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EFFECTS OF GRAFTING ON TEA 2. DROUGHT TOLERANCE

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SUMMARY

The drought tolerance of tea clones in Kenya can be improved by grafting onto appropriate rootstocks, with more susceptible clones showing greater improvement. It appears that drought may have distinct effects on rootstock and scion, with rootstock performance correlated with xylem water potential, while scion performance was correlated with stomatal conductance. Drought tolerance is not the only requirement for a rootstock under Kenyan conditions, however, and the most tolerant rootstocks do not necessarily give the greatest overall yield increase when non-drought years are included.

INTRODUCTION

In a previous paper, we showed that yield of many Kenyan tea (*Camellia sinensis*) clones can be increased by grafting onto appropriate rootstocks (Tuwei *et al.*, 2008). In Malawi, where there is a regular and long dry season, the main benefit of grafting appears to be increased drought tolerance, and rootstock selection has specifically concentrated on this aspect (Harvey, 1988). In South India, Satyanarayana *et al.* (1991) obtained improved yields during dry periods from grafted plants. In the Kericho district of Kenya the dry season is very mild in many years, but in our trials we found benefits of grafting every year, whether or not there was a drought. In years when drought does occur, however, improved tolerance would be advantageous, and in this paper we examine the possible benefits of grafting in this respect.

Drought has many effects on plants, and drought tolerance can be defined in various ways. We have defined it in terms of the depression of yield caused by drought, but we have also recorded the visual symptoms caused by drought, and the ability of tea bushes to survive through drought periods.

MATERIALS AND METHODS

Single node cuttings were cleft-grafted in the nursery, as described by Kayange (1990). In large-scale commercial practice, this method has given over 90% success (J.F. Beakbane, personal communication, 1996). The trials were planted in the Kericho

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district of Kenya (approx. 0°30′S, 35°20′E); the sites are described below as 'low' and 'high' altitude, but all were above 1700 m asl.

Trials

Trials 1 and 2 were planted as split-plot designs, with scions as the main treatments, and rootstocks as sub-treatments. This design was adopted because the main interest was in rootstock effects and stock–scion interactions.

Trial 1 included six well-known Kenyan clones, AHP S15/10, BBK7, BBK35, BBK152, TRFK 31/8 and EPK TN14-3, in all combinations as both stock and scion, and also as ungrafted cuttings (but self-grafts were not included). The trial was repeated on two sites: the lower altitude site was at 1707 m asl, while the higher site was at 2105 m asl, with two replications at each site. Sub-plots consisted of 6 × 3 bushes, with a complete unrecorded guard row around each. The trials were planted in 1989, with 10 764 plants ha^{-1} in a rectangular planting pattern (122 × 76 cm).

Trial 2 included seven scions (BBK7, BBK35, BBK152, TRFK 6/8, TRFK 12/19, TRFK 31/8 and AHP SC12/28) on each of six rootstocks (BBT1, BBT207, EPK TN14-3, and three new selections: BBK China 1, BBK China 2 and BBK China 3), together with cuttings of the scions. The trial was duplicated on the same sites as for Trial 1, planted in 1990, with four replications of 3 × 4 bush sub-plots, each surrounded by an unrecorded guard row, at each site. The planting pattern was the same as for Trial 1.

Trial 3 was on a single site (1815 m asl), planted in 1998. There were 19 scions, mostly clones selected primarily for quality of the made tea, in all combinations with four rootstocks, and also planted as ungrafted rooted cuttings. The rootstocks were BBK China 3 and EPK TN14-3, and TRFCA MFS87 and TRFCA PC87 from Malawi (Ellis and Nyirenda, 1995). To facilitate comparison with other trials, three standard clones were also included; these were BBK MRTM1, AHP S15/10 and TRFK 31/8. A standard 'composite' (grafted plant) was also included: 31/8 grafted onto TN14-3; based on results of Trials 1 and 2, this has been planted on a commercial scale by Unilever Tea Kenya. The trial was in a randomized block design, with two replications; plots consisted of 12 bushes, without guard rows between plots, at a density of 13 248 bushes/ha.

Recording

The trials were plucked at 10–14-day intervals, with a target shoot standard of three leaves and a bud, and yield of green leaf was recorded immediately after harvest at every plucking round. Yield of black tea was estimated from green leaf yield using a standard conversion factor of 22.5%, derived from factory records. Data from Trial 3 were analysed in two ways: first, the 19 scion × 4 stock combinations were treated as a factorial design. For comparison with the standard clones, a second analysis was done, regarding each individual stock–scion combination as a separate treatment.

In most years there is a dry season in the Kericho district from December into the first quarter of the next year, and in some years this develops into a severe drought.

Table 1. Rainfall for years in which drought records were collected.

Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Mean 1982–2006	131	153	136	149	156	100	97	84	150	248	235	147
1991–1992	97	196	115	151	77	46	21	88	79	212	199	186
1996–1997	178	129	199	126	168	60	82	2	75	322	120	119
2005–2006	119	181	126	97	60	18	78	107	224	355	226	174

During such drought periods, individual plots were visually scored for severity of drought symptoms, on a scale of 1 (drought susceptible, severe yellowing of leaves and heavy defoliation) to 6 (drought tolerant, no visible symptoms). As an indicator of the effect of drought on yield, yields in the drought year were expressed as a percentage of the mean yield in the previous or subsequent year, provided that the dry seasons in those years were relatively mild; we have called this ratio the 'drought tolerance index' (DTI). In Trial 1, there were droughts in 1992 and 1997 (Table 1), and yields were compared to those in 1993 and 1996 respectively. Trial 2 also suffered from drought in 1997, and the same ratio was used. The 1997 drought was particularly severe, and many bushes died; the number of deaths per plot in Trials 1 and 2 was recorded after the drought was over. In Trial 3, there was a drought from October 2005 to January 2006 (Table 1). In this case, the ratio of mean monthly yield from October 2005 to December 2006 to that in the first 9 months of 2005 was used as a DTI.

In February and March 1993, during a period of negligible water stress, measurements of photosynthetic rate (A), stomatal conductance (g) and xylem water potential (Ψ) were made in Trial 1, using an infra-red gas analyser (Mk II; Analytical Developments Company, Hoddesdon, UK), a porometer (Δ-t Devices, Cambridge, UK) and an Arimad-2 pressure chamber supplied by ELE International. About 10 measurements of g and A, and 3–4 of Ψ per plot were made, between 9:00 and 14:00 hours over a 2-week period. The data considered here are the means of all measurements on every sub-plot of straight cuttings.

RESULTS

Yield

In Trial 1 in 1992 there was a drought at the higher site, and plots were scored for drought symptoms. In 1997, there was a drought throughout the Kericho district; on this occasion many bushes died, and the number of deaths per plot was recorded, in addition to symptom scoring (this was only done at the higher site, as by 1997 the lower trial had been closed). There were no significant stock × scion interactions for any of the variables recorded. The behaviour of clones grown as cuttings is considered first, followed by behaviour as scions and finally as rootstocks.

Table 2 shows that for the clones grown as cuttings, there were significant differences in drought symptom scores and DTIs in both 1992 and 1997 at the higher site. The standard error for the 1997 death counts was very large and differences were not significant, but death counts were negatively correlated with both sets of symptom

Table 2. Effects of drought in Trial 1 at high altitude site. Scores are symptom scores; deaths are number of bushes per 18-bush plot. DTI for 1992: yield 1992 as % yield 1993; DTI for 1997: yield 1997 as % yield 1996.

	As cuttings					As scion					As rootstock				
	1992		1997			1992		1997			1992		1997		
Clone	Score	DTI	Score	Deaths	DTI	Score	DTI	Score	Deaths	DTI	Score	DTI	Score	Deaths	DTI
S15/10	4.0	80.2	3.0	0	72.3	4.4	89.2	3.4	0.6	72.3	4.7	82.9	3.5	2.0	64.5
BBK152	1.0	70.8	1.5	3	54.4	3.5	84.3	2.1	3.5	63.5	2.5	87.8	3.3	0.6	64.4
31/8	5.5	91.2	3.5	0.5	75.7	4.4	90.7	2.9	0.4	65.9	5.3	88.2	3.4	0.3	75.1
BBK7	6.0	92.1	5.5	0	79.5	4.9	91.0	3.9	0.2	73.1	4.0	85.8	3.8	0.7	77.0
BBK35	2.5	76.2	4.5	0.5	75.4	3.4	76.9	4.3	0.2	81.8	3.5	87.0	2.4	1.5	60.5
TN14-3	6.0	87.7	3.5	0	76.0	5.0	86.3	3.3	0.3	67.0	5.6	86.6	3.5	0	82.3
Mean	4.2	83.0	3.6	0.7	72.2	4.3	86.4	3.3	0.9	70.6	4.3	86.4	3.3	0.8	70.6
s.e.	0.55	5.7	0.30	1.97	6.1	0.27	2.7	0.42	0.14	4.2	0.22	2.3	0.12	0.80	2.5

scores (1997: $r = -0.735$, $p = 0.096$; all correlations in Trial 1 with 4 *d.f.* unless stated otherwise).

The DTIs in 1992 were positively correlated with the symptom scores ($r = 0.971$, $p = 0.0013$); thus the clones with the most severe symptoms (low scores) also suffered the greatest yield decline. DTIs in 1992 were also correlated with those in 1997 ($r = 0.799$, $p = 0.057$). All the indicators were consistent in identifying BBK152 as the most drought susceptible clone, while BBK7 was probably the least susceptible.

There were significant differences between clones as scions for symptom score and death rate, and behaviour was similar to that of cuttings: there were strong correlations between cuttings and scions for 1992 drought scores ($r = 0.930$, $p = 0.007$), 1997 scores ($r = 0.869$, $p = 0.025$) and for 1997 deaths ($r = 0.958$, $p = 0.003$), and 1992 DTIs were also positively correlated ($r = 0.710$, $p = 0.11$). Mean death rates for scions in 1997 were significantly correlated with symptom scores ($r = -0.813$, $p = 0.049$), but scores in 1992 and 1997 were not correlated, nor were DTIs for scions in 1992 and 1997 correlated. In 1992 performance of grafted clone BBK152 was much improved compared to straight cuttings (higher score and DTI), indicating that using other clones as rootstocks had improved its drought tolerance. Despite this, however, in 1997 grafted BBK152 suffered the highest death rate, and had the lowest DTI and symptom score.

There were no differences among rootstocks for DTI in 1992, but there were significant differences for symptom score, and mean scores for stocks and scions were positively correlated ($r = 0.762$, $p = 0.08$). Again, BBK152 had the lowest score. However, in 1997 the scores for stocks were not correlated with those for scions ($r = 0.36$, $p = 0.48$); the rootstock with the lowest score in 1997 was BBK35, not BBK152. Differences in death rate were not significant, but the most affected clones were S15/10 and BBK35, rather than BBK152. Clones S15/10, BBK152 and BBK35 had lower DTI than the other clones.

At the lower site, effects of the 1992 drought were not very strong, and by 1997 recording in the trial had been stopped.

Table 3. Effects of drought in Trial 2, lower site.

	Drought tolerance index (yield 1997 as % yield 1996)								Deaths
Scion	6/8	BBK35	SC12/28	BBK152	31/8	12/19	BBK7	Mean	mean (%)
Cuttings	52.3	18.2	27.5	20.1	47.5	45.2	59.0	38.6	13.3
BBT 1	48.5	57.6	38.6	38.5	46.4	65.3	61.1	50.9	18.3
CH1	27.5	35.4	31.0	33.5	46.8	58.0	48.2	40.1	23.3
CH2	37.5	51.1	30.9	35.7	37.3	44.6	71.8	44.1	24.2
CH3	58.5	65.6	51.5	54.5	53.5	65.1	79.0	61.1	5.8
14/3	52.9	51.0	33.8	33.5	54.2	65.5	54.8	49.4	11.7
207	23.0	28.8	38.1	33.9	41.5	33.1	26.2	32.1	46.7
Mean (ex. cuttings)	41.3	48.3	37.3	38.3	46.6	55.3	56.9	46.3	20.4
Mean deaths (%)	30.0	20.0	31.7	24.2	16.7	9.2	10.8		
DTI *s.e.*		Scions: 2.4		Stocks: 2.5		Scion× stock: 6.6			

Trial 2 also suffered in the 1997 drought, particularly at the lower site where 20% of bushes died (Table 3). A DTI comparing yield in 1997 with that in 1996 showed significant differences among stocks and among scions at both sites, and a significant stock × scion interaction at the lower site. Based on performance as cuttings, clones BBK152 and 12/28 were drought susceptible at both sites, while BBK35 was equally affected at the lower site. Clone 12/28 suffered 42% deaths, while BBK7 had none. The mean DTIs for scions were positively correlated with those for cuttings at both sites, significantly so at the higher site ($r = 0.869$, 5 *d.f.*, $p = 0.011$).

The DTIs for rootstocks at the two sites were positively correlated ($r = 0.837$, 5 *d.f.*, $p = 0.019$), with China 3 the best at the lower site, followed by BBT1. The same two clones were the best at the higher site, but with the order reversed. At both sites BBT207 was the worst, giving lower DTIs than cuttings with most scions. Bushes on this rootstock suffered nearly 50% deaths at the lower site, compared to 6% on China 3. Grafting onto China 3 greatly improved the performance of the drought susceptible scions BBK35, SC12/28 and BBK152; Table 3 shows that at the lower site these composite plants had DTIs close to that of cuttings of the least susceptible clone, BBK7.

In Trial 3, yield in 2006 was severely depressed by a drought from October 2005 to January 2006. As in the previous trials, there was a significant correlation between the DTIs for cuttings and those for scions ($r = 0.705$, 17 *d.f.*, $p = 0.001$). Grafting improved DTI (Table 4) and drought scores (data not shown). For both these parameters, there was a significant stock × scion interaction. Figure 1 shows that, while grafting gave little benefit for some clones, the drought tolerance of others was much improved. The best rootstock appeared to be China 3; several scions on that rootstock had DTIs comparable to the drought-tolerant standard clone MRTM1.

There was a tendency for those clones most affected by drought as cuttings to show the greatest improvement after grafting. This remained true even if clone 6/1, which was very severely affected as straight cuttings, was excluded (Figure 2; $r = -0.741$, 16 *d.f.*, $p < 0.001$).

Table 4. Drought tolerance indices, Trial 3. DTI is yield Oct 2005–Dec 2006 as % yield Jan–Sep 2005.

Rootstock:	China 3	TN14-3	PC87	MFS87	Cuttings	Mean	Gain from grafting (%)
Scion							
1/16	69.9	57.9	55.8	32.7	52.7	54.1	2.6
10/3	60.8	60.5	59.7	54.9	57.2	59.0	3.0
10/307	74.1	65.3	69.4	61.1	65.1	67.5	3.6
10/96	73.3	62.5	61.6	61.8	48.9	64.8	32.5
12/109	63.8	57.0	49.1	57.7	46.2	56.9	23.3
12/123	62.0	55.2	48.6	65.2	55.9	57.8	3.3
12/150	75.3	70.9	69.9	69.8	73.6	71.5	−2.9
12/228	73.7	65.7	71.2	72.7	65.9	70.8	7.5
12/53	59.7	60.7	58.3	52.5	49.7	57.8	16.4
12/69	58.5	54.3	51.1	51.2	46.7	53.8	15.1
13/005	61.6	58.2	65.4	57.1	62.2	60.5	−2.6
13/33	71.1	66.4	67.5	62.2	64.4	66.8	3.7
14/12	54.8	58.0	54.0	54.6	60.7	55.3	−8.8
14/77	57.1	58.9	52.5	60.4	54.2	57.2	5.7
16/163	63.6	69.1	56.7	65.5	55.2	63.7	15.3
16/88	64.2	68.2	60.5	64.3	69.5	64.3	−7.5
4/10	60.5	58.3	60.5	61.4	61.7	60.2	−2.5
6/1	55.7	54.6	47.1	56.8	27.5	53.6	94.6
6/134	59.2	57.2	61.1	59.8	56.0	59.3	5.8
Mean	64.2	61.0	59.0	59.0	56.5		
s.e.	Stocks: 0.8		Scions: 1.6			Stock × scion: 3.5	
Standards							
MRTM1	–	–	–	–	75.9		
S15/10	–	–	–	–	68.6		
31/8	72.5	71.7	–	–	57.7		
s.e. for comparing standards with individual stock × scion combinations: 3.6							

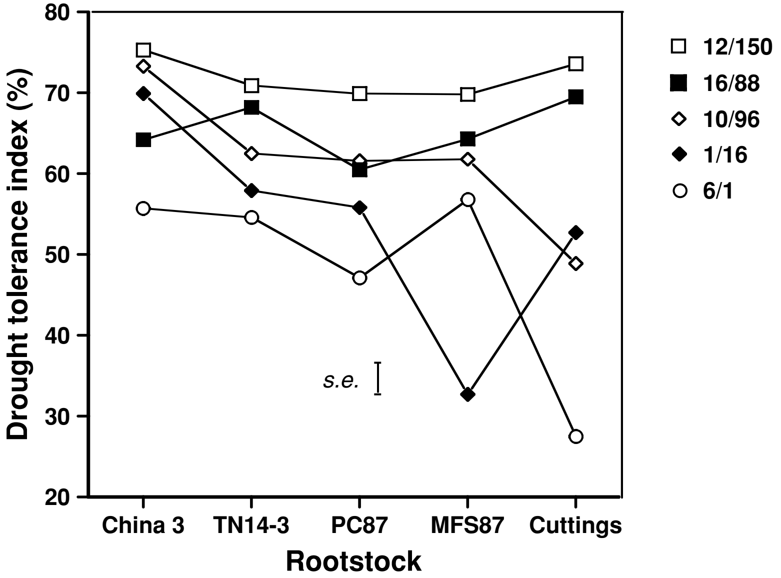

Figure 1. Drought tolerance indices of some scions in Trial 3, as affected by different rootstocks.

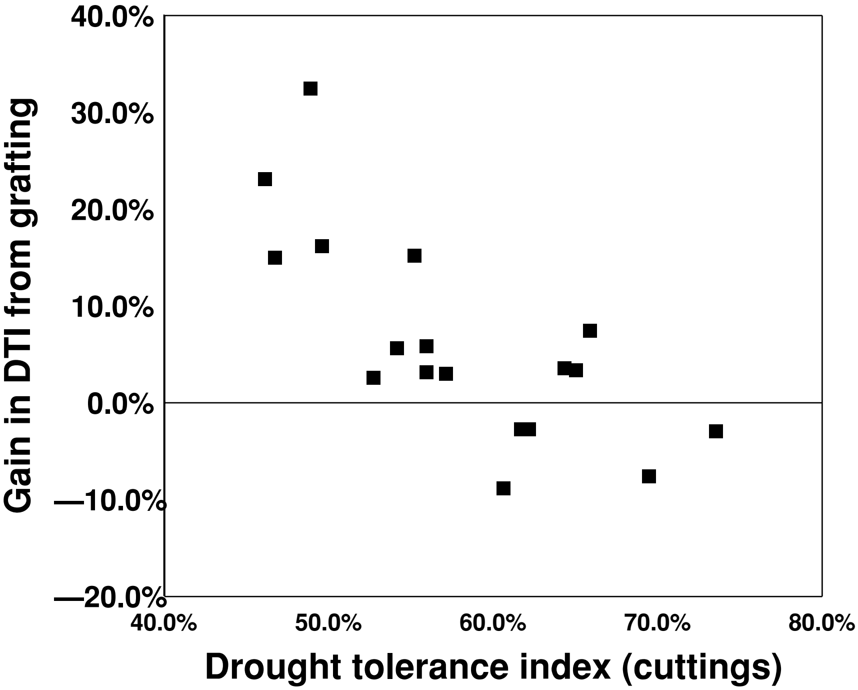

Figure 2. Improvement in drought tolerance index after grafting (mean for all rootstocks) compared to DTI of the same clones grown as cuttings, Trial 3.

Table 5. Physiological parameters for cuttings in Trial 1.

Clone	G (mmol/m^2.s)	A (μmol/m^2.s)	Ψ (Mpa)	A/g (μmol/mol)
S15/10	132	3.2	−8.7	27.0
BBK152	102	2.8	−5.8	29.4
31/8	91	2.5	−5.3	29.2
BBK7	137	3.2	−6.5	25.5
BBK35	145	3.2	−6.3	23.9
TN14-3	121	3.2	−6.2	29.0
Mean	125	3.0	−6.5	27.3

Physiological measurements

In 1993, measurements were made of stomatal conductance (g), photosynthetic rate (A), xylem water potential (Ψ), and water use efficiency (A/g) on the plots of cuttings in Trial 1 at the higher site; mean values for each clone are given in Table 5. There was a highly significant correlation between Ψ for cuttings and mean DTI for rootstocks in 1992 ($r = 0.984$, $d.f. = 4$, $p < 0.001$). That is, clones with strongly negative Ψ, in particular S15/10, performed relatively poorly as rootstocks during the drought (but note that the differences in DTI among rootstocks were not statistically significant – see above). In 1997 death rate was negatively correlated with Ψ ($r = -0.783$, $p = 0.065$); the correlation with DTI, though positive, was not significant

($r = 0.312$, $p = 0.5$). However, Ψ was not correlated with symptom scores in either 1992 or 1997. The other physiological variables, A and g, were not significantly correlated with performance as a rootstock.

Performance of clones as scions in 1997 was correlated with stomatal conductance (g) and water use efficiency (A/g). Clones with low drought scores had high A/g as cuttings ($r = -0.891$, $p = 0.017$), and low g ($r = 0.857$, $p = 0.029$); similarly DTI was negatively related to A/g ($r = -0.969$, $p = 0.001$), and positively to g ($r = 0.856$, $p = 0.03$). For performance in the 1992 drought, though, the correlations were all low and non-significant.

DISCUSSION

The drought tolerance index is a broad measure of drought tolerance, which effectively includes the ability to maintain yield during drought and also rapidity of recovery after drought. It is clear that one of the benefits of grafting is to improve the drought tolerance of susceptible scions. In some instances, the DTIs for susceptible scions on good rootstocks were raised to levels comparable to the more drought-resistant clones. The more susceptible clones in Trial 3 tended to show greater improvement after grafting, though not all clones responded.

In Trial 1, there were some differences in performance between the 1992 and 1997 droughts; we cannot determine whether those were due to differences in drought severity, or to changes in response attributable to plant age. Observations in commercial tea fields during the 1997 drought suggested that plant age might be important, with tea bushes aged 2–3 years after planting appearing more sensitive to drought than older bushes.

Drought symptom scores in Trial 1 showed clear differences between clones, with scores as rootstock and as scion positively correlated. However, while the 1992/1993 scion DTIs were correlated with scores, rootstock differences in score were not reflected in the index. This suggests the possibility that drought may affect yield in more than one way. The physiological measurements provide further evidence for this, with rootstock DTI correlated with xylem water potential, while scion DTI was correlated with stomatal conductance.

Smith *et al.* (1993) found that drought tolerant clones had the least negative Ψ values, and Carr (1977) also found that clones with small Ψ were drought tolerant. Xylem water potential is a measure of the internal water status of the plant, reflecting the balance between water uptake by the roots and loss through the stomata. Our results suggest that water uptake is the more important factor in this balance: clones with small values of Ψ were drought tolerant as rootstocks, but as scions their behaviour was not related to Ψ. Smith *et al.* (1993) also found that drought tolerant clones had high stomatal conductance and high A/g ratios. We found that for scions the drought score, which is a measure of damage to the foliage, was correlated with g, but for rootstocks drought scores were not related to g. That scions which are able to maintain open stomata should suffer less damage to the foliage (higher scores) during a drought is understandable, though the stomatal measurements were made during a period without water stress.

The behaviour of clone BBK152 in Trial 1 is notable: as cuttings it was very drought susceptible, suffering severe symptoms in 1992, and 17% of bushes died in 1997. In both years, it suffered the greatest yield depression (smallest DTI). When grafted onto other roots, symptoms were less severe in 1992, and yield was not much depressed, but in 1997 19% of grafted bushes died, and it had the lowest DTI. Used as a rootstock, the clones grafted onto it had relatively severe drought symptoms in 1992, but in 1997 deaths were below average. If drought has distinct effects on roots and shoot, as suggested above, one might argue that BBK152 is susceptible to the shoot effect (cuttings and scions suffer severely), but less so to the root effect. This is consistent with the physiological measurements: BBK152 had below average g, but above average (less negative) Ψ. However, one could not have predicted the extreme drought susceptibility of this clone from the physiological data. Clone 31/8 had similar characteristics (low g, high Ψ), but was not nearly so drought susceptible.

The studies mentioned above (Carr, 1977; Smith *et al.*, 1993) were conducted during a dry season; Smith *et al.* found no differences in Ψ among irrigated clones. However, the results in Trial 1 indicate that even in a non-stress period drought tolerant rootstocks may have small values of Ψ, and measurements of Ψ might therefore be used to identify new rootstocks, where drought tolerance is a requirement. For a rootstock in Kenya drought tolerance is not the only requirement, though: China 3 was the most drought tolerant rootstock in Trial 3, with both drought score and DTI significantly better than PC87, but PC87 gave a greater overall yield increase when non-drought years were included (Tuwei *et al.*, 2008). MFS87 gave a significant improvement in average DTI compared to cuttings (Table 4), but it did not improve overall average yields (Tuwei *et al.*, 2008).

CONCLUSIONS

In a previous paper we showed that grafting could be a useful and profitable way of increasing yield from some, but not all tea clones (Tuwei *et al.,* 2008), but we were unable to find a reliable method of identifying good rootstocks for Kenyan conditions, other than by testing them in grafting trials.

In some environments drought tolerance is the first requirement for a tea rootstock. In the Kericho environment, the dry season is not always very severe, but drought tolerance is still a useful attribute, so the finding that xylem water potential of a clone under non-drought conditions may be related to its drought tolerance as a rootstock could be helpful in a selection programme. Clones could first be screened for Ψ, and those shown to have small values would then be tested in grafting trials, to see whether they gave the yield increases needed in non-drought years; our results show that the most drought-tolerant rootstocks do not necessarily give the greatest overall yield increases.

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