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EFFECTS OF GRAFTING ON TEA 1. GROWTH, YIELD AND QUALITY

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SUMMARY

Trials in Kenya have shown that yields of tea clones can be increased significantly by grafting onto suitable rootstocks, with the best combinations giving profitable yield increases compared to straight cuttings. However, stock × scion interactions were significant, and not all clones gave useful responses to grafting even onto the best rootstocks, so combinations must be tested individually before commercial planting is considered. The effect of grafting was to increase the number of shoots harvested, with little change in mean shoot weight. Grafting had little or no effect on quality of the tea produced. Attempts to find a method of identifying good rootstocks without testing them in grafting trials were inconclusive.

INTRODUCTION

Grafting of tea (*Camellia sinensis*) has been done for at least 80 years; initially it was used in various ways to incorporate clonal material into breeding and seed production programmes (Barua, 1989). As a method of propagation for commercial planting, early work involved grafting scions of selected clones onto mature seedling bushes in the field (Bezbaruah and Saharia, 1982; Templer, 1971). The aim was to upgrade the planting material without the expense of replanting, but success rate was often low (Templer, 1971), and Willson (1992) considered that 'grafting and budding are unlikely to become economic at any time'.

More recent work has concentrated on grafting in the nursery using clonal rootstocks. In Malawi, Kayange *et al.* (1981) showed that yields from two low-yielding clones could be increased by over 40% by grafting onto vigorous rootstocks, without affecting the theaflavin content of the tea made from the scion clones. Even greater yield increases were reported by Satyanarayana *et al.* (1991) in South India. In Kenya, published results have been less impressive. Bore *et al.* (1995) described a trial in which yield of four scions was reduced by an average of 10% by grafting. In 1997, Bore considered that 'use of composite [grafted] tea is still at infancy in Kenya' (Bore, 1997). However, by that date Brooke Bond Kenya (now Unilever Tea Kenya Ltd) had planted 175 ha of composites, following results of trials conducted from the early 1990s onwards. Results of some of those trials are summarized in this paper. In addition to

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identifying good stock–scion combinations for commercial planting, an objective of the trials was to try to understand how to identify good rootstocks for Kenyan conditions.

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 comment, 1996). The trials were planted in the Kericho 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. Clone names are abbreviated below by omitting the initials of the organisation which developed each clone. Self-grafts were not included, but Bore *et al.* (1995) found that self-grafting had no effect on yield. The trial was performed at two sites, at altitudes of 1707 m asl and 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). Yields were recorded from 1990 to 1996 at the lower site, and from 1990 to 1997 at the higher site.

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 performed on the same sites as for Trial 1 and 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 from Kenya, and TRFCA MFS87 and TRFCA PC87, from the Tea Research Foundation of Central Africa in 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 was also included: 31/8 grafted onto EPK TN14-3, which, on the basis of results of Trials 1 and 2, has been planted on a commercial scale by Unilever Tea Kenya Ltd. 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^{-1}.

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. After some plucking rounds, samples of shoots were taken from each plot and the average fresh shoot weight determined. From these samples, total shoot number harvested could then be estimated. Shoot dry matter content was also measured on small samples on several occasions. 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.

Trials were pruned approximately every four years, following standard practice in Kenya. After pruning, the weight of pruned material ('pruning trash') per plot was recorded; these data were converted to dry weights assuming a dry matter content of 40%, based on unpublished work in other trials. From these figures and the yield data, we estimated dry matter production (DMP) above the pruning height. Unpublished work has shown that pruning trash weight is significantly correlated with total plant dry weight, so we have used the ratio of yield to yield plus pruning trash as a proxy for harvest index (HI), though clearly the ratio is an overestimate of true HI because dry matter in the roots and stem below the pruning height is omitted.

In Trial 1 measurements of root length were made at the end of the nursery stage, by uprooting surplus plants. An attempt was also made to estimate root surface area, using the method of Wulster (1985).

Quality of tea was assessed by manufacturing small samples with Teacraft mini-manufacture equipment. These samples were then tasted by professional tea tasters, and scored for various attributes. In Trial 1, samples were manufactured in batches of six, each batch including one scion on all rootstocks; thus possible scion effects were confounded with batch differences (attributable to sampling date, variation in manufacture or tasting date). Tasters scored samples for flavour, briskness, brightness, colour, thickness and leaf appearance, and gave them a value, relative to tea market prices at the time.

In Trial 3, samples were mini-manufactured from a factorial set of four scions on each of the four rootstocks and as straight cuttings. Tasters scored the samples for quality, thickness and colour. The samples were also subjected to analytical tests, including spectrophotometric analysis as described by Roberts and Smith (1963), and measurements of infusion colour using a Minolta colour meter.

Costs

In the cleft grafting method, two cuttings are prepared for each plant and grafted together. The cost of preparing a cutting was KSh 0.45. Cuttings are taken from bushes that would otherwise have been producing tea, so the cuttings have an opportunity cost; this depends on tea price, but was approximately KSh 0.13. The actual grafting

Table 1. Yields of black tea (kg ha.a^{-1}) in Trial 1.

	Scion:	S15/10	BBK152	31/8	BBK7	BBK35	TN14-3	Mean	as % cuttings
A – Lower site, 1990–1996									
Cuttings:		4745	4408	4449	4039	4651	4043	–	–
Rootstock:	S15/10	–	4173	4905	4533	4704	3892	4442	102.9
	BBK152	4671	–	4640	4282	4520	3531	4329	98.7
	31/8	5040	4202	–	4040	4751	3429	4292	97.7
	BBK7	4644	4131	4683	–	4652	3605	4343	97.2
	BBK35	4484	4299	4687	4232	–	3623	4265	98.4
	TN14-3	5330	4617	5030	4545	4872	–	4879	109.5
Mean (excl. cuttings)		4834	4284	4789	4326	4700	3616		
Mean response (% cuttings)		101.9	97.2	107.6	107.1	101.0	89.4		
s.e.:		Stocks: 49		Scions: 151		Stock × scion: 119			
B – Higher site, 1990–1997									
Cuttings:		3419	2719	3114	2629	3090	2662	–	–
Rootstock:	S15/10	–	2388	3408	2770	3310	2793	2934	102.9
	BBK152	3211	–	3235	2598	2983	2592	2924	98.1
	31/8	3206	2640	–	2490	3002	2304	2728	93.9
	BBK7	3200	2476	2981	–	2840	2421	2783	92.6
	BBK35	3029	2549	3117	2569	–	2362	2725	93.8
	TN14-3	3756	2978	3556	2733	3238	–	3252	108.5
Mean (excl. cuttings)		3280	2606	3259	2632	3075	2494		
Mean response (% cuttings)		95.9	95.8	104.7	100.1	99.5	93.7		
s.e.:		Stocks: 35		Scions: 126		Stock × scion: 86			

operation cost KSh 0.80 per plant. Thereafter, nursery and field planting costs are the same for cuttings and grafts, but losses in the nursery may be higher for grafts; we have assumed 80% success, compared to 90% for straight cuttings. The cost for a grafted plant is therefore $(2 \times (0.45 + 0.13) + 0.80)/0.8 =$ KSh 2.45, compared to $(0.45 + 0.13)/0.9 =$ KSh 0.64 for a cutting. For 13 000 plants ha^{-1}, the additional cost of grafting was KSh 23 530, equivalent to approximately US$ 360.

RESULTS

Yield and yield components

Trial 1. As expected (Squire *et al.*, 1993) yields were higher at the lower altitude site (Table 1). In a combined analysis of both trials, there were no significant interactions with site (stock × site, scion × site and stock × scion × site all non-significant). The stock × scion interaction was significant at the higher site (Table 1B), but not at the lower. The main reason for this appears to be the good response from grafting S15/10 onto 31/8, which had little effect on other scions.

As a rootstock, TN14-3 was the most effective, increasing scion yield by an average of 9% across both trials and all scions. S15/10 was the only other rootstock to give a benefit, averaging a 3% increase. The other four clones all reduced yield when used as rootstocks.

At both sites, the scions behaved much as expected from other clone trials, with S15/10 yielding highest, followed by BBK35 and 31/8. The scion most responsive to

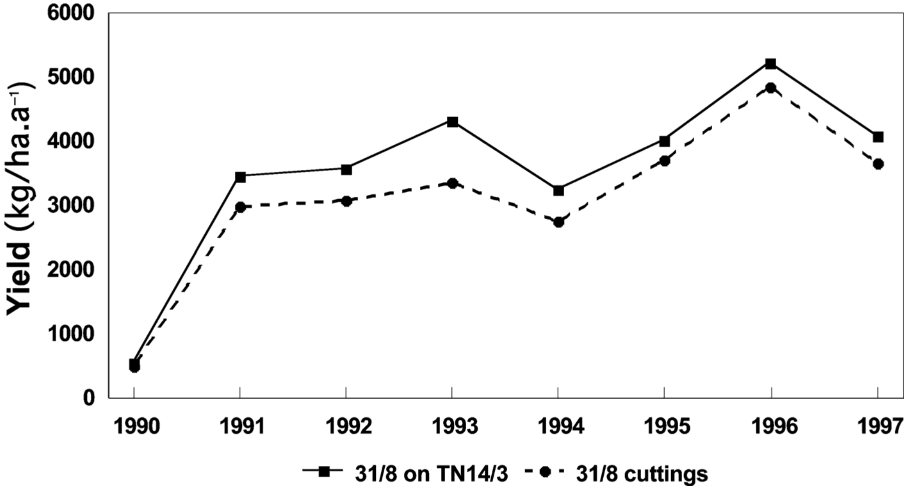

Figure 1. Yield of clone 31/8 as cuttings and on rootstock TN14-3, Trial 1, higher site.

grafting was 31/8; yield of this clone was increased by all rootstocks, except BBK7 and BBK35 at the higher altitude site. At the lower site, BBK7 also responded well. Yield of TN14-3 as a scion was depressed by grafting onto other clones, except for S15/10. The highest yield was obtained from S15/10 grafted onto TN14-3, which yielded 10% more than cuttings of S15/10. 31/8 on TN14-3 was the next highest yielding combination, producing 13% more than cuttings of 31/8 at the higher site and 14% more at the lower site; after the first year when there was little effect, the increase in yield was fairly consistent from year to year (Figure 1).

Mean weight per shoot was measured after each of 16 harvesting rounds in 1992; the plot means and the total weights of shoots (yield) were then used to estimate shoot numbers for the period 1990–1995. There was no effect of rootstocks on mean shoot weight at either site. Results for the higher site are shown in Table 2; differences in shoot numbers between rootstocks are greater than the differences in shoot weight. The poor yields on 31/8 and BBK7 as rootstocks (Table 1) were due to low shoot numbers, while the best rootstocks, S15/10 and TN14-3, gave the highest shoot numbers. Over all treatments (means for both sites), yield was highly correlated with shoot number ($r = 0.844$, 34 *d.f.*, $p < 0.001$), but not with shoot weight ($r = 0.306$, $p = 0.07$).

Trial 2. A combined analysis of yield data from both sites showed significant stock × site and scion × site interactions, but no three-way interaction (Table 3). The stock × scion interaction was significant at the higher site, but not when both sites were combined. Three rootstocks gave useful yield increases at both sites. At the lower site, China 3 was clearly the best, followed by TN14-3 and BBT1 (Table 3A); at the higher altitude site, China 3 and TN14-3 were equally good, followed by BBT1 (Table 3B). Of the other three roostocks, two were ineffective and one decreased yields; BBT207

Table 2. Yield components in Trial 1, higher site.

	Scion:	S15/10	BBK152	31/8	BBK7	BBK35	TN14-3	Mean	Mean as % cuttings
A: Mean shoot weight (g) (1992)									
Cuttings:		1.92	1.76	1.82	1.70	1.94	1.86	–	–
Rootstock:	S15/10	–	1.91	1.84	1.76	1.90	1.87	1.86	102.5
	BBK152	2.08	–	1.68	1.59	2.03	1.66	1.81	98.0
	31/8	1.94	1.93	–	1.93	1.74	1.69	1.85	101.1
	BBK7	1.97	1.94	1.94	–	1.81	1.82	1.90	102.3
	BBK35	2.01	1.97	1.55	1.71	–	1.70	1.79	99.0
	TN14-3	1.97	2.06	1.70	1.85	2.00	–	1.92	105.1
Mean (excl. cuttings)		1.99	1.96	1.74	1.77	1.90	1.75		
s.e.:		Stocks: 0.040			Scions: 0.137		Stock × scion: 0.089		
B: Shoot no. $m^{-2}.a^{-1}$ (1990–1995)									
Cuttings:		684	617	678	630	615	569	–	–
Rootstock:	S15/10	–	518	765	629	653	614	636	102.1
	BBK152	603	–	779	639	549	620	638	100.6
	31/8	613	560	–	507	660	544	578	92.7
	BBK7	639	492	628	–	605	541	581	91.9
	BBK35	592	520	854	600	–	557	625	98.0
	TN14-3	730	555	839	590	612	–	665	102.7
Mean (excl. cuttings)		503	513	583	570	532	575		
s.e.:		Stocks: 14.9			Scions: 35.1		Stock × scion: 36.5		

Table 3. Yields (kg made tea/ha.a^{-1}) in Trial 2, 1990–1997

	Scion:	6/8	BBK35	SC12/28	BBK152	31/8	12/19	BBK7	Mean	Mean as % cuttings
A – Lower site										
Cuttings:		2874	2986	3517	2915	3144	3408	3008	3122	–
Stock:	China 3	3221	3799	3882	3524	3752	3965	3298	3634	116.4
	TN14-3	3356	3733	3338	3110	3683	4018	3203	3491	111.8
	BBT1	3302	3763	3868	3098	3499	3445	3405	3483	111.6
	China 1	3548	3352	3300	3097	3486	3457	2878	3160	101.2
	China 2	2663	3323	3134	2994	3216	3438	2967	3105	99.5
	BBT207	2308	3088	2603	2680	3223	3156	2377	2776	89.0
Mean (excl. cuttings)		3066	3509	3354	3083	3476	3579	3021		
s.e.:		Stocks: 55			Scions: 63		Stock × scion: 167			
B – Higher site										
Cuttings:		1925	2344	2520	2042	2564	2040	2047	2212	–
Stock:	China 3	2137	2466	2574	2272	2667	2409	2195	2389	108.0
	TN14-3	2184	2563	2519	2223	2775	2457	2187	2415	108.2
	BBT1	2147	2449	2557	2162	2672	2302	2173	2352	106.3
	China 1	1972	1976	2251	1954	2050	1980	1937	2017	91.2
	China 2	2020	2537	2322	2003	2350	2224	2123	2226	100.6
	BBT207	2049	2343	2272	2189	2475	2276	2208	2259	102.1
Mean (excl. cuttings)		2084	2389	2416	2133	2498	2274	2137		
s.e.:		Stocks: 24			Scions: 40		Stock × scion: 65			

Table 4. Effect of rootstocks on shoot weights and numbers, Trial 2, lower site.

Rootstock:	Cuttings	China 3	TN14-3	BBT1	China 2	China 1	BBT207	*s.e.*
Shoot wt (g)	3.08	2.93	3.12	2.99	3.02	2.94	3.01	0.042
Shoot no. m^{-2}	394	462	419	430	396	400	366	10.4

was the worst clone at the lower site was and China 1 was the worst at the higher site.

Among the scions, 12/19 was best at the lower site, and 31/8 at the higher site; 6/8, BBK152 and BBK7 gave the lowest yields at both sites. The highest yielding combination at the lower site was 12/19 on TN14-3, and at the higher site 31/8 on TN14-3.

At the lower site, there were significant differences among rootstocks in both mean shoot weight and shoot number, but at the higher site, only shoot numbers were affected. Results from the lower site are summarized in Table 4. Rootstocks China 3 and China 1 gave mean shoot weights significantly lower than from cuttings, but with China 3 this was made up for by significantly greater shoot number.

Trial 3. Mean yield was increased by grafting onto TN14-3, China 3 or PC87, but not onto MFS87 (Table 5). Overall, the best rootstock was PC87, giving an average yield increase of 18%, and performing best with 14 of the 20 scions. The other five scions gave greater responses on China 3. However, the best of the stock–scion combinations yielded 15% less than the MRTM1 standard, and only one (13/33 on China 3) was not significantly lower yielding than 31/8 on TN14-3.

There was a significant stock × scion interaction, and Figure 2 shows that some scions gave much greater responses to grafting than others. There was a negative correlation between the yield of a clone as straight cuttings, and its average response to grafting (Figure 3; $r = -0.583$, 17 *d.f.*, $p = 0.009$); in other words, lower yielding clones were more likely to respond, though Figure 3 shows that not all low-yielding clones responded to grafting.

Dry matter production

Trial 1. There were no significant differences between rootstocks in weight of pruning trash, at either site. Despite the significant differences in yield noted above, effects on total DMP and HI were also non-significant, although TN14-3 gave mean DMP 14% above cuttings at the higher site and 5% at the lower site. Rootstocks did not differ in height of plucking table at the time of pruning in Trial 1 (this was not recorded in Trials 2 and 3).

Trial 2. Differences between rootstocks in weight of pruning trash were not significant, although China 3 gave 9% more trash than cuttings at both sites. However, the differences in yield were such that DMP and HI both showed significant responses. China 3, BBT1 and TN14-3 gave greater DMP than cuttings at the lower site, while China 3, TN14-3 and BBT207 gave greater DMP at the higher site. BBT207 gave lower HI than cuttings at the lower site, and China 1 gave lower HI at the higher site.

Table 5. Yields (kg made tea ha.a^{-1}) in Trial 3, 2000–March 2007.

	Rootstock						
Scion	14/3	China3	MFS87	PC87	Cuttings	Grafted mean	Mean response (%)
BBK 16/88	3124	3035	3108	3206	3149	3118	−1.0
BBK 16/163	3110	3135	2905	3260	2549	3103	21.7
BBK 13/33	2849	3403	2713	3289	2610	3063	17.4
BBK 12/53	3209	3012	2762	3223	2801	3052	8.9
BBK 12/150	3079	3072	2762	3212	2980	3032	1.7
BBK 12/109	2559	3217	2737	2959	2305	2868	24.4
BBK 12/228	2641	3006	2333	3230	2680	2803	4.6
BBK 10/307	2767	3045	2448	2903	2640	2791	5.7
BBK 6/134	2858	2769	2595	2891	2181	2778	27.4
BBK 10/3	2459	3137	2385	3003	2069	2746	32.7
BBK 1/16	2864	3078	2207	2753	2639	2725	3.3
BBK 14/12	2573	2774	2562	2967	2503	2719	8.6
BBK 12/123	2584	2708	2481	2971	2647	2686	1.5
BBK 4/10	2643	2599	2486	2896	2610	2656	1.8
BBK 10/96	2237	2652	2365	2869	2217	2531	14.1
BBK 12/69	2595	2589	2135	2764	2437	2521	3.4
BBK 14/77	2517	2371	2351	2690	2295	2482	8.1
BBK 13/005	2348	2517	2319	2706	2273	2473	8.8
BBK 6/1	1870	2514	1835	2303	2036	2131	4.6
Mean	2678	2875	2499	2952	2506	2751	
s.e.	Stocks: 31		Scions: 60		Stock × scion: 134		
Standards							
BBK MRTM1	–	–	–	–	4017		
AHP S15/10	–	–	–	–	3395		
TRFK 31/8	3742	3816	–	–	2771		

s.e. for comparing standards with indivdual stock × scion combinations: 132

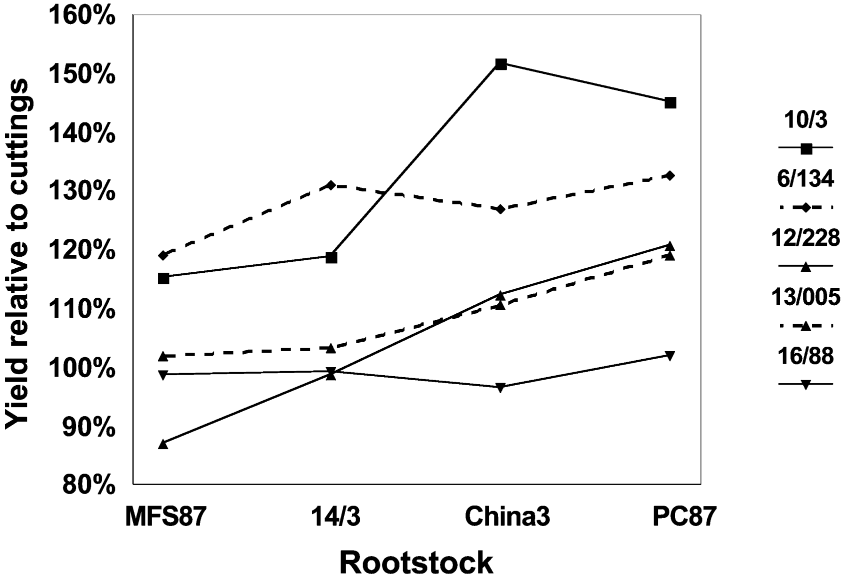

Figure 2. Yield, relative to cuttings, of some clones in Trial 3.

Table 6. Rootstock means for dry matter production in Trial 3, up to time of pruning in 2004.

Rootstock	Trash wt (kg plot^{-1})	Yield (kg ha.a^{-1})	Dry matter (kg ha.a^{-1})	Harvest index (%)
PC87	15.4	3009	4142	72.7
China3	15.9	2864	4034	71.0
14/3	14.6	2759	3831	72.1
MFS87	15.1	2596	3706	70.2
Cuttings	14.4	2557	3617	70.7
s.e.	0.41	31	49	0.54

Trial 3. The weight of pruning trash was increased by grafting onto China 3, as was DMP (Table 6). The percentage increase in yield was greater than that in trash weight for three of the rootstocks; this was particularly marked for PC87, where yield was increased by an average of 17.8%, but trash weight by only 6.9%. In consequence, this roostock gave the highest HI, and the only one significantly greater than for cuttings. There were no significant stock × scion interactions in these data sets.

Quality

Trial 1. Shoot size is an important factor in quality of tea, with agronomic treatments which result in smaller shoots generally associated with higher quality. As shown in Table 2, rootstocks did not affect shoot size in Trial 1. Samples were mini-manufactured from four scions on each of the rootstocks, with duplicate samples from three of the scions. There were no significant differences between rootstocks for any of the attributes evaluated by the tasters. There were significant differences between scions for leaf appearance, infusion briskness and colour, and market value, but as noted above these were confounded with possible batch differences.

Trial 2. No evaluation of quality was done in this trial, but Table 4 shows that shoot size was not increased by grafting onto any of the rootstocks.

Trial 3. Two samples were taken for mini-manufacture from four scions on all four rootstocks, and also as straight cuttings. The tasting results showed significant differences in Quality score between scions, but no differences between rootstocks, nor any stock × scion interaction. Similarly for the spectrophotometric analyses and infusion colour, there were differences between scions for some parameters, but not between stocks, and no interactions.

Characteristics of a good rootstock

In Trial 1 we looked for correlations between the yield responses obtained by grafting and other characteristics measured on the rootstocks grown as cuttings. We also measured a variety of other growth characteristics; these are listed in Table 7, where correlations with the mean effect of the rootstocks are given. There were very few significant correlations, and little consistency between sites. The response to grafting of a clone used as scion was negatively correlated with performance as

Table 7. Correlations between mean effect of rootstocks and measurements on rootstock clones grown as cuttings in Trial 1 (all correlations with 4 *d.f*).

	Correlation with effect on mean scion yield		
Measurement on rootstock clones	Lower site	Higher site	Mean both sites
Yield of rootstock clone (7-year mean)	−0.030	−0.004	−0.016
Yield of rootstock in 1st year	0.445	0.659	0.558
Response of clone as scion	−0.808+	−0.573	−0.780 +
Mean shoot weight	0.303	0.419	0.444
Shoot number ha.a^{-1}	−0.283	−0.347	−0.356
Shoot dry matter content	0.881*	0.566	0.831*
Phyllochron interval	–	−0.633	–
Height of plucking table	0.751+	–	–
Weight of pruning trash	0.420	−0.805+	−0.530
Dry matter production	0.216	−0.953**	−0.315
Harvest index	−0.621	0.524	0.329
Root surface area in nursery	0.034	−0.228	−0.081
Root length in nursery	−0.505	−0.195	−0.371

Probability of higher correlation (4 *d.f.*): $+\,p = 0.1$ $^{*}p = 0.05$ $^{**}p = 0.01$

a rootstock at both sites, but the correlations did not reach 5% significance. Shoot dry matter content was positively correlated with rootstock performance at both sites, significantly so at the lower site.

DISCUSSION

Yield

In all trials, one or more rootstocks significantly increased yields; significant stock × scion interactions were also observed, though in Trials 1 and 2 these were not consistent across sites. These interactions were mainly attributable to the fact that not all scions responded to grafting (e.g. Figure 3). Clone TN14-3 gave good results as a rootstock in all three trials, increasing yields by an average of 8% in Trial 1, 10% in Trial 2 and 7% in Trial 3. Clone 31/8 was among the more responsive scions, with a yield increase when grafted onto TN14-3 of 14% in Trial 1, 13% in Trial 2 and 35% in the standard plots of Trial 3.

In Trial 2, China 3 gave slightly better results than TN14-3, and in Trial 3 PC87 was better still. MFS87 gave no yield increase in Trial 3, but this clone performed well in Malawi (Kayange *et al.*, 1981), where it increased the yield of two scion clones by more than 40% over three years. MFS87 does improve drought tolerance of susceptible scions (Tuwei *et al.*, 2008), but its overall poor performance suggests that drought tolerance is not the only benefit from grafting in Kenya.

Kandiah *et al.* (1979) observed that, although yield depended on both root and shoot systems, a high-yielding scion with a low-yielding clone as rootstock performed better than the reverse combination, but the results of Trial 1 suggest that this is an oversimplification. As the following figures (mean yields for both sites, kg ha.a^{-1}) show, in some instances the higher yielding clone does give better results as scion than as

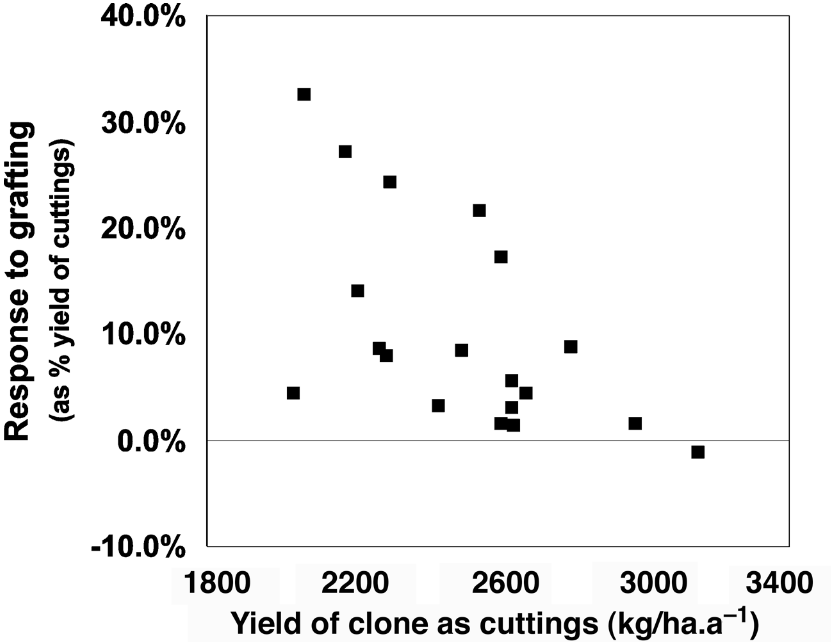

Figure 3. Response to grafting (mean % increase, all rootstocks) of the scion clones in Trial 3, in relation to yield of the same clones as cuttings.

rootstock, as for S15/10 and TN14-3, but clone BBK35 grafted onto S15/10 gave higher yields than the reverse combination:

S15/10: 4082 TN14-3: 3352 S15/10 on TN14-3: 4543 TN14-3 on S15/10: 3342
S15/10: 4082 BBK35: 3871 S15/10 on BBK35: 3756 BBK35 on S15/10: 4007

Kayange *et al.* (1979) and Nyirenda and Kayange (1984) observed that grafting gave greater responses with a low-yielding than with a high-yielding scion. This was confirmed in Trial 3, where there was a negative correlation between yield of a clone as cuttings and response to grafting, but there were some low-yielding clones which did not respond.

Quality

Shoot size (weight), as affected by agronomic treatments, is an important determinant of quality, but was little affected by grafting, in agreement with Pool and Nyirenda (1981). The increases in yield came from increased shoot numbers. There were no effects of rootstocks on either organoleptic assessments by tasters or on analytical measurements, in agreement with the results of Kandiah *et al.* (1979), Kayange *et al.* (1981) and Bore *et al.* (1995).

Dry matter production

In Trials 1 and 2, grafting had little effect on the weight of pruning trash; height of the plucking table was not affected in Trial 1. In Trial 3, grafting did tend to increase the weight of pruning trash, but the effect on yield was greater than that on trash weight. This was particularly marked for PC87, where yield was increased by an average of 17.8%, but trash weight by only 6.9%. In consequence, this roostock gave the highest HI (and the only one significantly greater than for cuttings). Nyirenda and Kayange (1984) found a greater effect of rootstocks on stem circumference and branch number in a low-yielding than in a high-yielding scion; the scions in Trial 3, selected primarily for quality, were generally lower yielding than those in Trials 1 and 2.

The increases in shoot number but not in shoot weight suggest that grafting may have an effect on shoot replacement ratio (the number of shoots which are released from dormancy for each shoot harvested). Shoot growth rate is probably not affected (Pool and Nyirenda, 1981); a single set of measurements of phyllochron interval in Trial 1 at the higher site showed no effects of rootstocks (but significant differences between scions). If growth rate were affected, then with the same plucking interval for all treatments, faster growth should result in heavier shoots at harvest, but this was not observed.

Yield of tea is generally considered to be sink-limited (Tanton, 1979), so an increase in potential shoot numbers could lead to higher yields, with little effect on weight of pruning trash. However, as the bush gains height an increased number of buds is likely to lead to an increase in branch number, as observed by Nyirenda and Kayange (1984), and hence an increase in weight of prunings. Satyanarayana (1980) and Pallemulla *et al.* (1992) found that grafting did have large and significant effects on the weight of pruning trash, and for some combinations, Satyanarayana *et al.* (1991) found that the percentage increase in pruning weight was greater than that in yield.

Characteristics of a good rootstock

One objective of Trial 1, where the rootstock clones were also included in the trial as cuttings, was to try to understand what characterizes a good rootstock for the Kericho environment. Without such information, the only way to screen possible rootstocks is to test them all in trials, which is very laborious. With only six rootstocks in Trial 1, the number of degrees of freedom was too small to allow useful multiple regression analyses, so we have only looked at simple correlations between rootstock performance (the average yield increase of scion clones brought about by grafting) and characteristics of the rootstock clones grown as cuttings. A more detailed study with a greater number of roostocks would be worthwhile.

In Malawi, it is considered that a rootstock should be vigorous and drought tolerant (Harvey, 1988). We found no significant correlations between rootstock performance and most measures of vigour for cuttings, including yield, bush height just before pruning and the weight of pruning trash, but there were positive (though not significant) correlations at both sites of rootstock performance with yield of the rootstock clone in the first year of production, which may be an indication of vigour. At the higher site there was a significant negative correlation of dry matter production with rootstock performance, the opposite to expectations from Malawi, but at the lower site the correlation was small and positive.

There were negative correlations (though not significant at the 5% level) of rootstock performance with scion response: the best rootstocks were least responsive as scions grafted onto other clones. This might be used to identify possible new rootstocks from among scions being tested on standard rootstocks, and is worth further study. For example, in Trial 3 clones such as 16/88 and 12/150, which gave no responses to grafting, might be worth testing as rootstocks.

Nyirenda (1990) found in Malawi that two good rootstocks had a greater proportion of 'storage' to 'feeder' roots than two out of three other clones. We did not measure this, but we found no differences in either root length or surface area between good and bad rootstocks. Drought is not a regular feature of the Kericho environment, and it is therefore not surprising that we found no correlations between measures of drought tolerance and average rootstock performance over all years of the trial. Effects in drought years are considered in more detail elsewhere (Tuwei *et al.*, 2008).

The only other result of note was positive correlations with shoot dry matter content, significant at the lower site. It is not clear why rootstock performance should be related to shoot dry matter content, but this may be worth further investigation.

Costs and benefits

The additional cost of a grafted plant compared to a straight cutting is about US$0.028, including grafting costs, the loss of production while extra cuttings are produced and a possible lower nursery survival rate for grafted plants (80% assumed, compared to 90% for cuttings). At 13 000 plants ha^{-1}, therefore, grafting adds US$360 to establishment costs. At current prices, the marginal value of each extra kg of tea is approximately US$0.65, so a yield increase of about 550 kg ha^{-1} is needed to cover the additional costs. With increases averaging over 500 kg ha.a^{-1} from 31/8 on TN14-3 at the lower site, and over 400 kg ha.a^{-1} at the higher altitude site (Table 1), costs would be covered in less than two years. Thus there is no doubt that grafting can be profitable.

The fact that grafting can increase yield with little or no effect on quality of the scion offers a way of improving the yield of high-quality but low-yielding clones. However, 19 clones originally selected for high quality were tested in Trial 3, and although yields were often increased, in one instance by over 50%, none of the combinations came within 10% of the standard clone MRTM1, or the standard composite 31/8 on TN14-3. Taking the best composite for each scion, the average yield was 19% below 31/8 on TN14-3, and 25% below MRTM1. Thus unless the tea could be sold with a 'quality premium' of 25% or more, it would not be financially worthwhile to plant such material; the standards would give a better return on investment.

CONCLUSIONS

In much of the published work on grafting, very small numbers of stocks and scions have been tested, but conclusions based on small numbers may be misleading. We have shown that stock × scion interactions can be significant, and that yield of a scion is not a good guide to its response to grafting. High-yielding scions such as S15/10 in Trial 1 may respond, while some of the low-yielding scions in Trial 3 showed no response. The significant interactions mean that one cannot assume that grafting will always be beneficial; rootstock–scion combinations must be tested individually before undertaking large-scale planting.

We conclude that grafting can offer a useful way of improving the yield of some clones, but it does not remove the need to include yield as a criterion in clone selection. Once high-yielding clones with acceptable quality have been identified, grafting may then be considered as a possible way of improving yields still further.

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