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EVALUATION OF SIMPLE HAND-HELD MECHANICAL SYSTEMS FOR HARVESTING TEA (*CAMELLIA SINENSIS*)

By P.J. Burgess[1,6], M.K.V. Carr[1,2,3], F.C.S. Mizambwa[2,5], D.J. Nixon[1,4], J. Lugusi[2] and E.I. Kimambo[2]

[1]*Cranfield University, Silsoe, Bedfordshire, MK45 4DT, UK*
[2]*Tea Research Institute of Tanzania, P.O. Box 2177, Dar-es-Salaam, Tanzania*

SUMMARY

Over an eight year period, harvesting methods based on simple mechanical aids (blade and shear) were evaluated against hand harvesting on mature morphologically-contrasting tea clones in Southern Tanzania. The effects of shear step height (5 - 32 mm) and the harvest interval (1.8 - 4.2 phyllochrons) were also examined. Except in the year following pruning, large annual yields (5.7 – 7.9 t dry tea ha^{-1}) were obtained by hand harvesting at intervals of two phyllochrons. For clones K35 (large shoots) and T207 (small shoots), the mean harvested shoot weights were equivalent to three unfurled leaves and a terminal bud. The proportions of broken shoots (40 – 48 %) and coarse material (4 - 6%) were relatively high. Using a blade, instead of hand-harvesting, resulted in similar yields from K35 but heavier yields from T207 (+13 %). The increase with small-leaved clone T207 was associated with the harvest of more shoots and heavier shoots, smaller increases in canopy height, and a higher proportion (7 – 9 %) of coarse material compared to hand-harvesting. On bushes, which had been harvested by hand for two years following pruning, using flat shears (no step) supported on the tea canopy resulted, over a three year period, in yields 8 - 14 % less than those obtained by hand harvesting and, for clone K35, a reduction in the leaf area index to below 5. The development of a higher leaf area index is possible by adding a step to the shear. However, since annual yields were reduced by 40 - 50 kg ha^{-1} per mm increase in step height, the step should be the minimum necessary to maintain long-term bush health. As mean shoot weights following shear harvesting were about 13 % below those obtained by hand harvesting, there is scope, when using shears, to extend the harvest interval from 2 to 2.5 phyllochrons.

Current addresses:
[3] Crop and Water Management Systems (Intnl) Ltd, Pear Tree Cottage, Frog Lane, Ilmington, Shipston-on-Stour, Warwickshire, CV36 4LG, UK
[4] South Africa Sugarcane Research Institute, Private Bag X02, Mt Edgecombe 4300, South Africa
[5] Booker-Tate Ltd, Masters Court, Church Road, Thame, Oxon, OX9 3FA
[6] Corresponding author: P.Burgess@cranfield.ac.uk

INTRODUCTION

The tea beverage is derived from young shoots harvested frequently during the growing season from tea (*Camellia sinensis*) bushes. The frequency of harvest depends primarily on the temperature, the incidence of drought, and the shoot standard (number of unfurled leaves per shoot) as specified by the processor for an identified market. Traditionally, in most developing countries, harvesters (often locally known as "pluckers") remove the shoots (typically two or three unfurled leaves and the unopened terminal bud) by hand. This can be a selective and skilful process involving between 140 and 190 individual hand actions per minute (Evans, 1993). In Southern Tanzania, pluckers typically remove between 4 and 9 kg of fresh shoots per hour depending on peaks and troughs in production (Squirrell, 1995). This represents 1700-5000 person hours ha^{-1} for a crop with an annual yield of 15-20 t ha^{-1} of fresh shoots. Labour on commercial estates, although cheap in absolute terms, currently represents 40–45 % of the total field costs when the provision of housing and other social benefits are included. If the tea industry in Southern Tanzania is to remain commercially viable, it must maintain competitive costs of production against the background of a long-term decline in world tea prices.

In some areas, there is also a shortage of men and women willing to undertake this repetitive work on a continuing and reliable basis. Strategically, there is also the need to plan for a declining workforce because of the high incidence of HIV/Aids in many of the tea producing regions of Africa. For smallholders in Tanzania, with average tea areas of 0.3-0.5 ha, there can also be a shortage of family and hired labour at critical times when peaks of production, for example after the start of the rains, coincide with other labour intensive activities such as the weeding of maize and other food crops.

It is for these reasons that producers are actively seeking alternative, but appropriate, ways for improving the productivity of tea harvesting. The choice is wide, from simple mechanical hand-held aids like shears and a blade, described in this paper, through motorised cutter bars (which may be hand held, pushed on wheels, or self-propelled), to large-scale machines harvesting two or three rows of tea at a time (Willson, 1992). Selection of the appropriate system depends on social, financial, technical, and environmental factors such as the availability and skills of labour, the capital investment and running costs, the supporting infrastructure for machine maintenance, and the terrain. Techniques developed under one set of conditions will not necessarily work successfully elsewhere. In Tanzania, except immediately after pruning, tea is typically harvested at intervals of 10-30 days representing 19-30 individual harvests per year. One machine could, in theory, be operating for five or six days per week for up to 250 days annually. By contrast machines developed and used in Japan on small (0.5 ha) family farms may only operate for five or six days a year due, in part, to the seasonal climate. Hence, it is not surprising that such machines may perform poorly in Africa.

As well as influencing the yield and quality characteristics of the harvested crop, the method of shoot removal can affect the number, size and type of shoots remaining on the bush. For example where tea is grown at relatively high temperatures in Malawi and Assam, plucking immature shoots can limit yields (Tanton; 1979; Manivel and Hussain, 1986) and some form of selectivity, as practised by skilled pluckers, is important for bush productivity. It can also affect the quality of the harvested crop, which can be defined in various ways. At the tea factory gate, the harvested shoots are often judged on the basis of the composition of a sample of shoots, including shoot size distribution and the proportion of broken shoots and coarse material. After manufacture the processed tea leaves and resultant tea liquor are judged and valued, depending on the market, by sensory characteristics such as colour, brightness, briskness and flavour.

Evaluating the effectiveness of different tea mechanical harvesting systems therefore requires several parameters to be assessed. These include yield, the composition of the harvested shoots, the value of the processed tea, the frequency and intensity of harvesting in relation to stages of bush and shoot development, long-term effects on the vigour (productivity) of a bush, ease of use including height control, maintenance, labour productivity, and economics. To complicate matters further, vegetatively propagated cultivars of tea, usually known as clones, can differ in the morphological characteristics of the shoots. This in turn may influence their suitability for mechanical harvesting.

This paper reports the results of a series of experiments conducted in Southern Tanzania over an eight-year period which were designed to evaluate the effectiveness, relative to hand harvesting, of simple mechanical aids (blades from Kenya, and shears from South India), and to specify how best they could be adapted and successfully used with tea clones having contrasting morphological characteristics.

METHODOLOGY

The experiments were all sited in areas of mature tea at the Ngwazi Tea Research Station (8º32´ S, 35º10´E, altitude 1840 m asl) in the Mufindi District of Southern Tanzania. Burgess and Carr (1996a) have presented full details of the site and its seasonal climate.

There were three related experiments: experiment 1 was primarily designed to compare the effects of three harvesting methods (hand, blade and shears) on the productivity of two clones with different size shoots. The first phase (experiment 1a) covered a three-year period (1992 - 1995); the second phase (experiment 1b) lasted four years (1996-2000). Experiment 2 examined the effects of harvesting frequency using shears for one year (1994) only, whilst experiment 3 compared three harvesting intervals and three harvesting methods over a four-year period (1996-2000).

Harvesting methods

In all the *hand harvesting* treatments, the 'pluckers' (men and women) were instructed to remove all shoots with two or more unfurled leaves, including soft dormant shoots, protruding above the level surface of the bush.

The blade harvesting technique was developed in Kenya by Brooke Bond Kenya Ltd (J. Rono, personal communication; 1992). The blade consists of a blunt knife, made from galvanised steel, positioned 15 mm above a horizontal aluminium platform or base plate (Fig. 1). The blade is held in one hand so that the platform rests on the bush surface. The blade is then moved towards the operator, who uses the other hand to guide shoots into the path of the knife, where they are broken. To minimise the observed adverse effects of the blade 'digging' into the canopy, the platform, which measured 100 mm x 150 mm for experiment 1a, was enlarged to 100 mm x 250 mm for experiments 1b and 3.

The shear harvesting system is based on ordinary garden shears with the following modifications: a tray is attached to the lower blade for collecting the harvested shoots and the upper blade supports a plate which pushes the cut shoots into the tray (Fig. 2). The base of the tray rests on the top of the crop canopy. The height at which the shoots are cut, relative to the effective surface of the canopy, is a measure of the intensity of harvesting. With shears this can be changed by varying the space (or step) between the base of the tray and the top of the lower blade (Suryanarayanan and Hegde, 1993). In turn this controls the rate of increase in height of the crop canopy above the ground.

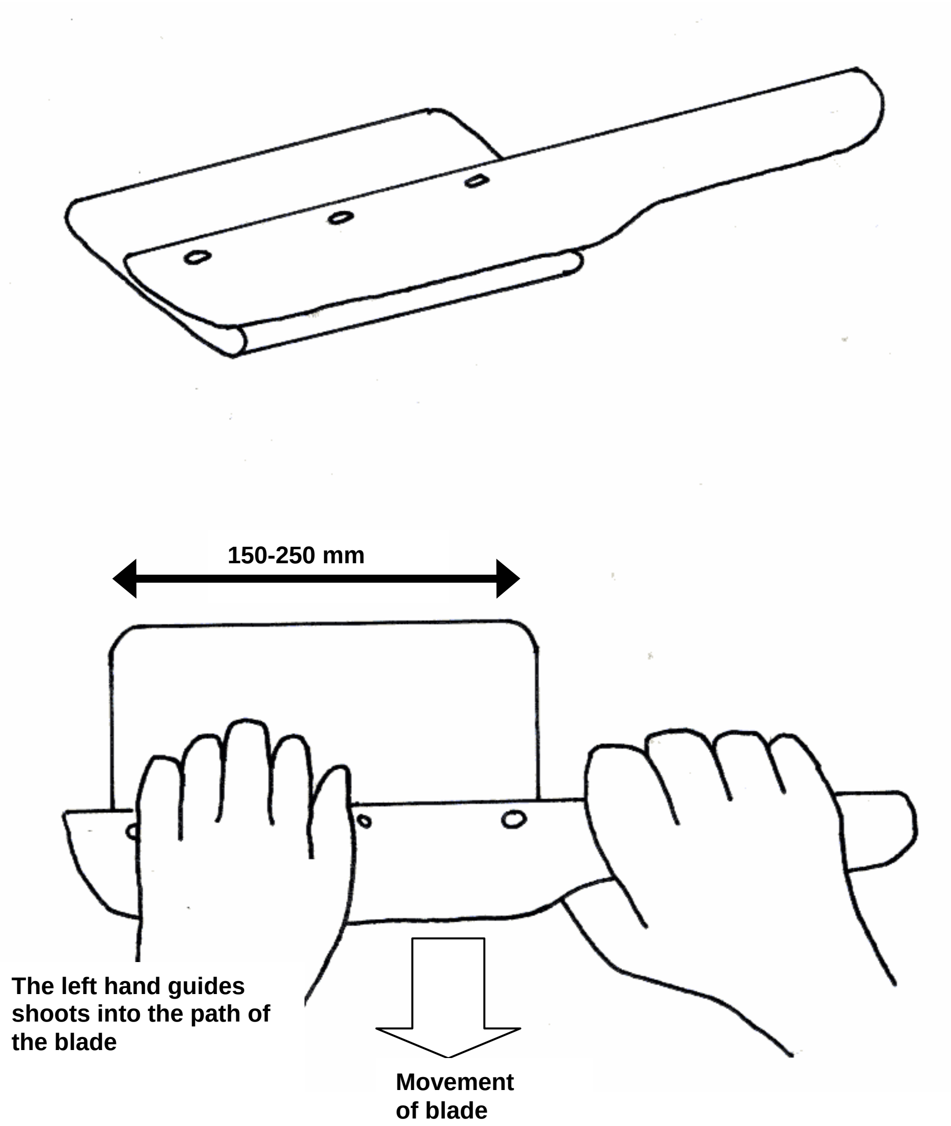

Fig. 1. The blade.

To assess the effects of the intensity of harvesting, three step heights were compared in experiment 1a: 5, 22, and 32 mm. The '5-mm step' treatment was in effect the minimum step height being the sum of the thickness of the lower blade and the tray. In January 1993, a small levelling plate was added to the upper blade to improve height control on the 22 and 32 mm step shears (Fig. 2). In experiment 1b, the levelling plates were removed and the step heights were modified to 5, 14, and 22 mm. In experiment 2, shears with a step height of 22 mm with a levelling plate were used in all the harvesting treatments. A 5-mm step (flat) shear was used in experiment 3.

After 1994, to overcome any bias resulting from the relative ability of people to harvest tea using the different techniques, everyone involved was trained in all of the harvesting methods. Individuals were then allocated at random to each treatment at each harvest event.

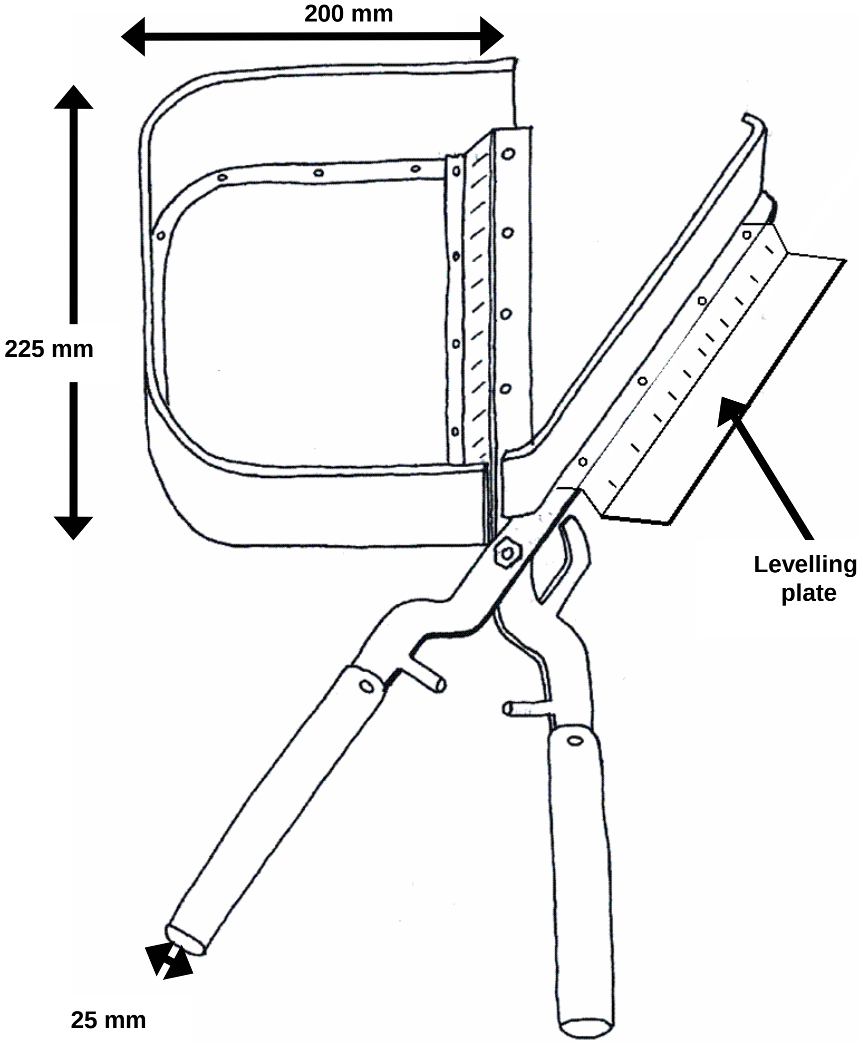

Fig. 2. The step shear including a levelling plate.

Clones

In total, four clones, representing a range of shoot and leaf sizes were compared. These ranged from two large-leafed Assam-type clones called KE BBK35 (from Kenya) and TZ BBT282 (from Tanzania) to a small-leafed China-type clone called TZ BBT207 also from Tanzania. The fourth clone, KE BBK7, was originally selected in Kenya and has intermediate-sized leaves and shoots. For brevity, in the rest of this paper, these clones are referred to as K35, T282, T207, and K7 respectively. All had been planted in 1971, at spacings corresponding to 0.9 m x 1.2 m and harvested by hand until the start of experiment 1a. Whenever the potential soil water deficit reached 80 mm, the site was uniformly irrigated with sprinklers during the dry season to bring the soil back to field capacity. In the year of pruning (1996), following bud break, irrigation was scheduled using pan evaporation adjusted for crop cover. Fertilizer was applied at an annual rate of 300 kg N ha^{-1}, as a $N:P_2O_5:K_2O$ 2:1:1 or 2:1:2 compound, in two equal splits. From April 1995, zinc was applied at annual rates of between 1.5 and 4.5 kg zinc oxide ha^{-1}. Prior to the start of experiment 1a in 1992, the experimental area was last pruned in June 1990. The normal interval between prunings in this part of Tanzania is four years.

Harvesting frequency

With the tea crop, a phyllochron (P) can be defined as the time interval (day) between a terminal bud unfurling its second and third true leaves (Burgess and Carr, 1998). In experiments 1a and 1b, the shoots were harvested at standard intervals of two phyllochrons (2 P), as recommended for hand harvesting in Tanzania, although an extended interval (4 P) was also tested. In experiment 2, the harvest interval was the principal treatment ranging in equal increments from 1.8 to 4.2 P. In experiment 3, the intervals were 2, 3 and 4 P. At the experimental site, an interval of 2 P corresponds to about 14-18 d during the warm season and up to 30 d during the cool winter months.

The seasonal change in a phyllochron, and hence the appropriate harvest interval was initially estimated from the mean air temperature (T_{mean}; ºC) and its relationship with the mean leaf appearance rate ($1/P$; d^{-1}) of six clones (Equation 1, Burgess and Carr, 1998):

$$1/P = 0.0162\ (T_{mean} - 9.0). \qquad (1)$$

After September 1993, the duration of a phyllochron was determined from a similar relationship determined specifically for the four clones represented in these experiments (Equation 2):

$$1/P = 0.0156\ (T_{mean} - 9.1) \qquad (2)$$

Although the clones differed in their apparent base temperatures for leaf appearance rate (K7: 6.0ºC; T282 and K35: 9.3ºC; T207: 10.6ºC), a common equation was adopted because logistically it was not possible to harvest individual clones on different days.

Experimental design

In *experiment 1a*, six harvesting treatments were replicated four times in adjacent areas of clones K35 (large shoots) and T207 (small shoots) in a randomised complete block design. There were 20 bushes in each plot, which were surrounded by single guard rows which were harvested in the same way as the 20 bushes. The treatments compared were hand, blade, and shear (with 5, 22, and 32 mm steps) harvested at 2 P intervals. The sixth treatment comprised the use of the 5-mm step (or flat) shears at an interval of 4 P. The harvesting treatments were first imposed in July 1992, at the start of the cropping year during the winter, and continued until June 1995 when the bushes were pruned. The residual effects of the harvesting treatments were then assessed by hand harvesting all the plots and recording yields for one year.

Experiment 1b began in June 1996 when six harvesting treatments, replicated in each of four blocks, were again imposed on clones K35 and T207. The allocation of harvesting treatments to plots was the same as in experiment 1a, except that 14-mm and 22-mm step shears were used in the previous 22-mm and 32-mm step shear plots respectively. Hence the methods compared were hand, blade (with a modified platform), and the shear (at step heights of 5, 14 and 22 mm), all at a 2 P interval, and the 5-mm step (flat) shear at a 4 P interval. The experiment continued for four years until July 2000 when it was pruned.

In *experiment 2*, five harvesting intervals were compared (1.8, 2.4, 3.0, 3.6 and 4.2 P), using the 22-mm step shears, in an area of clone K35 adjacent to experiment 1a and at the same stage in the pruning cycle (years four to five) for 12 months beginning in January 1994. There were four replicates of each treatment and the plot sizes and experimental design were similar to those described for experiments 1a and 1b.

In *experiment 3*, conducted from June 1996 to May 2000, the effects of three harvesting intervals on hand, blade and shear harvesting were examined on blocks of clones K7 (intermediate shoot size) and T282 (large shoots) adjacent to experiment 1b. Due to space restrictions, it was only possible to examine two harvest treatments on each clone. For K7, hand harvesting was compared with the blade at three harvest intervals (2, 3 and 4 P). For T282, hand harvesting was compared with the flat shear at the same three intervals. There were four replicates of each treatment combination and the experimental design and plot sizes were identical to those for experiments 1a and 1b.

Measurements

Across the four experiments, measurements were made of the yields of fresh shoots and corresponding dry matter contents, the composition of the harvested shoots, and indirect measures of plant vigour. There was an attempt to assess the quality of the processed tea from experiment 1a, during August and September 1993 at a time when the shoots were still growing slowly. However with this limited dataset, it was not possible to determine a significant effect of the harvest treatments on the value and character of the processed tea, and therefore this research is not reported.

Yield: in all the experiments, the fresh weights of shoots removed from individual plots were recorded at each harvest. In experiments 1a, 1b and 3, representative samples (about 30 - 70 g) were then taken from individual clones for dry matter determinations from which the yield of dried tea could be calculated. The effects of harvesting treatments on dry matter contents were small and were ignored. On days when dry matter contents were not determined, estimates for each clone were made by interpolation. The values for a single clone ranged from about 18 % during the rainy season to 30 % during the cool, dry weather.

In experiment 2, the mean dry matter content of the harvested shoots in 1994 was 23.3%, and this value was used to derive the dried tea yields from the fresh weight measurements. The yield data were also corrected to allow for differences in the duration of the experiment (range 358 to 366 d) depending on the harvest interval. The total number of harvests during the year varied from 11 (4.2 P) to 24 (1.8 P). The corresponding minimum and maximum harvest intervals were 27 and 51 d, and 11 and 26 d, respectively.

Fresh shoot composition and numbers: samples of shoots (150 - 200 g) were taken for analysis of shoot composition, from each plot at each harvest in three replicates of experiment 1a and from all four replicates in experiment 2. The samples were separated into broken, growing, and dormant shoots. A shoot was classified as broken if it had no terminal bud, even if the remaining leaves were intact. Broken shoots were also separated into “soft” and “coarse” categories. The coarse category included pieces of broken stem and those broken shoots where the most mature leaf broke, if folded on one side parallel to the mid-rib. The weight of broken shoots and coarse broken shoots were then expressed as a proportion of the total fresh weight of the sample. The growing shoots were categorised according to the number of unfurled leaves, the number of shoots in each category was counted, and each sample was weighed. The mean shoot weight (fresh) at each harvest was calculated as the total weight (including broken shoots) divided by the total number of buds. For each harvest, the total number of shoots harvested per plot was also determined by dividing the total fresh weight harvested by the respective mean shoot weight.

Plant vigour: the effects of different harvesting treatments on the inherent long-term vigour and productivity of the tea plants were assessed indirectly using several parameters. In experiment 1a, to provide a measure of harvesting intensity, seasonal measurements were made of the increase in the height of the canopy surface (known as the plucking table) above the ground at five randomly selected points in each plot. The leaf area index was also measured in experiment 1a in June 1995 immediately prior to pruning, and in experiment 2 in February 1995. The total area of leaves within a 200 mm x 200 mm section, taken through the centre of one representative bush from the guard row of each plot in each of three or four replicates, was measured using the technique described by Pethiyagoda and Rajendram (1965). This was converted to the equivalent leaf area index by dividing by the projected ground area (0.04 m^2). In experiment 1b, the leaf area index was measured in May 2000, immediately prior to pruning, on two bushes within each treatment of two replicate blocks.

When the bushes in experiment 1a were pruned in mid-July 1995, all the foliage was removed above a height of 0.45 m. The fresh weights of the prunings, taken from one representative bush per plot, were recorded. After chopping and mixing, the dry matter content of a sub-sample (about 50 g) was then determined by drying in an oven to constant weight.

RESULTS

Effects of harvest method on yield

In experiment 1a, the first two harvests after the imposition of treatments were influenced by the changeover in harvesting practice, with a large proportion of coarse broken shoots (20 - 50 %) from plots harvested with the blade or shears. At the third harvest, in September 1992, the coarse component had declined in all treatments to below 20 % where it remained. The yields reported here therefore begin from 1 September 1992. With that exception, the annual yields presented are for 12-month periods, 1 June to 31 May (Fig. 3).

By commercial standards the annual yields of dried tea obtained were large, ranging from 4000 to 8500 kg ha^{-1}. In experiment 1a, yields tended to increase with time for all harvesting treatments, even into the fifth year from prune (1994/95). The decline in yields observed in experiment 1b between June 1998 and May 1999, which was also apparent on commercial estates, was associated with an annual rainfall of only 650 mm compared to 1290 mm in the preceding 12 months.

Blade harvesting clone K35 (large shoots) gave similar yields to hand harvesting in each year of experiment 1a (Fig. 3a). However, with clone K35 over the four years in experiment 1b, there was an 8 % advantage ($p < 0.05$) in favour of hand harvesting (6540 ± 486 kg ha^{-1} a^{-1}) compared to the blade (6065 ± 401 kg ha^{-1} a^{-1}). By contrast, blade harvesting clone T207 (small shoots) resulted in annual yields 19 to 24 % greater than those from hand harvesting in the third (1992/93) and fifth (1994/95) years after pruning in experiment 1a (Fig. 3b). In experiment 1b, harvesting clone 207 with a blade rather than by hand resulted in: a yield benefit of 10 % in the first (1996/97) and second years (1997/98) after pruning, similar yields in the third year (1998/99), and a yield loss of 6 % in the fourth year (1999/2000).

Across the two clones, the flat (5-mm step) shears resulted in lower ($p < 0.05$) yields than those obtained by hand and blade harvesting in the fourth year from pruning (1993/94) in experiment 1a, and in each year of experiment 1b. There were indications that the yield reductions from these flat shears, relative to hand harvesting, were greater for K35 (large shoots) than T207 (small shoots). Across all seven years of both experiments the average annual yield from K35 when using flat shears (5470 ± 330 kg ha^{-1}) was 14 % less than that obtained by hand harvesting (6360 ± 355 kg ha^{-1}). For T207, the corresponding values were 5900 ± 263 kg ha^{-1}, - 8 %, and 6420 ± 315 kg ha^{-1}.

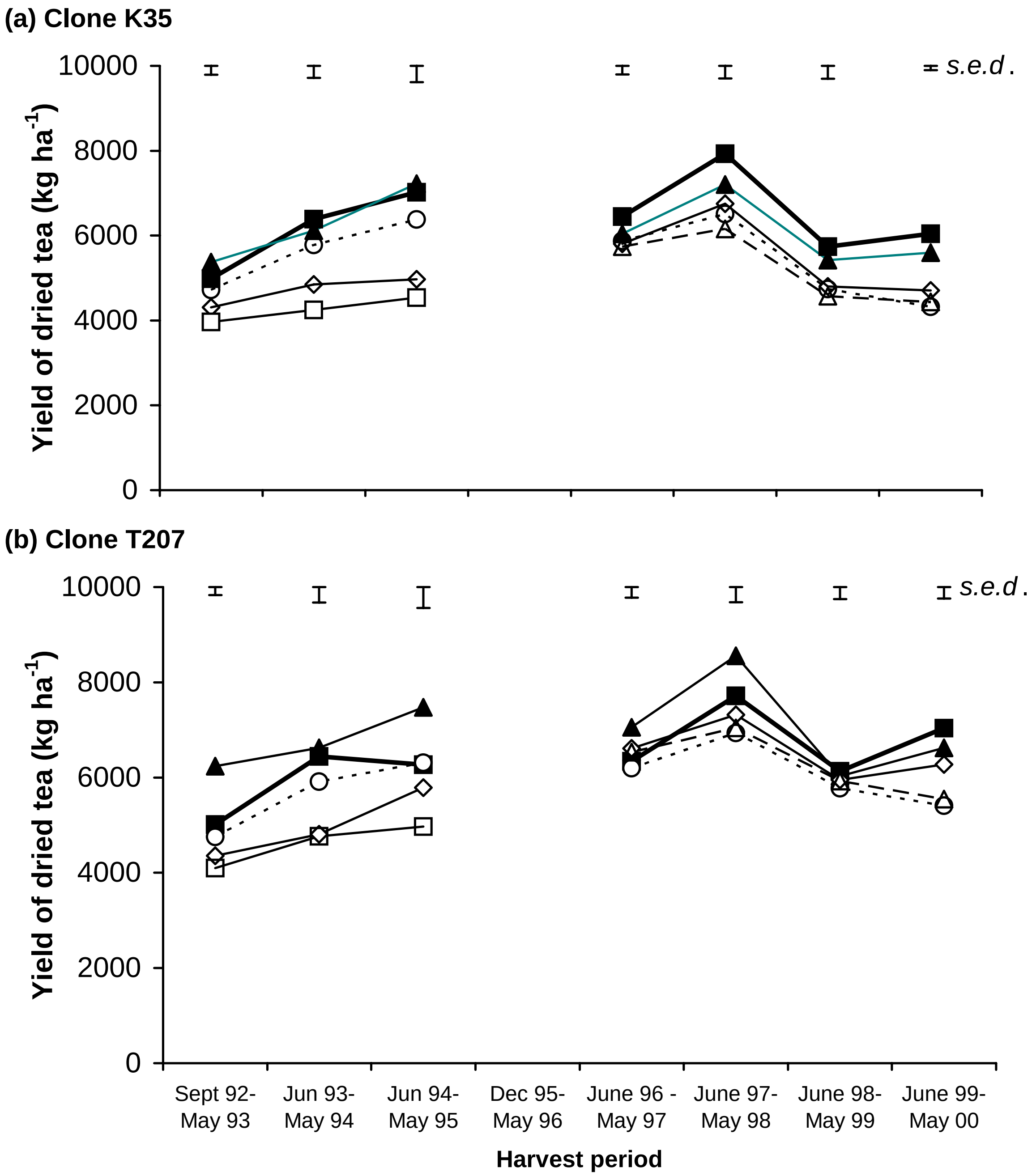

Fig. 3. Effects of harvest method (■: hand harvest; ▲: blade harvest, O: 5-mm step shear, △: 14-mm step shear (1996-2000), ◇: 22-mm step shear, and □: 32-mm step shear (1992-1995)) at an interval of two phyllochrons on the mean annual yields of dry tea from clones (a) K35 and (b) T207 between September 1992 and May 1995 (experiment 1a), and between June 1996 and May 2000 (experiment 1b) (n = 4).

In experiment 3, with K7 (intermediate-sized shoots), hand and blade harvesting (at 2 P intervals) resulted in similar yields in each of the four years (Fig. 4a). This response is intermediate to that observed for K35 and T207 in experiment 1b. For T282 (large shoots), when using flat shears the corresponding mean annual yield (5140 ± 470 kg ha^{-1}) was 85% of that (6030 ± 388 kg ha^{-1}) obtained by hand harvesting (Fig. 4b). This is similar to the response of K35, also large shoots, in experiment 1b.

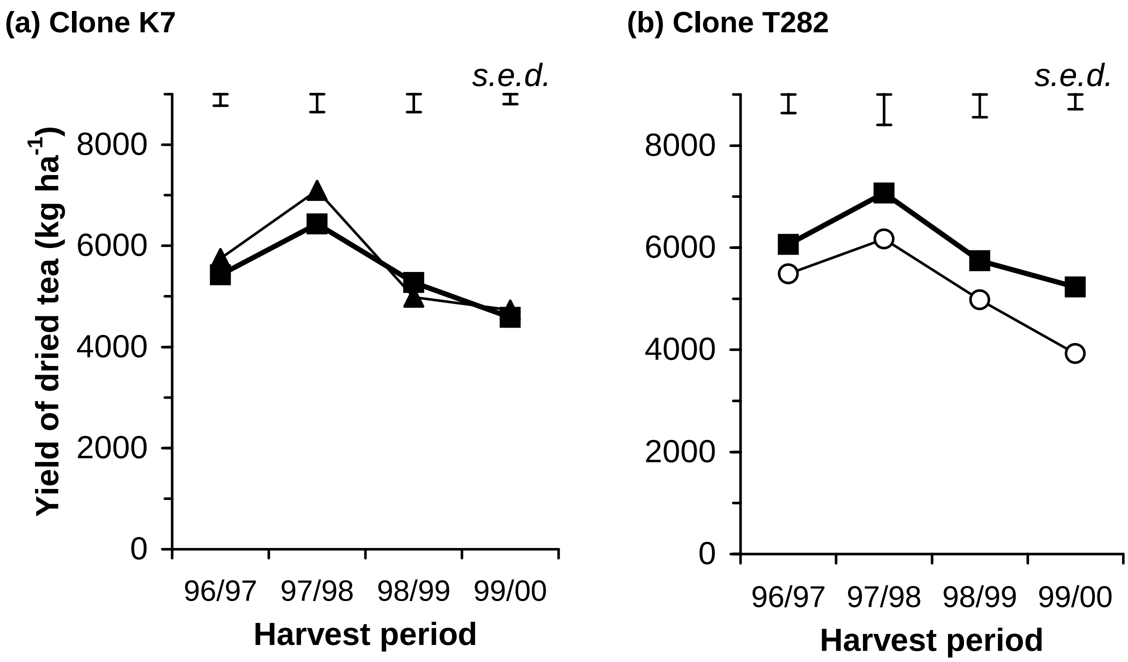

Fig. 4. Experiment 3: effects of harvest method at an interval of two phyllochrons on the mean annual yields of dry tea between June 1996 and May 2000 from clones (a) K7 (■: hand harvest and ▲: blade harvest) and (b) T282 (■: hand harvest and O: 5-mm step (flat) shear); (n = 4).

Effects of step height on yield

Over the three years of experiment 1a, an increase in the shear step height consistently resulted in a *decrease* in the mean annual yield from each clone. This was equivalent to 51 and 38 kg dry tea ha^{-1} per mm increase in step height, over the range 5 to 32 mm, for clone K35 and T207 respectively (Fig. 3). In experiment 1b, following the introduction of treatments 12 months after pruning and the removal of the levelling plates, the effect of step height appeared to change. Between June 1996 and May 2000, whereas the annual yields from K35 (large shoots) were similar regardless of step height (5 to 22 mm; Fig. 3a), yields from T207 (small shoots) *increased* at an average rate of 27 kg ha^{-1} mm^{-1} (Fig. 3b).

Effects of harvest interval on yield

When using *flat shears* (experiments 1a and 1b), doubling the harvest interval from 2 to 4 P increased the mean annual yields from K35, over the seven years, by an average of 17 % from 5470 ± 330 kg ha^{-1} to 6400 ± 295 kg ha^{-1} (Fig. 5). This is equivalent to an annual yield increase of 465 kg ha^{-1} per phyllochron. This response appeared to be more consistent during the second pruning cycle (1996 - 2000) than the first (1992 - 1995).

The effects of incremental changes in the harvest interval on K35 (large shoots) were also examined in experiment 2 using 22-mm *step shears*. Increasing the harvesting interval from 1.8 to 4.2 P increased annual yields of dry tea from 4780 to 6260 kg ha^{-1}, equivalent to about 620 kg ha^{-1} per phyllochron (Fig. 6). During the four years of experiment 3, the mean increase in the annual yield of the shear-harvested shoots from clone T282 was equivalent to 740 kg ha^{-1} per phyllochron (data not shown).

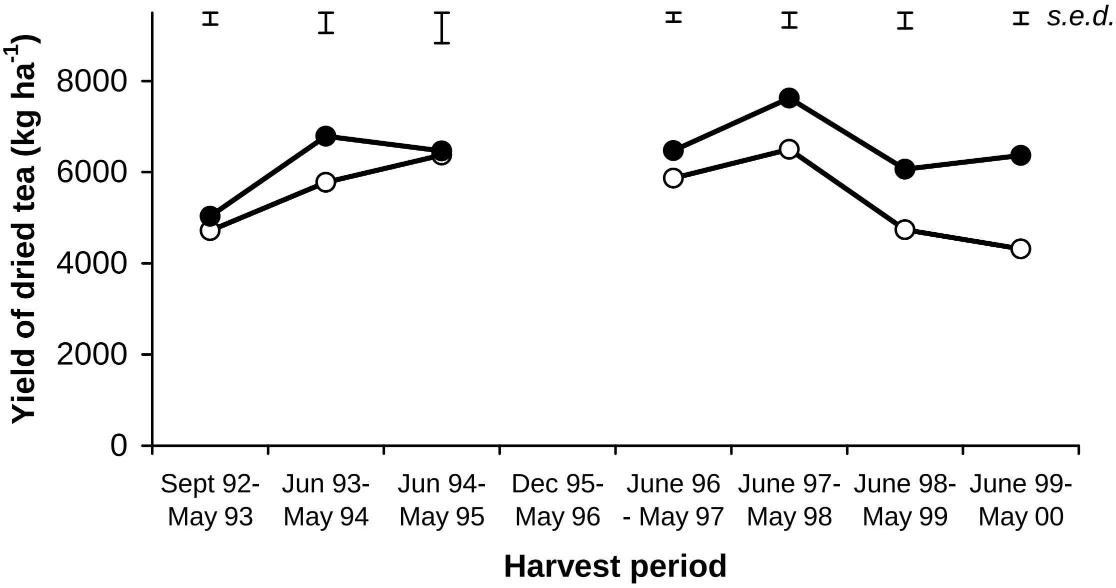

Fig. 5. Effects of harvest interval (○: 2 phyllochrons and ●: 4 phyllochrons) on the mean annual yields of dry tea harvested with 5 mm step (flat) shears from clone K35 between September 1992 and May 1994 (experiment 1a) and between June 1996 and May 2000 (experiment 1b) (n = 4).

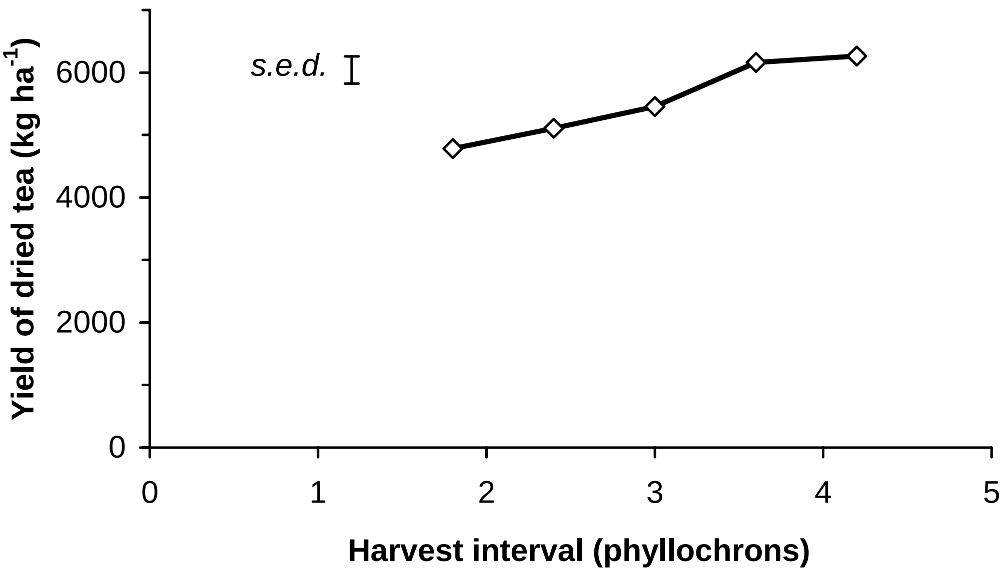

Fig. 6. Experiment 2: effect of harvest interval on the mean annual yield of dry tea harvested with a 22-mm step shear from clone K35 between 6 January 1994 and 4 January 1995 (n = 4).

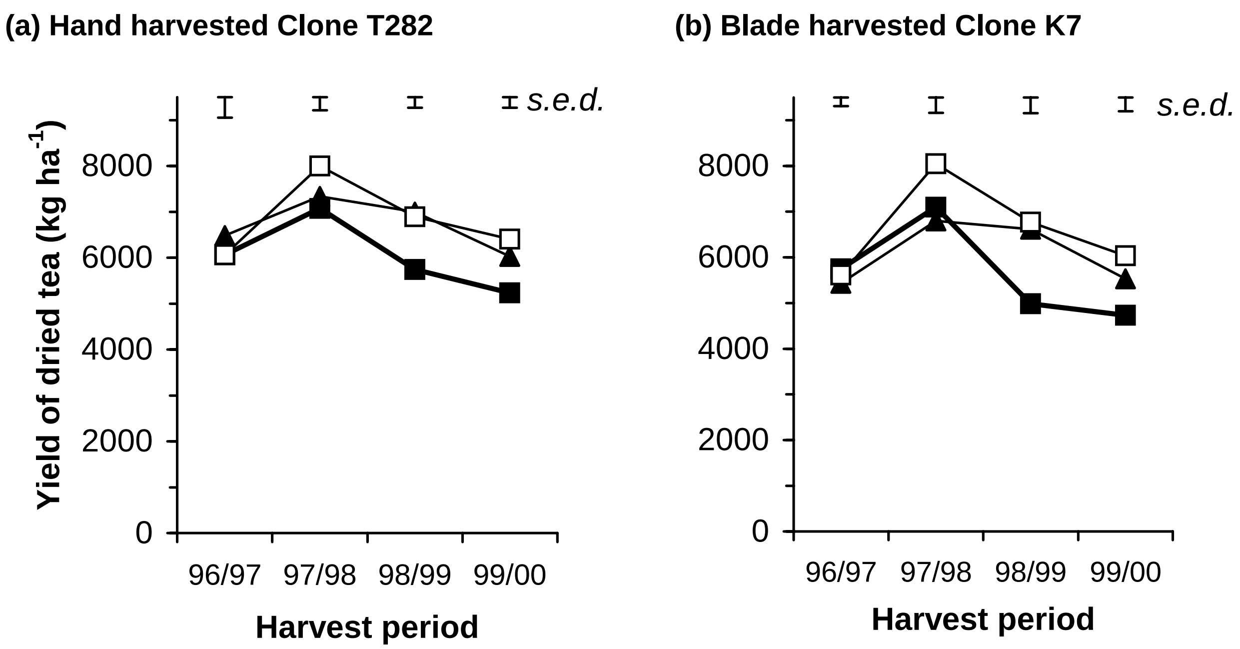

Fig. 7. Experiment 3: effects of harvest interval (■: 2, ▲: 3, and □: 4 phyllochrons) on the mean annual yield of dry tea from June 1996 to May 2000 from (a) hand harvested clone T282 and (b) blade harvested clone K7 (n = 4).

With hand harvesting, increasing the harvest interval from 2 to 4 P with K7 (intermediate-sized shoots) in experiment 3 had no significant effect on yields (data not shown). By contrast, for T282 (large shoots), annual yield benefits were apparent in the third, fourth and fifth years from pruning averaging 540 kg ha^{-1} per phyllochron (Fig. 7a). Similar comparisons were made with blade harvesting (experiment 3, K7). In the second year after pruning the yields at intervals of 2, 3 and 4 P were similar, but in the third, fourth and fifth years after pruning, the annual yield benefit from extending the harvest interval from 2 to 4 P averaged about 670 kg ha^{-1} per phyllochron (Fig. 7b).

Effects of harvest method on shoot numbers and composition

In experiment 1a with clone K35 (large shoots), similar numbers of shoots (2170-2740 m^{-2}) were harvested from the hand, blade and flat-shear plots within each year (Table 1a). However, increasing the step height on the shears to 32 mm decreased the number of harvested shoots by 25-30% from 2460-2740 m^{-2} to 1840-1880 m^{-2}. For T207 (small shoots), the number of shoots harvested with the blade and the flat-shear (5300-5530 m^{-2}) was 15-20% greater than that (4620 m^{-2}) harvested by hand in the third year after pruning (1992/93), and similar (4260-4890 m^{-2}) in the fourth (1993/94) and fifth (1994/95) years. Adding a 30-mm step to the flat shear reduced the number of harvested shoots within a given year by 20-32% from 4680-5300 m^{-2} to 3550-3730 m^{-2}.

In the same experiment, during the fourth year after prune (1993/94), hand-harvesting K35 and T207 at 2 P intervals resulted in mean shoot weights of 1.02 and 0.55 g respectively (Table 1b), just above those corresponding to shoots with three unfurled leaves, 0.89 and 0.47 g respectively (Fig. 8).

For K35, the mean weight of shoots harvested using a blade was similar to that from hand harvesting (Table 1b). By contrast with T207, in the fourth and fifth years after pruning (1993/94 and 1994/95), shoots harvested with a blade were 7 - 13 % heavier than those from hand harvesting. Across the three years, the mean weights of shoots harvested from K35 and T207 with flat shears were 87 and 88 % respectively of those obtained by hand-harvesting. There was also a trend, significant for T207 in 1992/93 and 1994/95, for mean shoot weight to increase with step height.

Table 1. Experiment 1a: effects of harvesting method, for clones K35 and T207, on (a) number of harvested shoots, (b) mean fresh shoot weight, and proportions of (c) broken shoots and (d) coarse broken shoots for each of three harvest periods (September 1992 to May 1993, June 1993 to May 1994, and June 1993 to May 1995; n=3).

Factor and clone	Harvest period	Harvesting method					*s.e.d.*
		Hand	Blade	Shear 5 mm	Shear 22 mm	Shear 32 mm	
(a) Number of harvested shoots (m^{-2})							
K35	92-93	2170	2480	2460	2200	1840	142
	93-94	2710	2460	2740	2060	1880	224
	94-95	2670	2520	2490	1940	1860	130
207	92-93	4620	5530	5300	4480	3590	277
	93-94	4600	4460	4680	3900	3730	373
	94-95	4260	4500	4890	4140	3550	371
(b) Mean shoot weight (g)							
K35	92-93	1.05	1.00	0.88	0.92	0.98	0.042
	93-94	1.02	1.08	0.90	1.04	1.01	0.066
	94-95	1.16	1.22	1.06	1.08	1.08	0.047
T207	92-93	0.49	0.51	0.40	0.44	0.51	0.015
	93-94	0.55	0.59	0.51	0.51	0.53	0.025
	94-95	0.62	0.70	0.55	0.57	0.61	0.018
(c) Broken shoots (%)							
K35	92-93	40	42	51	54	54	1.7
	93-94	43	43	58	64	57	1.7
	94-95	48	49	64	65	60	0.9
T207	92-93	42	39	49	53	50	2.1
	93-94	47	44	60	56	51	2.5
	94-95	47	50	65	60	57	1.5
(d) Coarse broken shoots (%)							
K35	92-93	5.7	7.5	8.5	6.4	6.8	1.07
	93-94	3.7	6.9	7.2	3.5	4.5	0.92
	94-95	4.4	7.3	4.7	3.8	4.4	0.48
T207	92-93	5.8	7.8	8.3	7.5	5.4	0.73
	93-94	6.3	9.4	6.4	5.4	6.0	0.90
	94-95	4.1	6.8	3.8	4.0	3.9	0.42

For K35, the proportions of broken shoots were similar whether harvested by hand or blade, increasing from 40 - 43 % in the third and fourth years after pruning to 48 – 49 % in the fifth year (Table 1c). Shear harvesting resulted in proportionally more broken shoots (53 – 65 %), and again there was an increase with year from pruning. T207 showed a similar response.

With hand harvesting, the proportion of coarse broken shoots obtained from clones K35 and T207 ranged from 3.7 to 6.3 % (Table 1d). Although the effect was not always significant, blade harvesting increased this proportion (6.8 - 9.4 %). In the first nine months following the imposition of treatments, shear harvesting resulted in more coarse broken shoots (8.3-8.5%) than hand harvesting (5.7-5.8%). However by 1994/95, two years after the imposition of treatments, values were uniformly low (3.8 - 4.7 %) for both harvesting methods.

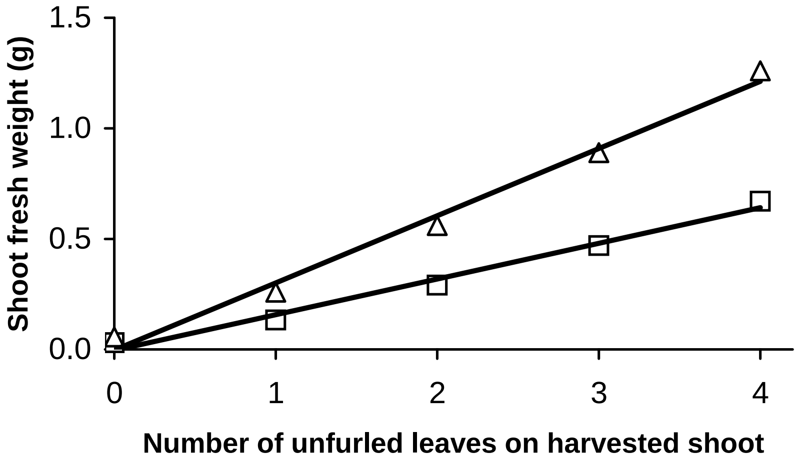

Fig. 8. Relation between the shoot fresh weight and the number of unfurled leaves for hand harvested shoots from fully irrigated clones K35 (△) and T207 (□) during the fourth year from prune, between June 1993 and May 1994.

Effects of harvest interval on shoot numbers and composition

In experiment 1a, for clone K35, doubling the harvest interval from 2 to 4 P when using flat shears, reduced the number of harvested shoots by 19% from 2740 to 2230 m^{-2}, and increased the mean shoot weight by 52 % from 0.90 to 1.37 g (Table 2). In the same experiment for clone T207, doubling the harvest interval reduced the number of harvested shoots by 23 % from 4680 to 3580 m^{-2} and increased the mean shoot weight by 49 % from 0.51 to 0.76 g. Although doubling the harvest interval decreased the proportion of broken shoots from 58 – 60 % to 44 – 46 %, the proportions of coarse broken shoots were similar (5.2 - 7.2 %).

Table 2. Experiment 1a: effects of harvest interval when using 5-mm step (flat) shears on clones K35 and T207 on the number of harvest shoots, mean fresh shoot weight, and proportions of broken and coarse broken shoots from June 1993 to May 1994 (n=3).

Factor	Clone and harvest interval (phyllochron)					
	K35			T207		
	2.0	4.0	*s.e.d.*	2.0	4.0	*s.e.d.*
Harvested shoots (m^{-2})	2740	2230	188	4680	3580	360
Mean shoot weight (g)	0.90	1.37	0.036	0.51	0.76	0.048
Broken shoots (%)	58	46	3.3	60	44	6.8
Coarse broken shoots (%)	7.2	5.7	1.0	6.4	5.2	1.0

In experiment 2 extending the harvest interval from 1.8 to 3.6 P, when using 22-mm step shears on clone K35, decreased the number of harvested shoots by 26% from 2480 to 1830 m^{-2} and increased the mean fresh weight of harvested shoots by 75% from 0.83 to 1.45 g (Table 3). Based on an extrapolation of the results presented in Fig. 8, these weights correspond to shoots with three and five unfurled leaves respectively. A further increase in the harvest interval from 3.6 to 4.2 P had no additional effect on shoot numbers and weight. When the harvest interval was increased from 1.8 to 3.6 P, the proportions of broken shoots and coarse broken shoots declined from 65 to 55 %, and from 7.7 to 4.4 % respectively (Table 3).

Table 3. Experiment 2: effects of the harvest interval with 22-mm step shears on clone K35 on number of harvested shoots, mean fresh shoot weight, and proportions of broken and coarse broken shoots harvested between 6 January 1994 and 4 January 1995 (n = 3), rise in the canopy height (15 January 1994 to 6 February 1995), and leaf area index (February 1995) (n = 4).

Factor	Harvest interval (phyllochron)					
	1.8	2.4	3.0	3.6	4.2	*s.e.d.*
Harvested shoots (m^{-2})	2480	2170	1810	1830	1880	172
Mean shoot weight (g)	0.83	1.00	1.31	1.45	1.43	0.042
Broken shoots (%)	65	60	57	55	56	1.7
Coarse broken shoots (%)	7.7	6.8	5.1	4.4	6.4	0.5
Canopy rise (mm a^{-1})	18	26	36	64	51	1.0
Leaf area index	6.3	6.0	6.2	7.2	7.7	1.33

Effects of harvesting method on plant vigour

In experiment 1a, the annual increase in the height of the top of the crop canopy, the leaf area index, and the weight of prunings were all influenced by harvesting method. In general, the canopy height increase was least with the blade and flat shears and greatest for the 32-mm step shears (Table 4). The canopy of clone T207 consistently rose more rapidly than that of K35, and the increase was greater in the fifth year from pruning (1994/95) than in the third and fourth years.

Following three years of differential harvesting, the leaf area indices recorded before pruning were greatest on bushes harvested with the step shears, and least for the flat shears (Table 4). Values were consistently larger for T207 than for K35, for example 12.1 and 7.1 respectively for hand harvested plants, a reflection again of differences in plant morphology. The lowest and highest values recorded were 4.7 (flat shear; K35) and 14.8 (32-mm step shear; T207).

At the end of experiment 1a, large dry weights of prunings were associated with large rises in the table height and large leaf area indices (Table 4). The mean weight of prunings obtained from T207 (24 t ha^{-1}) was almost significantly (p = 0.06) greater than that from K35 (19 t ha^{-1}). There was no significant ($p \leq 0.05$) clone x harvest method interaction. Although the weights of prunings obtained from the hand, blade and flat shear treatments were similar, they increased with step height (from 5 to 32 mm).

In the 12 months following pruning, all the plots were hand harvested, regardless of previous harvesting methods, to monitor any residual effects on bush vigour. Yields were generally similar, but there was a suggestion that, for both clones, bushes previously harvested by the shears out-yielded those that had been harvested by hand or blade (Table 4).

Table 4. Experiment 1a: effects of harvesting method, at an interval of two phyllochrons, on clones K35 and T207 on the annual increase in canopy height for two periods (n = 4), leaf area index (n=3), pruning weight (n=4), and dry shoot yield in the year after pruning (n=4).

Factor and clone	Time period	Harvesting method					*s.e.d.*
		Hand	Blade	Shear 5 mm	Shear 22 mm	Shear 32 mm	
Canopy height rise (mm a^{-1})							
K35	Jun 92-Apr 94	46	40	12	50	77	8.9
	Apr 94-Jun 95	75	36	25	56	99	9.9
T207	Jun 92-Apr 94	84	41	44	73	93	16.0
	Apr 94-Jun 95	95	76	56	107	134	13.7
Leaf area index							
K35	June 1995	7.1	7.9	4.7	7.9	9.0	1.78
T207	June 1995	12.1	9.3	8.9	12.7	14.8	1.86
Pruning weight (t dry matter ha^{-1})							
K35	June 1995	20	14	14	25	22	2.9
T207	June 1995	22	19	23	27	29	4.0
Shoot yield (t ha^{-1})							
K35	Jun 95-May 96	2.1	2.0	2.5	2.3	2.3	0.13
T207	Jun 95-May 96	2.1	2.2	2.3	2.5	2.6	0.18

In experiment 1b, where harvesting treatments were imposed 12 months after pruning, the leaf area indices (3.5-6.8) (Table 5) measured in May 2000, five years after pruning, were substantially less than those (4.7-14.8) measured in experiment 1a, also five years after pruning (Table 4). Across the two clones, the mean leaf area indices of the bushes harvested with blades (4.5) and the flat and 14-mm step shears (3.7-4.1) were less than that (6.3) of the bushes harvested by hand.

Table 5. Experiment 1b: effects of harvesting method and harvest interval on the leaf area index of clones K35 and T207 in May 2000 (n = 4 for individual clone).

Clone	Harvesting method and harvest interval (phyllochrons)						*s.e.d.*
	Hand	Blade	Shear 5 mm	Shear 14 mm	Shear 22 mm	Shear 5 mm	
	2.0	2.0	2.0	2.0	2.0	4.0	
K35	6.8	5.0	3.3	4.8	5.4	5.3	0.22
T207	5.8	4.0	4.2	3.5	4.8	6.1	1.11
Mean	6.3	4.5	3.7	4.1	5.1	5.7	0.56

Effects of harvest interval on plant vigour

In experiment 1a, extending the harvest interval from 2 to 4 P, when using flat shears, increased the mean annual incremental rise in canopy height by K35 and T207, between April 1994 and June 1995, from 39 to 68 mm (Table 6). The mean leaf area index was also increased by 27 % from 6.8 to 8.6. The weights of the prunings and the subsequent yields (data not shown) when all the plots were hand-harvested were similar for the two harvest intervals.

In experiment 2, extending the harvest interval from 1.8 to 4.2 P using step shears (22 mm), increased the annual rise in canopy height from 18 to 51 mm (Table 3). The leaf area indices recorded one year after the imposition of treatments were similar, ranging from 6.0 to 7.7 across the five harvest intervals (Table 3).

Table 6. Experiment 1a: effects of harvest interval (two and four phyllochrons) with a 5-mm step (flat) shear on the annual rise in the height of the canopy (n = 3) (June 1994 to May 1995), the leaf area index (n = 3) (June 1995), and the pruning weight for clones K35 and T207 (n = 4).

Factor	Clone	Harvest interval (phyllochron)		
		2.0	4.0	*s.e.d.*
Canopy height rise	K35	25	58	15.4
(mm a^{-1})	T207	56	77	17.0
	Mean	39	68	11.5
Leaf area index	K35	4.7	6.7	1.07
	T207	8.9	10.6	0.34
	Mean	6.8	8.6	0.56
Pruning weight	K35	14	14	2.3
(t dry matter ha^{-1})	T207	23	23	2.7
	Mean	19	19	1.8

DISCUSSION

As hand harvesting is still the control against which other harvesting methods are compared, the results from the hand-harvested treatments and their application to commercial practice are discussed first. This is followed by a consideration of the results from blade and shear harvesting. For shear-harvesting, the effects of step height and the choice of harvest interval are also examined.

It is important first to consider the environment in which this research was conducted, particularly the effect of temperature on shoot size and density. In the tea area (ca. 1800 m asl) of the Mufindi District of Southern Tanzania, the monthly mean air temperature ranges from 13 to 18 °C. The annual mean temperature of 16.5 °C is similar to the value recorded at high altitudes (up to 2200 m asl) close to the equator, where seasonal variations are small, for example at the Tea Research Foundation of Kenya in the Kericho District of Kenya (15 - 17 °C), but substantially less than those (18 – 24 °C) found at the headquarters of the Tea Research Foundation of Central Africa, Mulanje, Southern Malawi (ca. 650 m asl), where seasonal variations are large (Carr and Stephens, 1992). Low air temperatures result in reduced shoot extension and development rates (Burgess and Carr, 1997), which make true selective plucking difficult. Hence the commercial practice used in Southern Tanzania, known as 'hard' or 'black' plucking, involves the removal of all but the very smallest shoots that protrude above the canopy surface. By using derived relationships between shoot development rate and air temperature to specify the harvest interval for non-drought stressed tea in a rational and reproducible way, it is possible to allow for the seasonal differences in temperature (Burgess and Carr, 1998). Corrections can also be made for the effect of potential soil water deficit (Burgess and Carr, 1998). In turn, this approach allows the results to be extrapolated to elsewhere in East Africa (for example), and for tea harvesting to be scheduled in a scientific way, particularly for clones.

Hand harvesting

Annual yields, excluding the year following pruning, obtained by hand harvesting the morphological contrasting clones K35 and T207 ranged from 5.7 to 7.9 t ha^{-1}. These values are substantially more than the corresponding quantities harvested by hand from mainly seedling tea on commercial estates in the Mufindi District (currently about 4 t ha^{-1}), and suggest potential target yields in this locality. Some of this difference is due to the difficulty in maintaining a tightly-regulated harvesting regime, which results in the removal of all of the desired shoots at each harvest, particularly when employing workers on a piece-rate basis. Care therefore needs to be taken when directly relating experimental results to commercial practice. For example, it can be difficult to harvest by hand large yields from vigorous clones having a large number of small shoots such as T207, except in the initial stages of a pruning cycle when shoot density is low. The close monitoring of plucking standards, together with improved crop nutrition, may also explain why the hand harvested yields in experiment 1a increased from the fourth to the fifth year after pruning, whereas yields on local commercially-managed estates tend to decline after the third year.

It is not only yield that is important, as the quality of the harvested shoots and the resulting processed tea can have a large effect on the price realised in the world market and hence the profitability of tea production by estates or smallholders. Because we were unable to get reliable assessments of treatment effects on the value of the processed tea, we relied on criteria used to assess the quality of the fresh shoots entering the factory gate, namely mean shoot weight, the number of unfurled leaves on the shoots, and the proportions of broken shoots and coarse broken shoots.

In Kenya, Obanda and Owuor (1995) compared the quality of black tea produced from shoots with one, two, three and four unfurled leaves from two clones. As the number of unfurled leaves increased, the theaflavin content was reduced and the associated liquor had less colour (i.e. tended towards yellow rather than red) for both clones. Although coarse shoots decreased the brightness of the liquor for one clone, this effect was not significant for the other. Coarse shoots also tend to decrease caffeine content and, in Kenya, the aroma quality of black tea (Owuor and Obanda, 1998). Hence professional tasters and buyers generally place a lower value on tea produced from coarse, rather than fine, shoots. However the magnitude of this reduction will be dependant on the clone and the specific environmental conditions (Obanda and Owuor, 1995; Nyirenda, 1995). For example, in Malawi, Nyirenda (1995) reported a 1 to 13 % decline in the value of tea harvested from five clones if shoots with four rather than three unfurled leaves were processed.

In experiment 1a, the mean fresh shoot weight for a given harvesting standard varied considerably with clone. Although hand-harvesting K35 and T207 at 2 P intervals resulted in mean shoot weights corresponding to shoots with three unfurled leaves in both clones, shoots from K35 (0.89 g) were about 90% heavier than those (0.47 g) from T207 (Fig. 8).

Broken shoots can lead to premature oxidation of the harvested shoots and consequent reduced quality of the processed tea. For the hand-harvested treatment in experiment 1a (Table 1), the proportion of broken pieces increased from 40 to 48 % between the third and fifth years after pruning. These values are larger than those reported (26 - 28%) for hand

and shear harvesting of seedling tea in Malawi (Nyasulu, 2001), and Clowes (1986) suggested that the maximum proportion by weight of broken shoots in Malawi should be between 10 and 20 %, depending on the time from pruning. Using the same definition of "broken shoots" as used in this paper, Seyfullah (2001) reported that the proportion of broken shoots from hand-harvested clone PC 108 within an experiment in Southern Malawi was 24-33% during the growing season in the third year after prune. The high proportion of broken shoots, reported in this paper for harvesting experiments in Southern Tanzania, is probably a result of the local commercial practice of 'hard' or 'black' plucking and the difficulty in harvesting small shoots, resulting from relatively low temperatures and extended pruning cycles, compared to larger shoots that are produced in Malawi.

The mean proportion, by weight, of coarse broken shoots from hand-harvesting clone K35 ranged from 3.6 to 5.6 %. These values are close to that (3 %) reported for hand harvested clonal tea from Malawi (Jose, 1998; Seyfullah, 2001), but higher than the levels (0.3 - 0.7 %) reported for both hand and shear harvesting of experimental seedling tea in the same country (Nyasulu, 2001).

Blade harvesting

In experiment 1a, the use of the blade instead of hand harvesting, increased the yield from clone T207 (small shoots) by about 15 %. This yield increase resulted from the harvest of more shoots in the third year after pruning and the harvest of heavier shoots in the fourth and fifth years (Table 1a). By contrast, in the same experiment, there was no consistent difference between the yields from hand and blade harvested clone K35 (large shoots). One explanation for this is that, in the early stages of a pruning cycle, whereas it is relatively easy to remove most of the shoots of a large-leaf clone by hand, a greater proportion of the shoots of the small-leaf clone will be left on the bush. This is supported by the greater canopy height rise of hand-harvested compared to blade-harvested T207 for the period June 1992 to April 1994 (Table 4).

The relative intensity of blade harvesting in experiment 1a was also examined by determining a 'harvest index', defined as the dry yield of harvested shoots (Fig. 3) divided by the total dry matter produced above the height of the last prune (i.e. the sum of the weight of prunings plus harvested shoots, ignoring any fallen leaves; Table 4). For the period between September 1992 and May 1995, the 'harvest indices' calculated in this way for the blade harvested treatments (52 – 56 %) were greater than those for hand harvesting (44 - 47 %).

Although the proportion of broken shoots resulting from blade harvesting was similar to that from hand harvesting, the proportion of coarse broken shoots was greater (7 - 9 % compared to 4 - 6 %). A high proportion of coarse broken shoots increases the mean age of the harvested material and this may result in less theaflavin content and a reduction in the 'total colour' of the resultant liquor (Jose, 1998). In Malawi, the value of the tea processed from shoots with 10 % coarse broken shoots was 10 % less than that of tea with no coarse fraction, and the relationship was broadly linear between 0 and 40% (Jose, 1998). The results presented here therefore suggest that in Malawi, the increased coarse material associated with blade harvesting would reduce the value of the processed tea by 2 - 3 % compared to hand harvesting.

Shear harvesting

Harvesting with a flat shear reduced the yield of both K35 (large shoots) and T207 (small shoots) relative to hand harvesting. However, this reduction averaged over seven harvest years (experiments 1a and 1b) was greater for the clone with large (-14 %) rather than small (-8 %) shoots. Again, this difference may reflect the relative difficulty of harvesting by hand all the shoots from clone T207.

The proportion of broken shoots in the samples harvested using flat shears (50 – 65 %) was greater than those resulting from hand or blade harvesting (40 – 50 %) (Table 1c). This difference was probably caused by double cutting shoots when using shears. In southern India, Ravichandran and Partiban (1998) also reported that shear harvesting led to a greater proportion of mechanically-injured than unbroken shoots. One way to decrease the proportion of broken shoots is to extend the harvest interval (Tables 2 and 3), as discussed later. The proportion of coarse broken shoots obtained with the flat shear was 2.5 – 2.8 % greater than that for hand harvesting during the initial nine months after the imposition of harvesting treatments, but similar in the third year. A similar increase of about 1 % point in the proportion of coarse broken shoots in shear harvested compared to hand harvested samples has also been reported in Malawi (Jose, 1998).

Step height: in experiment 1a, harvesting clone K35 with a flat shear reduced the annual canopy height rise to 12 - 25 mm and reduced the leaf area index to 4.7 (Table 4). In this experiment, the shears were introduced after the bushes had been harvested by hand for 25 months following pruning. By contrast in experiment 1b, the use of a flat-shear on the same clone reduced the leaf area index to 3.3 (Table 5). The lower leaf area index in experiment 1b, compared to that in experiment 1a, may partly be a result of the shear being introduced 12 months, rather than 25 months, from pruning. This may have prevented the establishment of a sufficiently-dense canopy to support the shears or to maintain bush productivity.

Assuming Beer’s law (Saeki, 1963; Squire, 1990) and a light extinction coefficient for tea of 0.6 (Burgess and Carr, 1996b), leaf area indices of 4.7 and 3.3 would result in the leaves intercepting only 94 % and 86 % respectively of the incident solar radiation, compared with 99 % at an index of 8.0. Below a certain leaf area index, the reduction in light interception will have a significant effect on tea yields and long-term plant vigour. Whereas, in experiment 1a, a decline in the leaf area index of large-leaf clone K35 to 4.7 appeared to have no significant effect on the subsequent yield in the year after pruning, leaf area indices below 4.0 were associated with reduced yields in experiment 1b. Further research is needed to establish the critical leaf area index required to maintain maximum tea yields. However the results presented here suggest that a leaf area index of about 4 may be critical.

Where the leaf area index was maintained above about 4, adding a step on the shear generally reduce yields. In experiment 1a, during the fourth and fifth years (1993/94 – 1994/95) from prune, the annual yield reduction was equivalent to 62 kg ha^{-1} per mm increase in step height for K35, and 46 kg ha^{-1} mm^{-1} for T207. This yield reduction was the result of harvesting less shoots and, in part, a lower proportion of coarse broken shoots. This effect was less apparent in experiment 1b. This may partly be a result of the lower leaf area indices, discussed above. In addition the removal of the levelling plate on the upper blade in 1996 may have allowed individuals to tilt the shears into the canopy, mitigating the primary effect of the step.

On the basis of these observations, a possible strategy for designing a harvesting policy with shears (that cannot be tilted) is to choose the minimum step height that will create an adequate leaf area index to maintain yields. Once this minimum leaf area index is achieved, then experiment 1a indicates that any further increase in step height will decrease yield. Because of the reduced capacity of a tea canopy with a low shoot density to support shears, the minimum step height to maintain an adequate leaf area index is likely to be greater for large-leaf clones with a low shoot density, or for clones in the early stages of the pruning cycle, than for small-leaf clones with a high shoot density. However other clonal differences, such as variations in the rate of leaf abscission may also be important.

Harvest interval: the mean fresh weight of a shoot harvested with a flat shear in experiment 1a was about 90 % of that obtained by hand harvesting. To harvest shoots of a similar size to those obtained by hand harvesting (assuming they are the optimum size), a case can therefore be made for extending the harvest interval when harvesting with shears. In experiment 1a, when using a flat shear to harvest clone K35, extending the harvest interval from 2 to 4 P increased the mean shoot weight from 0.90 to 1.37 g, equivalent to 0.23 g per phyllochron (Table 2). In experiment 2, extending the harvest interval from 1.8 to 3.6 P using the 22-mm step shear increased the mean fresh weight of a harvested shoot from 0.83 to 1.45 g, equivalent to 0.34 g per phyllochron (Table 3). For the same period (1993/94), the corresponding mean shoot weight from hand harvesting was 1.02 g (Table 1). Based on this analysis, to raise the mean shoot weight from 0.90 g to about 1.00 g (equivalent to that obtained from hand harvesting), the harvest interval for the flat shear could be increased by between 0.35 and 0.50 P.

An additional effect of extending the harvest interval was to increase yields. In experiment 1a, lengthening the harvest interval from 2 to 4 P when using the flat shear resulted in a mean annual yield increase (from K35) of 570 kg ha^{-1} per phyllochron (Fig. 5). In experiment 2, when using the 22-mm step shear on the same clone, extending the harvest interval from 1.8 to 4.2 P raised the annual yield by 1480 kg ha^{-1}, equivalent to 620 kg ha^{-1} per phyllochron (Fig. 6). On this basis, lengthening the harvest interval by 0.5 P is likely to increase the annual yield when using flat shears by about 300 kg ha^{-1}. This would have been sufficient to offset about 60% of the yield loss observed in experiment 1a, when shear and hand harvesting were compared at a harvest interval of 2 P.

CONCLUSIONS

- The results of these experiments demonstrate the large yields and acceptable shoot quality that can be obtained from closely-monitored hand-harvested tea in the Mufindi District.
- The use of blades, with an appropriate plate and supervision, can result in even higher yields than hand harvesting, particularly for clones with a large number of small shoots that are difficult to harvest by hand (+13 %).
- Further research is required to establish the minimum leaf area index needed to maintain maximum tea yields. The results presented here suggest that it may be about 4. Assuming that this minimum leaf area is maintained then the step height on a shear should be as small as possible, as an increased step height leads to reduced yields. Because of the limited capacity of a tea canopy with a low shoot density to support the shears, the minimum step height is likely to be greater for large-leaf clones with a low shoot density than for small-leaf clones with a high shoot density.
- Using shears, at the same harvest interval as hand harvesting (2 P), results in lower yields and a higher proportion of broken shoots. However because the mean shoot size is smaller than that harvested by hand, the harvest interval could be extended slightly, up to 2.5 P, when shears are used.
- The impact of harvesting method on labour productivity and the value of the processed tea still needs to be evaluated.

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