.686
6/8	0.717	0.647	0.654	0.691	0.695	0.692	0.683
31/8	0.694	0.722	0.708	0.657	0.737	0.743	0.710
Mean	0.756	0.630	0.662	0.698	0.704	0.723	
CV (%) 6.46							
LSD (P< 0.05) Rootstocks 0.037; Scions NS; Interaction 0.074							

TRFK8/112, TRFCASFS150 and EPKTN 14-3 as straight (ungrafted) clones. However, if other reasons are considered, then, own rootstocks, followed by TRF-CASFS 150, EPKTN 14-3 and TRFK57/15 were better alternatives.

Tea grafting could benefit tea plants if soil moisture content was not limiting. The influence of adequate water application in tea gave a response that was closely correlated with the stress severity (Romero *et al.*, 2004). Other related work also showed that as soil moisture deficit increased, the daily maximum stomatal conductance decreased and that, on a seasonal basis, stomatal conductance and daily transpiration were mainly related to predawn leaf water potential and thus to soil moisture content (David *et al.*, 1997)

The environment of plant origin is also critical in its relation to plant water relations and supports the view that their parental rootstock - scion characteristics are important and hinges on hybridization and selection criteria that may modify the performance of composite

plants (Zineet *et al.*, 1994). Differences between plants also influence water relations (Wilson and Clark, 1998). Leaf water potential was related to soil volumetric water content. Midday leaf water potential values presented very large diurnal variations and very low values independent of treatments. The low leaf water potentials observed for some composites during low soil water content suggested that this parameter may be related to the evaporative demand (Correia *et al.*, 1995).

Similarly, the differences in results reported herein was attributed to the genotypes constituting the composites for example; in addition to water stress avoidance due to deep root systems, some mechanisms of water stress tolerance may operate among tea varieties.

Diurnal variability's in water status parameters were large for some clones that regulated water loss conservatively with only limited reductions in leaf water potential in high or moderately low water contents but large decreases in low water contents.

Relative water content

The soil moisture contents had a significant ($P < 0.001$) effect on the relative water content whereby the rootstocks had mean relative water content (RWC) of 82%. The RWC reduced with reduction in the soil water content. The high soil water 40%v/v content had the highest RWC of 92.66% and the least being 12.5% v/v having RWC of 74.94% (Table 5). The scion varieties also had

similar RWC ranging from 82.04 - 82.48%. There were significant rootstocks and scion interactions.

The variety with the highest RWC was TRFK 6/8 on 57/15 and TRFK 6/8 on TRFCA SFS150 with RWC of 86.12% while the least was AHP S15/10 on TRFK 57/15 with RWC of 78.95% (Figure 4).

The RWC was highest for clone TRFK6/8 at soil moisture content of 12.5% and the least was AHP S15/10.

Table 5: Relative water contents (%) values of rootstocks subjected to different soil moisture (%v/v), and scions grafted on different rootstocks

Soil water content (%v/v)/Scions	Rootstocks						Means
	ungrafted	Own	SFS150	TN 14-3	57/15	8/112	
40	87.71	94.75	93.96	93.45	92.91	93.19	92.66
30	88.17	87.56	86.06	85.20	85.51	84.94	86.24
20	78.33	74.08	77.42	75.42	79.13	75.50	76.65
12.5	76.34	76.36	73.71	74.84	74.23	74.17	74.94
Means	82.64	83.19	82.79	82.23	82.94	81.95	

CV (%) 3.34

LSD ($P < 0.05$) Rootstocks NS; Soil Moisture 1.86; Interaction NS

S15/10	81.08	85.50	84.45	81.87	78.95	80.40	82.04
303/577	81.71	84.41	80.86	84.64	83.26	79.99	83.02
6/8	82.15	80.57	86.12	80.59	86.12	82.57	83.02
31/8	85.61	82.28	79.72	81.81	83.44	84.84	82.95
Mean	82.64	83.19	82.79	82.22	82.94	81.95	

CV (%) 2.77

LSD ($P < 0.05$) Rootstocks NS; Scions NS; Interaction 3.78

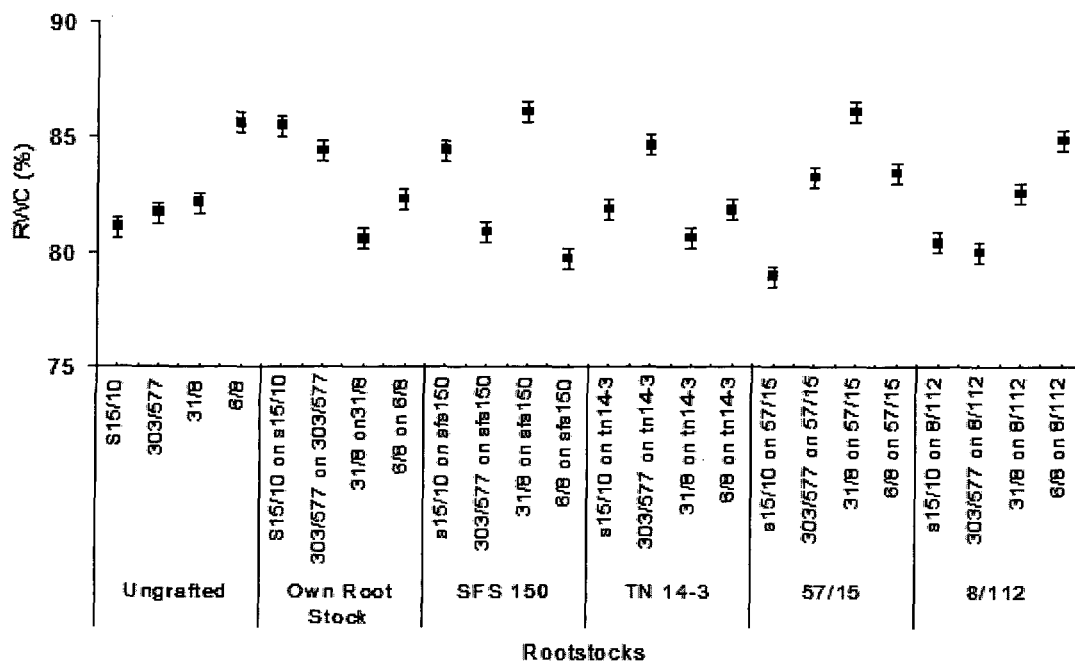


Fig. 4: Relative water content (%) of scion clones grafted to different rootstocks. Vertical bars indicate standard error.

Also, AHP S15/10 had the lowest RWC at soil moisture content of 40% (Figure 4). The mean RWC of all clones decreased linearly ($R^2=0.9915$, $P<0.001$) with decrease in the soil moisture contents. Varietal maintenance of higher RWC at a specific soil moisture contents suggests that they are resistant to desiccation and confers drought resistance. These results provide evidence that AHPS15/10 was more droughts susceptible than all the tested scion materials (Figure 5). However, grafting on most rootstocks except TRFK 57/15 improved their RWC.

Relationship between water potential and leaf relative water contents

The physiological response of the tea plant to water stress is important in that it allows identification of traits that form a basis of selection of varieties that are drought tolerant. Differences in drought tolerance between different plant species or between varieties of specie depend on the relationship between relative water content and low leaf water potentials (Jarvis and Jarvis, 1963). The results of RWC and water potential relationships (Figure 6) showed a general decline in both parameters with a decrease in soil moisture content.

Although the age of the leaf was not assessed for tolerance, visually, it was observed that the young tea leaves wilted earlier than the old leaves at various soils moisture levels (Sandanam *et al.*, 1981; Williams, 1971) probably because of their nearness to the water transport pathway. Both the RWC and leaf water potentials can effectively be used as composite tea plant water stress indicators.

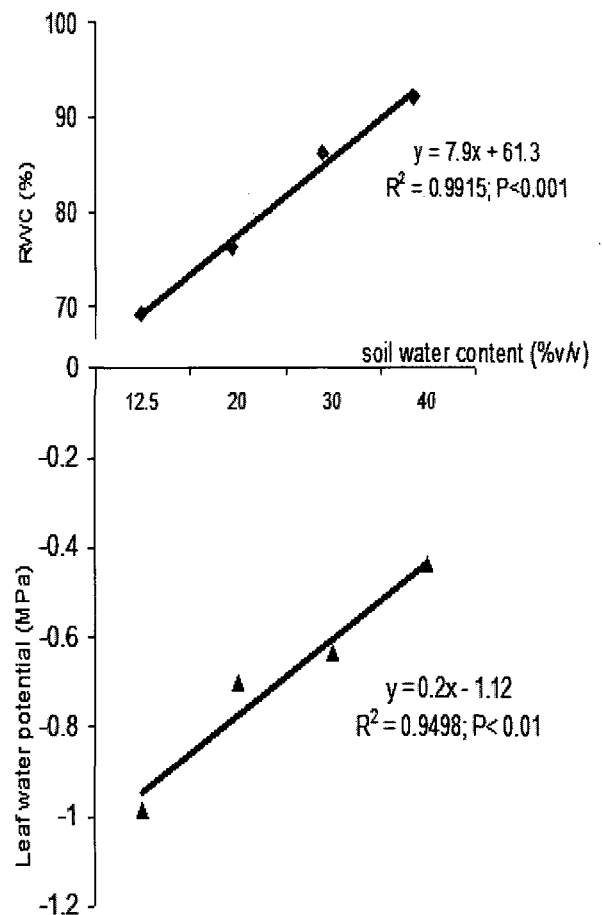


Fig. 6: Relationship between RWC (%) and leaf water potentials (MPa) under four different soil moisture contents (%).

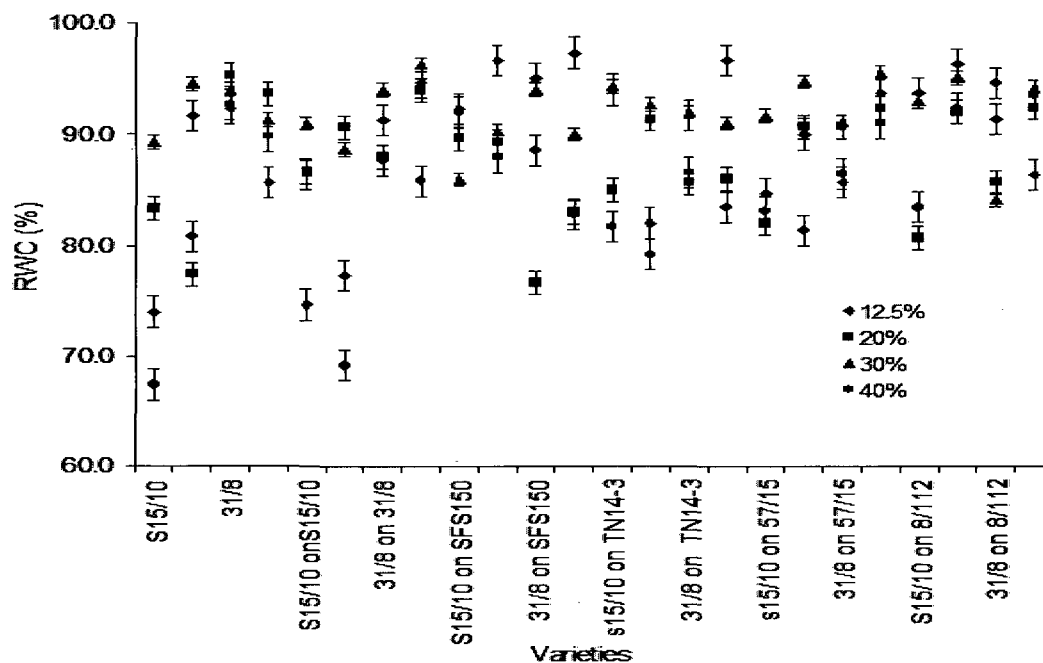


Fig. 5: Relative water content (%) of tea plants under four different soil moisture content (%v/v). vertical bars indicate standard error.

Chlorophyll

Drought induces several responses in plants including leaf senescence, which plays a major role in the survival of several species. Drought-induced leaf senescence contributes to nutrient remobilization during stress, thus allowing the youngest leaves, fruits or flowers to benefit from the nutrients accumulated during the life span of the leaf. The SPAD measurements were made for the leaves from the treatment plants and the values obtained were correlated with absolute values for chlorophyll contents for the same leaves. The results were analyzed to establish the best functional relationship; between the SPAD and the chlorophyll contents. There were similar polynomial and linear relationships for chlorophyll *a* with $R^2=0.511$ ($P<0.001$) whereas for chlorophyll *b*, and total chlorophyll contents only polynomial was slightly better than the linear relationship (Figure 7).

The concentration levels of chlorophyll *a* were found to be twice as much as chlorophyll *b* and the total

contents in all clones was ranging between 4 – 6 $\mu\text{g g}^{-1}$ of tissue although the concentration varied between varieties tested and decreased with increase in soil moisture content. The decrease could be attributed to high leaching of soil nitrogen, by the high soil water in high soil water treatments or reduced leaf area in low moisture treatments, leading to high concentration of chlorophylls in a small leaf area. Studies on yellow and green Scots pine (*Pinussylvestris*) needles confirmed recovery of green colour to an increase in chlorophyll *a* and *b* content (Sutinen *et al.*, 2000). The results obtained therefore showed that the yellowing of leaf colour of tea was an indication of a deeper state of photo-inhibition and slower deacclimation and was not directly related to desiccation stress. Leaf yellowing (i.e. chlorophyll degradation) and specific changes in cell ultrastructure (e.g. chromatin condensation, thylakoid swelling, plastoglobuli accumulation), metabolism (e.g. protein degradation, lipid peroxidation) and gene expression

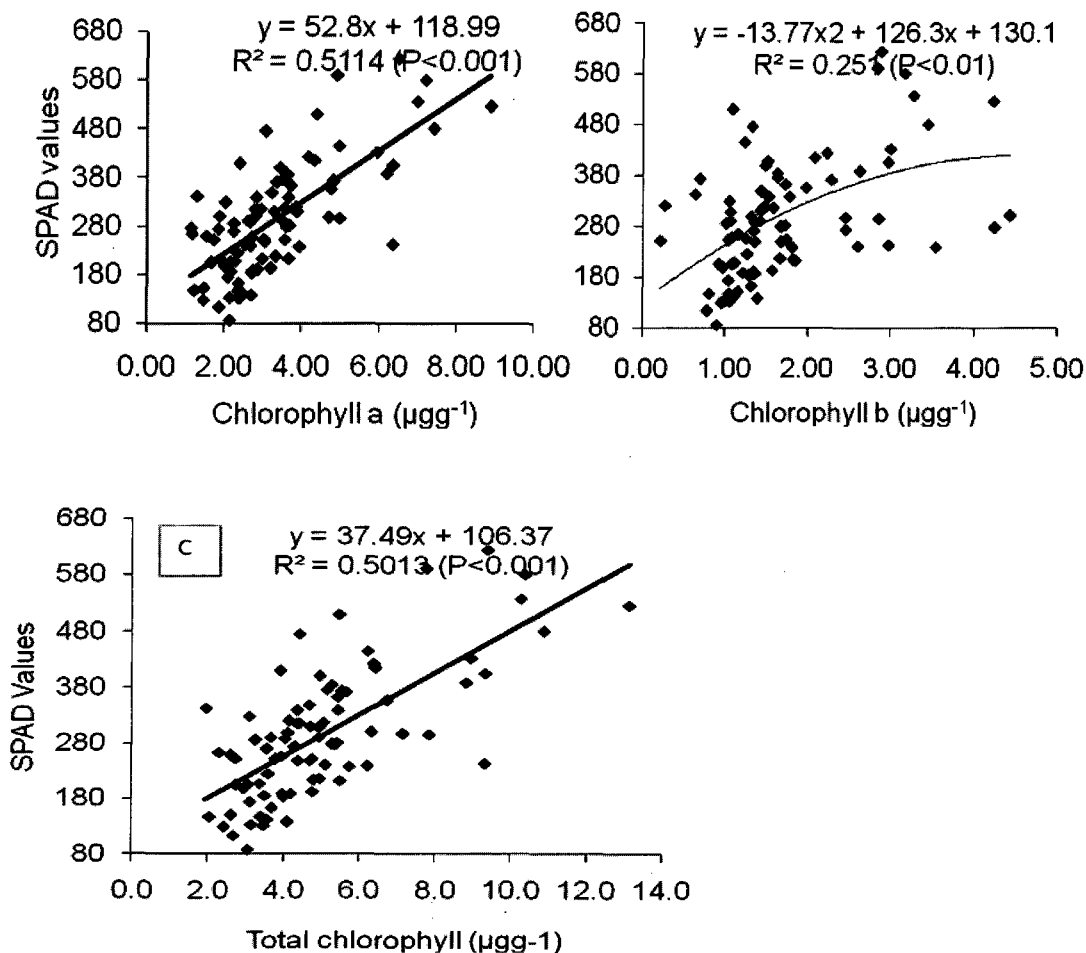


Fig. 7: Relationship between SPAD values and chlorophyll a (A), chlorophyll b (B) and total chlorophyll (C) contents for leaves of grafted tea scions and rootstocks under four different soil moisture levels (%v/v) at Tea Research Foundation, Kericho.

occur during leaf senescence in drought-stressed plants (Munne Bosch and Alegre, 2004).

Studies on soybean (*Glycine max*) plants under control conditions with increasing soil drying progressively retarded shoot and root growth (length and dry mass production), reduced RWC and decreased the contents of chlorophyll and lowered osmotic water potential of shoots and roots (osmotic adjustment) (Gadallah, 2000). Similarly, Munne Bosch and Alegre (2000) showed that Chlorophyll and carotenoid (particularly beta -carotene) levels decreased progressively with drought. In a low soil moisture regime, decreased chlorophyll content and stomatal limitation leads to reduced photosynthetic capacity (Li *et al.*; 2004). The decreased water content may lead to damages to photosynthetic apparatus thus imposing additional non-stomatal limitation to photosynthesis under water deficit (Souza *et al.*, 2004).

In order to determine the contribution of individual rootstocks and scions, results showed that all the rootstocks did not affect total chlorophyll contents but scions AHP S 15/10 had low chlorophyll contents, whereas TRFK 303/577 had high levels. Both soil moisture levels and clones had no significant interactions indicating that clonal differences did not contribute to significant chlorophylls. However, there were notable chlorophyll contents in ungrafted and SFS 150 at 40% and 30% soil moisture contents (Table 6). Both clones TRFK 303/577 and TRFK 6/8 naturally have lighter

colours, and this could have contributed to the high chlorophyll contents.

SPAD values and the corresponding total chlorophyll contents were higher in low soil moisture treatments confirm similar results reported for other crops like cotton (Pettigrew, 2004) and *Acacia saligna* (Nativet *et al.*, 1999). Water stress condition had 19% greater leaf chlorophyll content, which contributed to their higher CO₂ exchange rates during the morning and supports the results of high WUE (Bore, 2008). Drought stress results in chlorosis and it is concluded that water-stress caused by drought could affect development due to the effects on the chemical composition of the plant.

The results reported herein do not concur with those reported elsewhere as chlorophyll decreased with increase in soil water contents. The probable reason may have been due to the dilution effect of water in the pots, which could have leached nitrogen that is an important component of chlorophyll. Also, the reduced leaf area in low moisture contents could have lead to higher concentration of chloroplasts. Based on this, it evident that chlorophyll contents may be involved in regulating the tea response and productivity under water stress.

Conclusion

After having evaluated the plant water potentials, relative water content, chlorophyll contents of the grafted tea materials, the study concluded that the rootstocks

Table 6: Total chlorophyll contents ($\mu\text{g}\cdot\text{g}^{-1}$ of tissue) in rootstock tea clones and scions subjected to four varying levels of soil moisture stress (%v/v), at Tea Research Foundation, Kericho- Kenya

Soil moisture (%v/v)	Rootstocks						
	ungrafted	Own	SFS150	TN 14-3	57/15	8/112	Mean
40	9.78	12.84	12.77	12.66	12.00	12.00	12.34
30	14.71	12.58	9.73	12.02	12.31	12.02	12.23
20	13.14	17.51	15.70	16.85	16.10	14.95	15.70
12.5	16.47	17.48	16.79	17.27	15.83	15.03	16.47
Mean	13.51	15.11	13.75	14.71	14.31	13.75	
CV (%) 8.62							
LSD ($P \leq 0.05$) Rootstocks NS; Soil moisture 1.85; Interaction NS							
Scions							
S15/10	12.15	15.33	12.26	12.61	12.13	12.50	12.82
303/577	15.51	13.46	12.88	16.66	16.18	15.30	14.98
6/8	13.17	15.09	14.37	15.27	16.10	14.12	14.69
31/8	13.27	16.55	15.49	14.26	12.82	13.11	14.26
Mean	13.54	15.11	13.75	14.69	14.31	13.75	
CV (%) 12.50							
LSD ($P \leq 0.05$) Rootstocks NS; Scions 1.40; Interaction NS							

that are recommended for commercial exploitation are TRFK 57/15, TRFK 8/112, TRFCA SFS 150, and EPK TN 14-3. The scion material that was found to be drought susceptible was AHP S15/10. The results indicated that the ability of drought tolerance in tea strongly depend on clones, drought intensity and duration.

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