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INTENSITY OF HARVESTING IN TEA

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SUMMARY

Intensity of harvest in tea can be defined in terms of the number of leaves or axillary buds left behind after a shoot is harvested; we describe a simple method for measuring it. Application of the method in trials confirms that yield increases with more intense (harder) harvesting. Differences in intensity of harvest explain much of the variation in yield between different harvesting treatments, including semi-mechanical and mechanical harvesting methods. We recommend that measurements of intensity of harvest should be made routinely in experiments with tea.

INTRODUCTION

Harvesting or 'plucking' of tea (*Camellia sinensis*) involves the removal of tender, growing shoots from the surface of the bush. A horizontal 'plucking table' surface of mature 'maintenance' foliage is preserved, so that new shoots project above the surface and are easily removed. The harvested shoots are then processed in various ways to make green or black tea. There are four important variables in a harvesting system:

- The target shoot (TS) or shoot stage: this is usually two leaves and an apical bud ('fine' shoots, abbreviated to 2+bud), or three leaves and a bud ('coarse' shoots, 3+bud).
- Harvesting interval (HI), expressed either in days or in phyllochrons: one phyllochron is the time interval between the opening of successive leaves on the same shoot; this varies with temperature, being longer at lower temperatures (Burgess and Carr, 1998).
- Selectivity: with fully selective plucking, only shoots which have reached the target stage will be taken; with non-selective plucking, all shoots above the plucking table surface are removed. Mechanized harvesting methods are inevitably non-selective.
- Intensity of harvest (IoH): intensity may be 'hard' or 'light'; hard plucking means plucking close to the base of the growing shoot; in contrast, with light plucking, when one or more leaves are left on the stump of the shoot below the plucking level. The latter allows some replacement of maintenance foliage, but the height of the plucking table will rise.

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All four variables are, in principle, under management control, with the choice of system affecting tea yield and quality, and labour productivity. First, the target shoot must be identified, depending on the type of tea that it is intended to produce. In general, finer shoots give better quality (but lower yield). A given target shoot can be harvested either by plucking selectively with an HI of no more than one phyllochron (to ensure that shoots do not have time to grow past the target stage), or by non-selective plucking with an HI carefully controlled to ensure that the majority of shoots will be at the correct stage. Burgess and Carr (1998) showed that the required HI for the latter method could be estimated reliably from daily mean air temperatures. Labour productivity is likely to be greater with non-selective plucking. Willson (1992) considered that a balance should be kept between hard and light plucking, to allow some replacement of maintenance foliage, without too much rise in plucking table height.

In practice, it is important to monitor closely what is actually achieved in terms of these variables, as the outcome may not always be what was specified in instructions to the pluckers. Analysis of the shoot stages in a sample after harvest will show whether the target shoot was achieved, and the variation within the sample gives an indication of the degree of selectivity.

Harvesting intensity presents particular problems. Visser (1960) showed that hard plucking gave higher yields than light plucking, and there is general agreement among tea researchers that intensity needs to be controlled, if high and sustained yields are to be obtained. However, there is confusion over what is actually required. Part of the problem derives from descriptions of tea harvesting trials. Terminology differs between tea-growing areas; for example, 'plucking to the fish leaf' means one thing in India and another in East Africa. Additionally, one does not know exactly what harvesting intensity was actually achieved in a trial. An instruction may have been given to the pluckers to 'pluck to the fish leaf', for example, but there is no measure of whether or to what extent this was actually done. With mechanical or semi-mechanical harvesting, we have even less idea of what intensity is achieved; we can only specify the height of the cutter above the bush surface. A further complication is that in most mechanical harvesting trials, there is a hand-plucked control treatment, but the intensity of this hand plucking cannot be compared with that of mechanical harvesting. If intensity differs, yields are likely to differ, so if we are to understand comparisons of harvesting methods, we need a measure of harvesting intensity.

The annual rise in height of the plucking table may give some indication of intensity: clearly, if long stumps are left behind, there will be a tendency towards greater rise in table height. However, a typical annual rise would be of the order of 10 cm; as the usual reference point is ground level, measurements over periods of much less than one year are too inaccurate to be useful. In this paper, we describe a method for obtaining instantaneous measurements of IoH, and give examples of its application.

MATERIALS AND METHODS

Measuring intensity of harvesting

It is a relatively simple matter to record the average number of leaves remaining on the plucked stump. The smaller this number, the harder the plucking, and we define

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intensity of harvesting (IoH) in terms of the number of leaves (excluding bud scales) left on the stump of the shoot below the plucking point. If no leaves other than scales are left, the intensity is 0; with one leaf remaining, it is 1, with two leaves, 2, and so on. Figure 1 illustrates this, and also shows interactions between intensity, time and target shoot: at the same time after release from dormancy, a shoot can be plucked hard and coarse (B), or fine and light (C). To pluck hard and fine, the shoot must be harvested one phyllochron earlier in development (A); conversely, to pluck coarse and light, it must be harvested one phyllochron later (D).

We measure IoH by laying a 30 cm diameter steel ring, or a 30 × 30 cm square, on the surface near the centre of the bush, immediately after harvesting, and count the plucked stumps, grouped into classes according to the number of leaves on the stump. Strictly, of course, it is the number of axillary buds which is important; leaves may be partially removed, by mechanical harvesting or clumsy hand plucking, but are still counted if the axillary bud remains. From the number of stumps in each class, the average number of leaves remaining can be calculated. As an example, the figures might be as follows:

Class		No. of shoots in sample	Total leaves
0	No leaves remaining	20	0
1	1 leaf remaining	56	56
2	2 leaves remaining	18	36
3	3 leaves remaining	6	18
	Total	100	110

The IoH index is simply the average number of leaves per stump, in this instance 1.1. The greater this number, the lower the intensity of harvesting.

Trials

Trial 1 was at Kericho, Kenya (0°21′S, 35°19′E, 2070 m asl), and compared several different harvesting regimes on seedling tea, planted in 1928 with 4972 bushes ha^{-1}. The trial had 10 treatments, with three replicates of 16-bush plots in a randomized block design. IoH was recorded from five 30 × 30 cm squares in each plot, for a total of 30 plots, at several harvesting rounds over a four-month period. The resulting data were used to estimate the best sample size for IoH measurements. The effects of the treatments are not considered here.

Trial 2 compared four intensities of harvest, the aim being to ascertain whether IoH does have an influence on yield. Highly selective hand plucking was done at an interval of one phyllochron, with a target shoot of 3+bud. The operation was very carefully supervised to ensure that all shoots were plucked at the intended intensity. The trial consisted of five-bush plots, with five replicates in a randomized complete block design. This trial was done with 80-year old seedling tea, planted at 7500 bushes ha^{-1} on Stanmore Estate in South India (10°19′N, 76°57′ E, 1000 m asl).

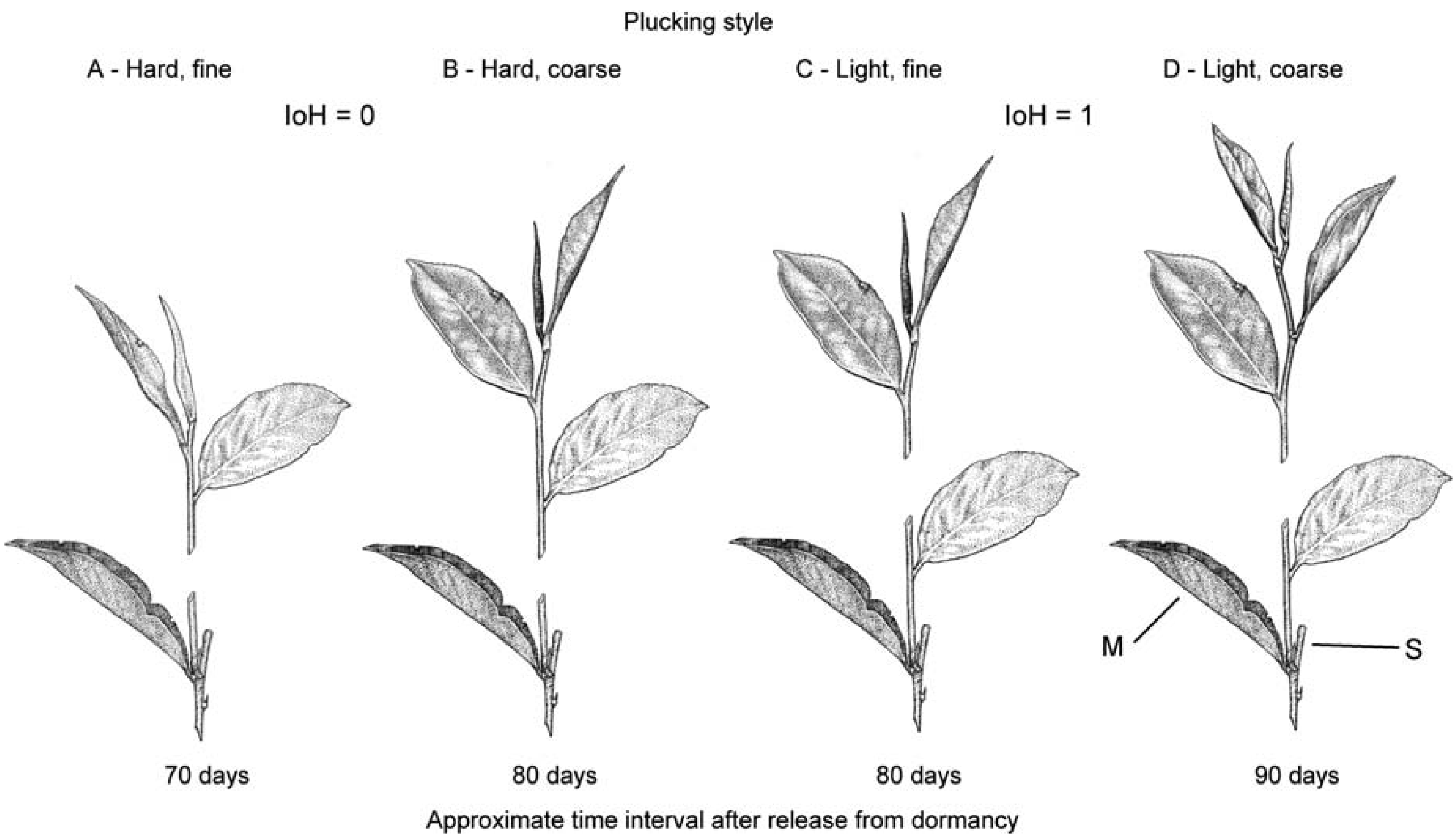

Figure 1. Different plucking styles applied to a new shoot growing from the axil of a maintenance leaf (M) on the stump from a previous plucking (S). The time required from release of dormancy (previous plucking) to reach stage B or C depends on ambient temperature, but would be approximately 80 days under the conditions of our trials, where one phyllochron is equal to about 10 days.

In Trials 3 and 4, we applied the method of measurement to harvesting trials, to see whether we could detect differences in IoH, and whether the information would be useful for interpreting trial results. Trial 3 was done with 33-year old clone SA-6 planted at 10 000 bushes ha^{-1}, on Venniar Estate in South India (9°37′N, 77°21′E, 1300 m asl), and included four treatments:

1 Standard estate harvesting practice – shears with a 1.25 cm step
2 Hand plucking 'below the mother leaf' – intended IoH = 2
3 Hand plucking 'above the mother leaf' – intended IoH = 3
4 Flat shears

The trial consisted of five-bush plots, replicated five times in a randomized complete block design. IoH was measured on two occasions, on every plot.

Trial 4 was done with 15-year old clone SA-6 planted at 12 000 bushes ha^{-1}, on Injipara Estate in South India (10°19′N, 76°57′E, 1000 m asl), and compared shears with three different regimes using a hand-held harvesting machine. There were six replications in a randomized complete block design, with 1000-bush plots (much larger plots are needed with the harvesting machine than with hand plucking). Treatments 2 and 3 had the same target shoot, but differed in the intended harvesting intensity.

1 Standard estate harvesting practice – shears with a 1.25 cm step
2 Mechanical harvester, 'light', TS = 3+bud
3 Mechanical harvester, 'hard', TS = 3+bud
4 Mechanical harvester, 'light', TS = 2+bud

In all trials, yields of green leaf were weighed after each harvest, and converted to 'made tea' yields using a standard factor of 22.5 %, derived from factory records.

Shoot weights and numbers

In Trials 2 and 3 samples of 50–100 g fresh weight were taken, at random, from the accumulated leaf after harvest. The number of apical buds in the sample was counted, to allow calculation of mean weight per shoot; the assumption here is that every shoot had a bud, so that the figure would be correct even if some shoots had been cut into several pieces by the shears, for example. The total number of shoots harvested was calculated from yield (fresh weight) and mean weight per shoot.

RESULTS

Trial 1

Precision of IoH measurements is likely to be low, if only single quadrats are scored. The number of quadrats can be increased by increasing the number recorded per plot at a single harvesting round, or by recording at several different harvesting rounds. In this trial, we investigated the effect of both methods on the standard error of IoH means. Where more than one sample per plot was taken, the data were combined, to give a single figure for each plot. Figure 2 shows that either increasing the number of harvesting rounds at which recording was done, or increasing the number of samples

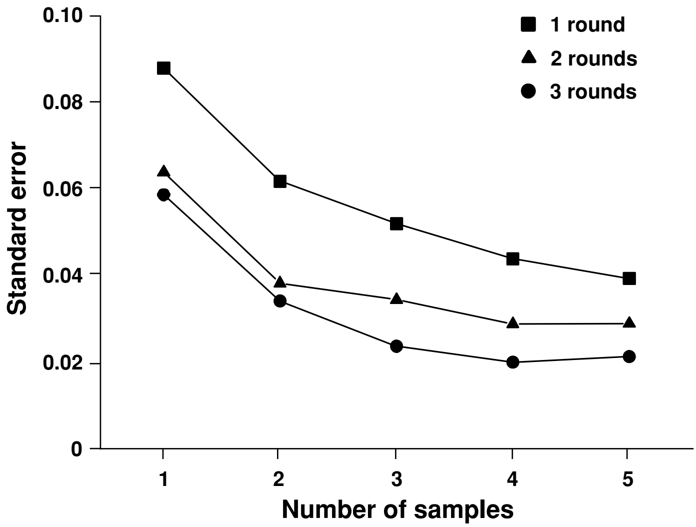

Figure 2. Effect of increasing number of samples (quadrats) and rounds of measurement on standard error of IoH means in trial 1.

Table 1. Effect of intensity of harvest on yield and yield components, Trial 2. Yields were recorded for 2 years 4 months; bush height was measured two years after the trial commenced.

Treatment	Actual IoH	Bush height (m)	Yield made tea (kg ha^{-1} y^{-1})	Mean shoot fresh weight (g)	Shoot number (millions ha^{-1} y^{-1})
IoH = 0	0	1.05	3311	0.79	18.2
IoH = 1	1.0	1.09	2654	0.83	13.9
IoH = 2	2.0	1.08	2810	0.80	15.3
IoH = 3	3.0	1.90	2039	1.57	5.6
s.e.	–	–	111	–	–

taken per round, reduced the standard error. The best results were obtained by recording at least three quadrats per plot, at three different harvesting rounds. The standard error was not reduced by increasing the number of samples beyond three per plot. We did not investigate larger quadrat sizes, but we consider that it is better to increase the area covered by increasing quadrat number (and hence the number of bushes sampled) rather than quadrat size.

Trial 2

Results from this trial are summarized in Table 1. The actual IoH figures show that, in this trial, the intended harvest intensities were achieved. Yield was highest under the hardest harvesting regime (IoH = 0). This was due to a much larger total number of shoots harvested; there was little difference in mean shoot weight between the first three treatments, but the lightest regime had much heavier shoots. We did not study shoot growth in detail, so cannot explain this last observation. The only difference in table height was between IoH = 3 and the other treatments.

Table 2. Effect of different harvesting methods on yield and harvest intensity, Trial 3. Yields were recorded for 1 year 11 months.

Treatment	IoH	Yield made tea (kg ha^{-1} y^{-1})	Mean shoot fresh weight (g)	Shoot number (millions ha^{-1} y^{-1})
Stepped shears	2.1	4677	0.84	24.75
Hand, below 'mother leaf'	2.0	3816	0.72	23.56
Hand, below 'mother leaf'	3.0	4106	0.63	28.96
Flat shears	1.6	5599	0.67	37.14
s.e.	0.14	120	–	–

Table 3. Effect of different harvesting methods on yield and harvest intensity, Trial 4. Yields were recorded for 1 year 5 months.

Treatment	IoH	Yield made tea (kg ha^{-1} y^{-1})
Estate practice	1.8	5257
Machine, 'light', 3+ bud	2.0	4641
Machine, 'hard, 3+ bud	1.4	6472
Machine, 'light', 2+ bud	2.0	4697
s.e.	–	210

Trial 3

Results from this trial are summarized in Table 2. The IoH was significantly smaller with flat shears than with the hand-plucking treatments, and this treatment also gave the highest yield. As in Trial 2, the yield increase came from an increase in the number of shoots harvested; mean shoot weight was slightly smaller. The IoH achieved for treatments 2 and 3 was precisely that specified, but without the measurements, we should not have known for certain that the semi-mechanical harvest was harder than the hand-plucking treatments.

This trial was done before the sampling study in Trial 1 had been completed, and results were based on one measurement per plot. The standard error for IoH measurements was 0.14 units, rather greater than for single measurements in Trial 1.

Trial 4

Results from this trial are summarized in Table 3. As in Trial 3, yield and IoH were negatively related. Trials 3 and 4 were done with the same clone, though at different sites, and Figure 3 shows that, with the exception of one treatment in Trial 3, the relationship between yield and IoH was similar in the two trials.

DISCUSSION

Method

Shoot numbers from more than one quadrat may be combined in two ways: IoH can be calculated for each quadrat, and then a mean taken. Alternatively, the numbers

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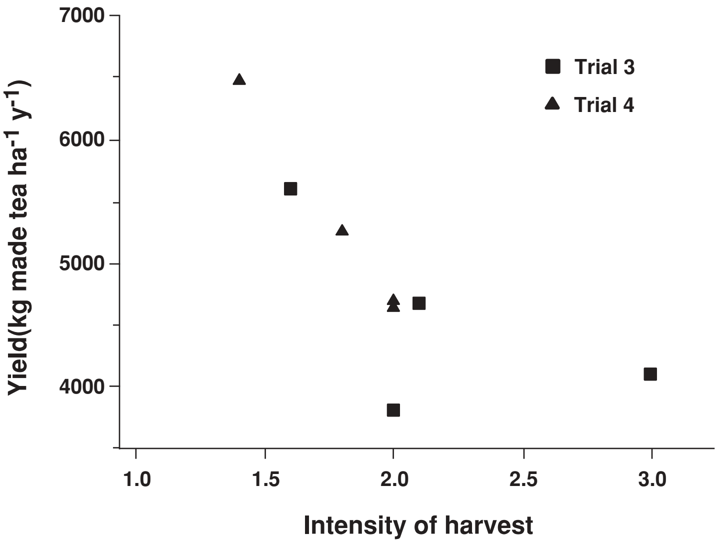

Figure 3. Yield of clone SA6 in Trials 3 and 4 in relation to intensity of harvest.

in the leaf classes can be added together, and then a single IoH calculated from the totals. These methods do not necessarily give the same result, because the number of shoots per sample may vary. We consider that the second method is preferable, as this gives equal weight to all plucking points.

The numbers of shoots harvested from a 30 × 30 cm square may be quite small. In order to maximize the numbers, we suggest that the quadrat should be placed near the centre of the bush, where the shoots tend to be concentrated, rather than placing it at random on the table.

The standard procedure for recording IoH, which we recommend, is as follows:

1 Collect data from at least four separate harvesting rounds. Where different treatments are harvested on different dates, choose times when all treatments will be harvested within a relatively short period (say, one week). For long term trials, one set of measurements could be made every three months.
2 Place quadrats near the centre of the bush, on bushes chosen at random. Use two or three quadrats per plot, on different bushes, and combine the shoot numbers. An alternative would be to use a larger quadrat, but it is preferable to sample from more than one bush.
3 Calculate IoH for each plot for each round. Finally, calculate the mean IoH over all rounds, for each plot. These figures will be the data for statistical analysis.

The procedure known as 'breaking back' is a complicating factor. This involves breaking off the stump remaining after plucking, if it is too long. This is regarded as necessary to maintain a tidy plucking table (Sharma and Murty, 1993), but if it is done before recording IoH, the data will be misleading. In estate practice, breaking back is often routine, though little should be necessary if the harvest interval is correct,

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as shoots should not have grown past the target shoot stage. In trials with extreme treatments such overgrown shoots may be frequent, and the recording procedures must take account of this.

It should be noted that the IoH figures obtained for different clones may not be exactly comparable. Most, but not all, clones have a small 'fish leaf' near the base of the shoot (the shoot illustrated in Figure 1 did not); plucking below the first full-sized leaf will give an IoH of 1 if there is a fish leaf present, but 0 if it is absent.

Trial results

In Trial 2, with careful supervision of plucking, the intended plucking regimes were achieved, and the hardest regime gave the highest yield. This result agrees with that of Visser (1960). There are at least three possible reasons for this trend of yield with intensity: firstly, if a standard shoot stage of, say, two leaves and a bud is the target, then under hard plucking such a shoot can be taken as soon as two leaves have opened (shoot A in Figure 1). Under lighter plucking, harvesting must be delayed until a further leaf has opened (shoot B); there will be a longer interval between harvesting of successive shoots from the same 'plucking point', and thus fewer shoots per year and lower yield. Secondly, Visser (1960) stated that, under harder plucking, plucking of a single shoot released more than one bud from apical dominance, so that the total number of plucking points should increase from one generation of shoots to the next. Thirdly, there is some evidence that shoot development is faster from axillary buds at the base of the shoot than from those higher up (Goodchild, 1961), so plucking to release the lower shoots from dormancy will lead to faster shoot growth. All these factors lead to larger numbers of shoots, and the results of Trials 2 and 3 confirmed that shoot number was increased under more intensive harvesting.

An estimate of the effect of IoH on yield can be obtained from Figure 3. With the exception of one treatment in Trial 3, there is a close relationship, with some suggestion of curvilinearity. Over the range from IoH 1.5 to 2.0, yield declined by about 1000 kg ha^{-1}, approximately 20 %. It is clear that IoH is not the only factor affecting yield, though; the low yield of treatment 2 in Trial 3 cannot easily be explained in terms of IoH, while in Trial 2 an IoH of 1.0 gave lower yield than IoH of 2.0. There are also differences in magnitude of the response between trials: in Trial 2, increasing IoH from 2.0 to 3.0 reduced yield by nearly 30 % (Table 1), compared to only about 12 % in Trial 3 (Figure 3). More detailed analysis of shoot growth would be needed to explain these differences.

Our method of measuring intensity of harvest is simple, and sufficiently precise to show differences between treatments with relatively few measurements. While IoH does not explain all the yield differences found in our trials, it does provide confirmation that intended treatments were actually achieved (Trial 2), and helps to explain differences in yield in Trials 3 and 4. We anticipate that clones will differ in their responses to harvesting intensity; this may partly explain the differences between Trial 2 (mixed seedling material) and Trial 3 (small-leaved clone SA-6).

We advocate that these measurements should be made regularly in tea harvesting trials, but we suggest that application of the method should not be restricted to harvesting trials. It is possible that achieved IoH may differ between treatments in some trials despite the intention to harvest all treatments similarly. Given the large effects of IoH on yield, it could be important to look at this. For example, if treatments such as fertilizers were to cause differences in shoot growth rate, but all treatments were harvested at the same time interval, and with the same target shoot, harvesting of the faster growing plots would have to be lighter, and a potential yield increase could be missed. IoH measurements should reveal that this was happening.

The method is rather laborious for day-to-day management of tea harvesting, but could be useful where a change in plucking regime is to be made. In our experience, unless very closely supervised, pluckers tend to continue with their normal practice, regardless of the instructions given. A combination of IoH measurements and analysis of shoot stages would show whether the intended regime was being achieved.

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REFERENCES

Burgess, P. J. and Carr, M. K. V. (1998). The use of leaf appearance rates estimated from measurements of air temperature to determine harvest interval for tea. *Experimental Agriculture* 34:207–218.

Goodchild, N. A. (1961). The development of tea shoots. In *Proceedings 7th Conference, Tea Research Institute of East Africa, Kerich, Kenya*, 52–64.

Sharma, V. S. and Murty, R. S. R. (1993). 'Breaking back', an essential sanitary measure while harvesting tea. *United Planters' Association of South India Tea Research Foundation Advisory Leaflet* 8, Valparai, India.

Visser, T. (1960). Plucking practices in relation to maintenance foliage. *Tea Quarterly* 31:38–52.

Willson, K. C. (1992). Field operations: 2. In *Tea: Cultivation to Consumption* (Eds K. C. Willson and M. N. Clifford), London: Chapman and Hall.