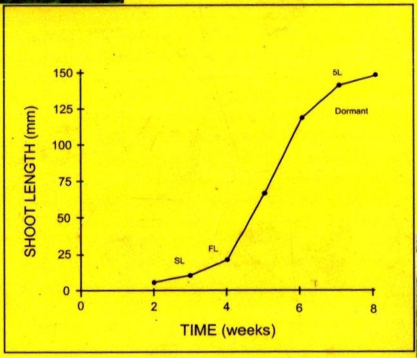
SHOOT GROWTH AND HARVESTING OF TEA



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THE TEA RESEARCH INSTITUTE OF SRI LANKA

Reference Only

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DEDICATED TO MY PARENTS AND TEACHERS

PREFACE

Although the Tea Research Institute of Sri Lanka has, from time to time, published monographs on aspects of tea production and manufacture, there have been none hitherto on shoot growth and harvesting practices. That deficiency is now met by the present monograph which is meant for tea growers, students, and all interested in the cultivation of tea.

The harvesting of green leaf is the most expensive element in the cost of production of made tea, making up over a third of the total. It is the most labour intensive of all the agricultural practices connected with tea-growing, and the most influential in affecting productivity and profitability. Dr Wijeratne's monograph is therefore another one of the frequent TRI publications that will be read and re-read by practitioners of tea cultivation, as well as by others.

The monograph must not be seen necessarily as containing TRI recommendations on tea harvesting, but more as background knowledge with a scientific base on this important cultural practice. It could profitably be used, for example, by a tea grower in selecting for himself the best option for his fields based on the knowledge he will acquire on the pros and cons of harvesting from consulting it. At a time when workers are becoming a scarce resource, this knowledge could conceivably make all the difference to the continued success of our country's tea industry.

It is appropriate to mention here that Dr Wijeratne has had an interest in tea harvesting for many years, and that his invention of the TRI selective tea harvester won a Gold Medal at the 28th International Exhibition of Inventions in Geneva in April 2000, in addition to winning the Presidential Award 1998 in August 2000.

As Director of the Institute, I have continuously exhorted my colleagues to put their knowledge and experience down in monographs of this nature, and I am gratified that Dr Wijeratne has responded so well to this exhortation.

St Coombs, Talawakelle
April, 2001

Dr W W D Modder
DIRECTOR

ACKNOWLEDGEMENTS

I thank Dr.W.W.D.Modder, Director, Tea Research Institute of Sri Lanka, for his encouragement and guidance given to write this book. Some of the information published in this book are based on my Ph.D. programme at Wye College, University of London. Hence, my sincere thanks are due to Dr.Ray Fordham, Wye College, University of London, for his discussions and constructive comments. The editorial assistance and important suggestions of Mr.B.Sivaram and Mr.P.B.Ekanayake are also gratefully acknowledged. I also thank my colleagues at the Tea Research Institute for their numerous contributions on completion of this book.

M.A.Wijeratne

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1. INTRODUCTION

The marketable product of tea is manufactured from tender shoots that are harvested at varying intervals depending on their rate of growth. The method of harvesting tea shoots is termed as plucking. Unlike in many other perennial cash crops, harvesting policies of tea namely, method, standard, severity and frequency adopted in a field have a profound influence on the profitability of tea plantations. This is mainly due to the impact of harvesting policies on:

Cost of production
Quality of the end product and
Growth of the tea bush.

1.1 Effect on cost of production (COP)

Harvesting is the single largest component in the COP of tea. The proportion varies from region to region and from estate to estate depending on its harvesting policies. In Sri Lanka, harvesting accounts for about 35 per cent of the COP, this high proportion being mainly influenced by the labour intensive nature involved in manual harvesting. With about 70 per cent of the labour force deployed daily on estates for harvesting, this is the most labour intensive field operation in tea cultivation. Under average field conditions in Sri Lanka, the labour requirement for manual harvesting is about 10-12 workers/ha.

1.2 Effect on quality of the end product

The marketable product of tea, known as made tea, is produced in the factory using the shoots supplied from the field. The quality of made tea is greatly determined by the chemical constituents of the tea leaf and its fibre content that varies with the growth and maturity of shoots. When the quality parameters of tea are considered, the best quality tea can be produced from tender shoots having 2-3 succulent leaves. Moreover, the physical condition of shoots determined by leaf handling, that is, collection and transport of shoots also affects the quality of made tea. Therefore, proper harvesting policies should be exercised so that tender shoots having 2-3 immature leaves are harvested and transported to the factory with minimum damage and delay.

1.3 Effect on growth of the bush

Harvesting removes the photosynthetically active green tissues. Frequent removal of shoots stimulates axillary buds below the points of plucking to produce new generations of shoots by which growth a large amount of food materials are also utilised. Accordingly, production, partitioning and utilisation of assimilate which determine the growth and vigour of the tea bush are largely influenced by the harvesting policies.

Appropriate harvesting policies should therefore, be adopted to generate a higher yield with enhanced labour productivity, while ensuring the good quality of the end product and sustaining the productivity of the tea bush.

2. GROWTH OF TEA SHOOTS AND SHOOT GENERATIONS

The tea bush in harvesting consists of a large number of shoots at varying stages of growth. Harvesting removes all or part of these shoots depending on the method employed. It is therefore, important for tea producers to comprehend the pattern of shoot growth and the distribution of shoots on the bush.

2.1 Growth of shoot

Harvesting of tender apices of shoots removes the apical dominance over which the growth of many axillary buds is suppressed. The axillary bud is a contractive shoot having several leaf initials or primordia in it. After the apical dominance is broken, the axillary bud below the point of harvesting starts swelling and first unfurls its two outer covers as scale leaves, which are usually very small. This appearance of scale leaves is known as bud break and can be recognized by visual observation of the node of the next leaf between the margins of scale leaves (Fig. 2.1)

The two scale leaves have a short lifetime and generally fall off within a few days after opening. The next leaf appendage to unfurl is the fish leaf (Fig. 2.2). This is an oval shape, blunt leaf without apparent serration and veins. It is bigger than scale leaves, but very small compared to normal leaves. Some buds produce two fish leaves under which circumstances, the smaller one just above the scale leaves is termed small *fish* leaf and the other *big fish* leaf. Sometimes, the small *fish* leaf is also called *Janam* leaf (Arunachalam, 1995). When growth progresses, the terminal bud produces normal leaves. The rate of shoot growth is very slow until it commences the production of normal leaves. On a harvested tea bush, the terminal bud of a growing shoot produces several leaves before it ceases leaf production and emerges as a dormant bud known as a *banji or wangi*. This is a few millimetres long tiny bud usually covered by leaf hair. It has no leaf primordium to immediately open and is therefore, very small compared with an actively growing apical bud. After a lapse of the period of dormancy, which could be extended to several weeks or months depending on various ecological and genetic factors, the dormant apical bud re-activates and opens a set of similar leaves as described above. Thus, a free growing tea shoot passes through an active and a dormant phase of growth that occurs alternatively. This phenomenon is known as periodic growth or growth periodicity of tea.

Although not clearly understood, the formation of dormant buds has been reported to be the result of either hormonal interaction (Pethiyagoda, 1964; Ranganathan *et al.*, 1983) or lack of nutrient supply to actively growing apices (Bond, 1945). Accordingly, the stage in pruning cycle, temperature, depletion of food reserves (Ranganathan *et al.*, 1983), types and levels of fertilizers (Kulasegaram and Kathiravetpillai, 1972) and clonal characteristics (Stephens and Carr, 1990) have a greater influence on the formation of dormant buds.

Nevertheless, most of the growing shoots after pruning do not show a clear periodic growth as observed on a tea bush in harvesting. The growing shoots of a tea bush recovering after pruning usually show a vigorous active growth,

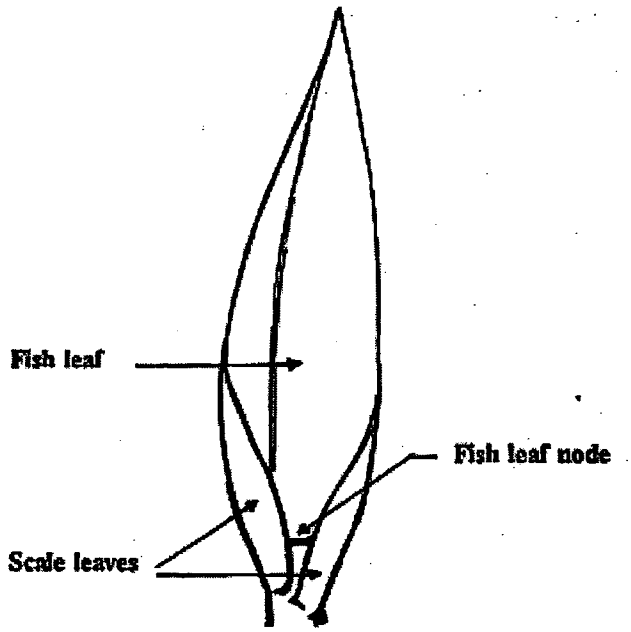


Fig.2.1- Bud break of tea

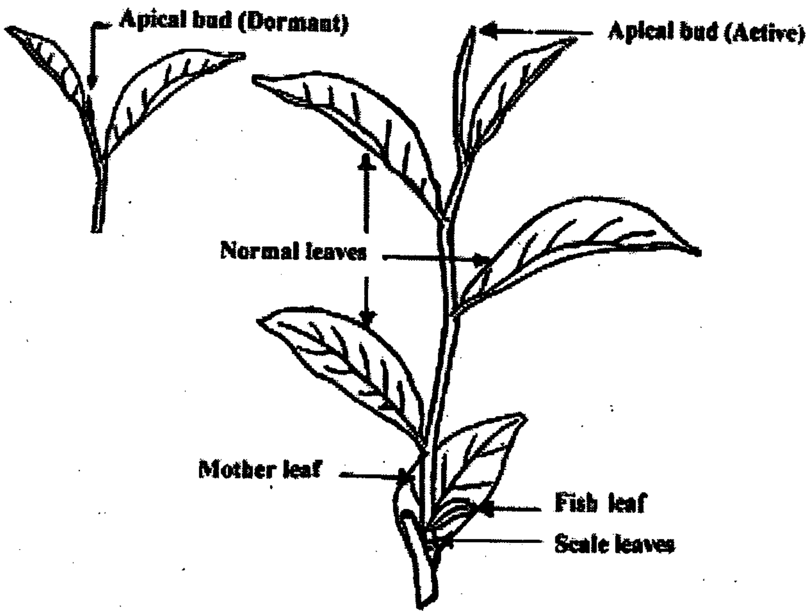


Fig.2.2-A typical tea shoot showing different leaves

unfurling many leaves. But they are still not aperiodic and become dormant after some time.

2.2 Shoot generations

The top of the tea bush is trained as an even (flat) or dorm shape surface for easy harvesting. This surface is known as the plucking table. On a tea bush in harvesting, there are a large number of shoots at different stages of growth ranging from growing axillary buds to shoots with a few leaves. A group of shoots at the same stage of growth (generally identified by the number of leaves) is called a generation. The presence of many generations (5-6) at a time is the result of frequent harvesting at short intervals and the variation of the rate of shoot growth. The shoot generations of a regularly harvested bush is found to be more or less equally distributed (Fig. 2.3). However, this may not be true when growth of shoots is seasonal or soon after a long stress period and after pruning or tipping which processes also synchronize bud break. The number of generations depends to a greater extent on harvesting policies, mainly the frequency of harvesting. Moreover, environmental factors such as temperature or drought and cultural practices such as pruning also influence the number of shoot generations by accumulating potential sites (axillary buds) for shoot growth and later synchronizing the bud break. When there are more number of generations, a higher degree of selectivity is required to harvest standard shoots.

In selective harvesting, one or two older generations are usually harvested as flush shoots, leaving the other younger generations for the successive rounds. The older generations of shoots (actively growing shoots with more than 2 leaves and dormant shoots) are called harvestable (pluckable) shoots while the other younger generations are called *arimbu*. It is the presence of many shoot generations (5-6) that ensures frequent harvesting at shorter intervals (5-10 days) under tropical climatic conditions. However, when the shoot growth is seasonal such as in temperate tea growing regions (e.g. Japan), there is only a few shoot generations. Under such climatic conditions, the majority of shoots become harvestable at a time and hence, the entire crop of the year can be harvested at a few extended rounds (30-50 days) in the growing season.

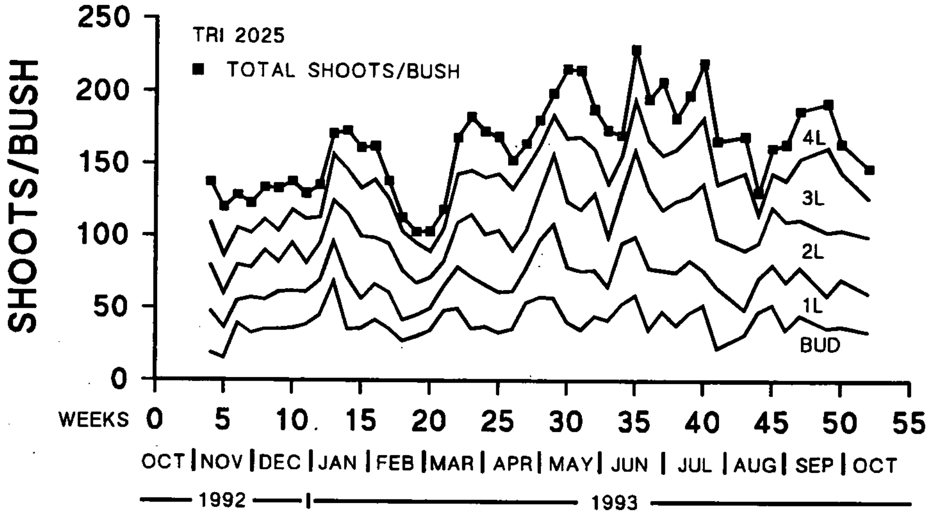
2.3 Leaf initials (Primordia)

A tea bud (apical or axillary) consists of several leaf initials (primordia) which opens later with the extension of internodes (Plate 2.1). Bond (1942) carried out initial studies on the leaf primordia in apical buds of the tea shoot. His findings revealed that there can be 3-7 leaf primordia in an apical bud, depending on its phase of growth that is whether dormant or active. Although there is no leaf appearance, the leaf primordia are being initiated or enlarged inside the dormant bud. These results concluded that the tea bud does not have a truly dormant phase of growth. Studies by Barua and Das (1979) and Goodchild (1968) provided further evidence on the fact that the development of leaf primordia in a tea bud is a continuous process.

Recent findings in Sri Lanka revealed that the number of leaf primordia in a terminal bud can vary from 4 to 6. The actively growing apical bud contains 6 leaf primordia. The dormant apical bud on its first exposure has 4 primordia, including the two scale leaves covering the younger primordia. Hence, the development of leaf initials in an active apical bud is found to cease temporarily during unfolding of the last two leaves (Wijeratne, 1994). The number of primordia in axillary buds of an actively growing shoot increases from the uppermost leaf axil (3 primordia) to the second or third leaf axil (5 primordia) from the apical bud. The other mature axillary buds below the third leaf from the apical bud consist of a maximum number of 5 leaf primordia (Fig. 2.4). Although axillary buds of fish and scale leaves may have a varying number of primordia from 4 to 5 depending on their size or the vigour, a well grown fish leaf axillary bud contains 5 primordia. At the time of bud break, an elongating tea bud possesses 8 leaf primordia. This means that a mature axillary bud with 5 leaf initials needs to develop 3 more leaf initials to attain bud break. Accordingly, if a younger axillary bud with 3 leaf initials is exposed for growth by plucking, it may take a longer time for bud break than a mature bud with 5 leaf primordia as the former requires to produce 5 additional primordia where as the latter needs only 3.

2.4 Plastochron and phyllochron

The rate of leaf appearance of a tea shoot is equal to the rate of primordium initiation in the apical meristem until it becomes dormant. Weekly measurements during wet weather in Sri Lanka show that the primordia initiation of tea buds (TRI 2025) cease by the 6th week after harvesting while leaf appearance continues until the 7th week (Fig. 2.5). The time taken to produce one primordium is termed as plastochron and that for a leaf is termed as phyllochron or leaf period. The plastochron and phyllochron periods vary with different clones and are extended by adverse weather conditions such as drought. As the meristematic activity appears to cease temporarily during the unfolding of last two leaves, the true dormancy of a tea shoot is initiated by about two phyllochrons prior to the appearance of its apical dormant bud (Chapter 2.3). The phyllochron that could be determined by field observations becomes very important when harvesting policies are related to the number of leaves on a shoot.



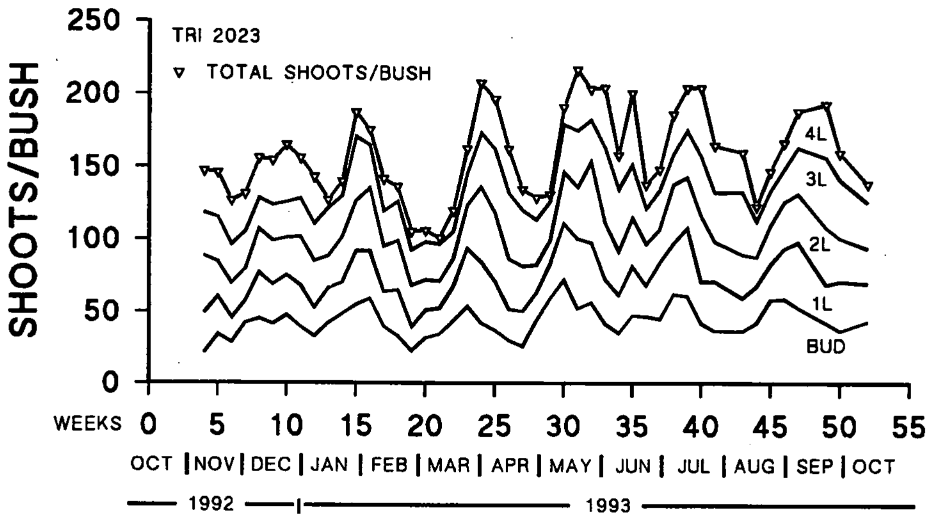


Fig.2.3-Distribution of shoot generations in plucking table. (Bud: elongating buds with scale and fish leaves; 1L-4L: shoots with 1-4 normal leaves)

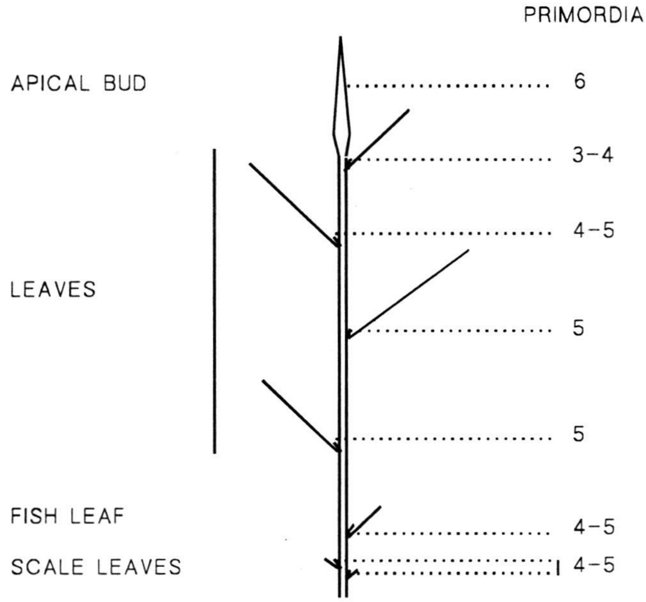


Fig. 2.4-Number of primordia in buds of an actively growing tea shoot

Plate 2.1- Scanning Electron Micrograph of an elongating axillary bud of tea after dissection

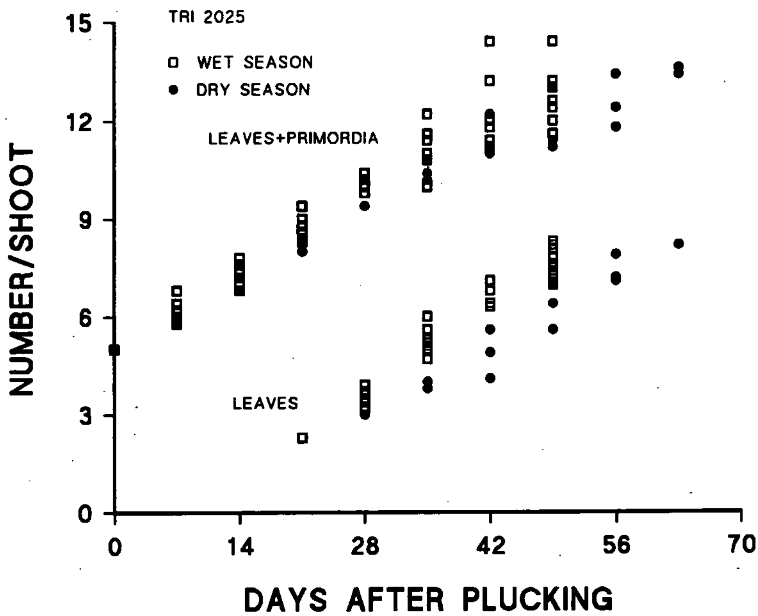


Fig. 2.5 - Rate of primordia initiation and leaf appearance of elongating axillary buds after harvesting (The number of leaves includes fish and two scale leaves.)

3. YIELD COMPONENTS OF TEA

Yield components are the parameters that determine the potential productivity of a crop. While considering the productivity of tea lands, the yield is greatly influenced by the bush density which, in turn, is determined at the time of planting. However, the yield determinants of a tea bush are shoot density and mean shoot weight. Therefore, these two parameters are considered to be the yield components of tea.

Of these two components, shoot density is the major factor that determines tea yield. More than 80 per cent of the variation in tea yield is accounted for by the shoot density. Recent studies in Sri Lanka established the following relationship in respect of two TRI clones harvested at weekly intervals.

$$Y = -7.61 + 0.17\,D + 43.5\,W \text{ ——— TRI 2025, } R^2 = 98\%$$

$$Y = -9.40 + 0.18\,D + 52.2\,W \text{ ——— TRI 2023 } \quad R^2 = 98\%$$

Where Y, D and W are the dry matter yield (g/bush/week), density of harvested shoots (number of shoot/bush) and weight of shoot (g/shoot) respectively (Wijeratne, 1994).

The relationships clearly demonstrate that these two yield components need to be maximized for obtaining a higher yield, that is harvesting a larger number of heavier shoots ensures a greater yield. However, the increase in shoot weight is a limiting factor as the degree of maturity of shoots influences the quality of the end product. Hence, plucking policies should be selected to maximize these two components without affecting the quality of the end product.

The density and weight of shoots at harvesting are greatly influenced by the rate of growth (e.g. Fig. 3.7). If the rate of shoot growth is fast, it may become a harvestable (pluckable) shoot within a short period of time and also secure more weight. The above two yield components are therefore, affected by the rate of shoot growth. The time taken by an axillary bud to become a harvestable shoot (Chapter 2.2) is termed as the shoot replacement cycle.

3.1 Variation of yield components

The yield components are affected by various factors such as genetic (inherent) characteristics, management and environmental conditions. However, the environmental factors are of greater practical importance to the tea grower as they impose severe limitations on tea cultivation. The environmental stress adversely affects the yield components of tea.

Although harvesting of tea is a continuous process under humid tropical conditions, there is a distinct fluctuation in shoot population density and yield over the year. Such peaks and troughs in production are mainly caused by changes in weather conditions. Environmental (moisture, temperature) stress delays or stops bud break, leading to accumulation of dormant buds in the tea bush. Once the stress is removed, all these buds start growing simultaneously. This phenomenon is known as the synchronization of bud break. As a result, a peak (rush) crop, which is also termed as "Fordham peak" is formed. Once all the fast growing vigorous shoots are harvested within the peak cropping period, a subsequent trough in production takes place due to the absence of harvestable shoots (Fordham, 1970; Fordham and Palmer-Jones, 1977). Nevertheless, it has also been proposed that the occurrence of peak and trough in tea yield is the result of hormonal interaction (Rahman, 1988). The assimilates are mostly diverted to roots during less cropping (trough) periods and are utilised by growing buds during peak periods (Chapter 4.1). Hence, a rhythmic pattern of shoot growth enables the bush to maintain a balance growth of shoot and root (Carr, 1970; Fordham, 1972; Kulasegaram and Kathiravetpillai, 1983; Manivel and Hussain, 1982; Tanton 1981a).

3.2 Shoot density

The shoot density, that is the number of shoots per unit area of the bush, has a wider variation depending on the *jat* (clone), weather and management conditions. Usually it is greater in the centre of the plucking table than in the periphery. Wijeratne (1994) reported shoot population densities of 140-320 shoots/m^2 in the low-country tea growing regions of Sri Lanka while higher densities such as 310-560 shoots/m^2 have been recorded on some clones of Tanzania (Stephens and Carr, 1994). When the shoots are selectively harvested, the density of harvested shoots shows a cyclic pattern of variation with maxima and minima more or less equally distributed. These fluctuations recur at every 7-8 week intervals in the low-country tea growing regions (<600 m amsl) of Sri Lanka (Fig. 3.1).

The density of dormant (*Wangi or banji*) shoots in the harvest also shows a cyclic pattern of variation. Moreover, there are distinct clonal variations of the formation of dormant shoots under field conditions. The majority of shoots produced by drought tolerant clones (e.g. TRI 2025) appear to become dormant when they are of harvestable size (Fig. 3.2). A greater production of dormant shoots has been considered as a useful mechanism for drought tolerance (Odhiambo *et al.*, 1993) because it reduces the growth of shoots and production of transpiring leaves. This may reduce the moisture requirement and the transpiration losses from the bush. Although a marginal reduction in yield can occur due to the abundance of dormant shoots (Wijeratne, 1994), such disadvantages can be overcome by adopting proper plucking policies to remove dormant buds at their first appearance on the plucking table. However, some investigations have shown that the formation of dormant shoots has no significant bearing on the tea yield (Pethiyagoda, 1964; Tanton, 1981b).

Some environmental factors such as soil moisture stress, high vapour pressure deficit and high ambient temperature reduce shoot population density (Wijeratne and Fordham, 1996; Burgess, 1992; Fordham, 1971; Odhiambo *et al.*, 1993). Wijeratne and Fordham (1996) reported an apparent reduction in the population of harvested shoots with increasing ambient temperatures from 27-29 °C during

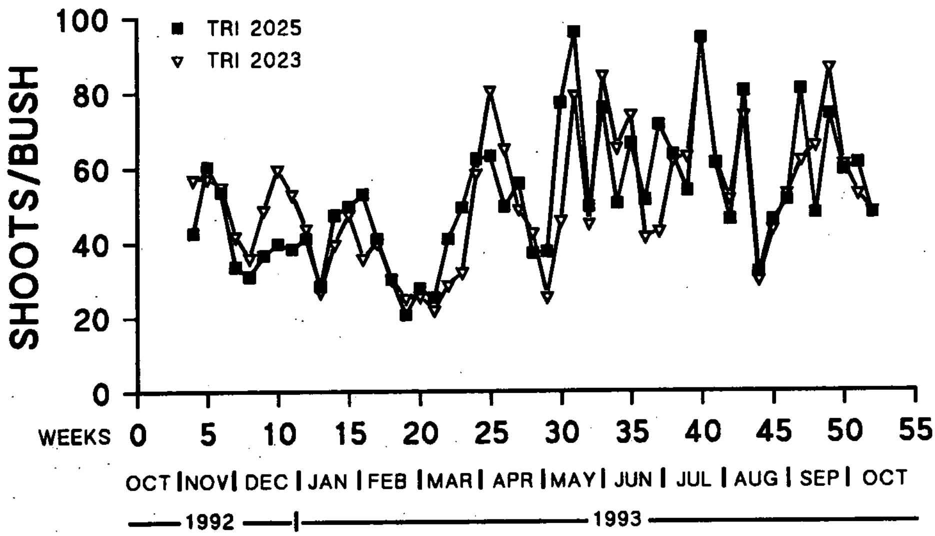


Fig. 3.1 - Variation in the number of harvested shoots (February and March were dry months)

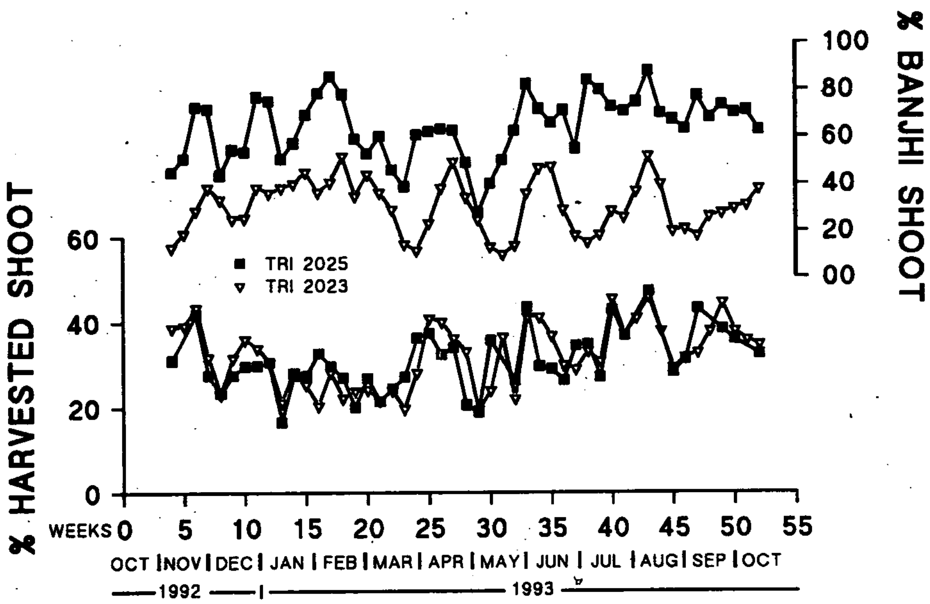


Fig. 3.2 - Variation in the harvested percentage of shoots and dormant (*banji*) shoots in the harvest (February and March were dry months; TRI 2025 is a drought tolerant clone)

high cropping months with wet weather conditions. High vapour pressure deficit above 1.2 kPa and soil moisture deficit above 35 mm in the low-country Wet Zone of Sri Lanka also reduced the harvested shoot density. The density of harvestable shoots is low during a dry period when the proportion of dormant shoots is high. As the length of shoot replacement cycle and the shoot replacement ratio (number of new shoots produced by each harvested shoot) vary with plucking system, the shoot density can be modified to increase yield. The generation of several shoots on a harvested shoot butt is the result of the release of apical dominance of 2-3 axillary buds (or simultaneous bud break) below the point of plucking. This is common when shoots are harvested below the most matured true leaf, leaving the fish leaf in a region where the inter-nodes are very short. Moreover, changes of weather pattern and application of fertilizers and other growth promoters also contribute to the production of several shoots per harvested shoot, thereby increasing the shoot replacement ratio and shoot population density. Under such conditions, the shoot replacement ratio becomes more than 1:1 (Herd and Squire, 1976; Odhiambo *et al.*, 1993, Wijeratne, 1994; Stephens and Carr, 1994). However, the uppermost shoot is more vigorous and larger than the lower ones, and also the latter become dormant early. Further, most of such dormant shoots may not reach the plucking surface, thus giving no apparent contribution to yield (Chapter 5.7).

3.3 Shoot weight

Shoot weight has been reported to be less influential than shoot population density in the determination of tea yield and yield variations. Nevertheless, it has been observed that clones with a moderate shoot population density can still out-yield those with high shoot population densities when the former is producing bigger shoots (Odhiambo, *et al.*, 1993). Hence, it is also possible to secure a higher yield by harvesting of bigger shoots. In this strategy, the weight gain in relation to shoot extension needs to be carefully evaluated. However, over-exploitation of weight gain can adversely affect the quality of the end-product as over-matured shoots are unacceptable for processing. Hence, quality aspects of harvested shoots, that is, the presence of fibrous tissues, should be taken into account.

Figures 3.3, 3.4 and 3.5 show the weight gain of a tea shoot in relation to unfolding and expansion of leaves and shoot extension. This relationship shows that a weight gain of about 75 per cent can be expected at each addition of a leaf on a shoot reaching harvestable size. There is also a linear relationship between leaf area and weight of a tea shoot. This relationship provides a rational basis for the selection of harvesting policies based on the number of leaves on a tea shoot, rather than on shoot length.

Depending on the phase of shoot growth, that is, whether active or dormant, shoot weight can differ. A harvestable tea shoot with an active terminal bud weighs 10-18 per cent more than that with a dormant bud. In Sri Lanka, the mean dry weight of a harvested shoot has been reported to be in the range of 130 - 250 mg (Nathaniel, 1976; Wijeratne, 1994; Wijeratne and Fordham, 1996). The mean shoot weight usually reduces with the increase in shoot population density (Fig. 3.6). Moreover, the mean weight and extension rates of tea shoots are positively related (Fig. 3.7). The size (weight) of a shoot is influenced by weather conditions, that is, smaller shoots are produced under dry weather conditions (Mwakha, 1985; Wijeratne and Fordham, 1996). Due to higher plant water deficit during the dry period, the weight of a harvested shoot has been reduced by about 15 per cent in the low-country tea growing regions in Sri Lanka. In contrast, the dry matter content of shoots has been increased during dry weather (Fig. 3.8). The dry matter content of tea shoots is also an important parameter in determining the marketable yield because tea is marketed as a dry product.

3.4 Rate of shoot growth

The growth rate of shoots has been identified as one of the major causes for the seasonal fluctuation of tea yield (Tanton, 1981b). The tea shoot grows very slowly until it opens rudimentary leaves such as scale and fish leaves, and thereafter passes through a period of rapid extension (Fig. 3.9). At the end of the growing cycle or soon before dormancy, the rate of shoot extension again reduces with a less weight gain. Therefore, it is important to harvest a shoot at the phase of rapid extension and before it becomes dormant.

The rate of shoot extension is greatly influenced by environmental factors (Fig. 3.10 and Fig. 3.11) of which temperature, soil moisture deficit and vapour pressure deficit are the most influential ones (Carr and Stephens, 1992; Hoshina *et al.*, 1983, Fordham, 1969; Tanton, 1992; Squire, 1979; Wijeratne, 1994). Although

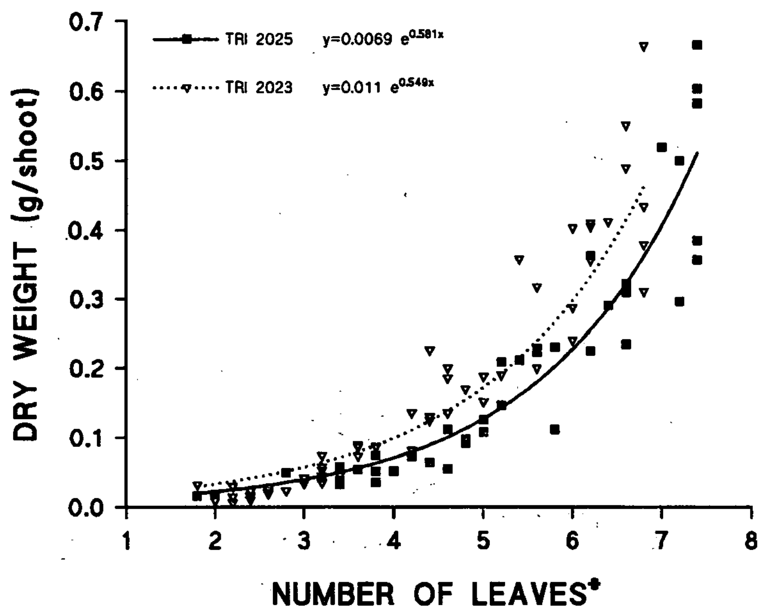


Fig.3.3 - Weight gain of a tea shoot in relation to leaf appearance (* Number of leaves includes fish and two scale leaves)

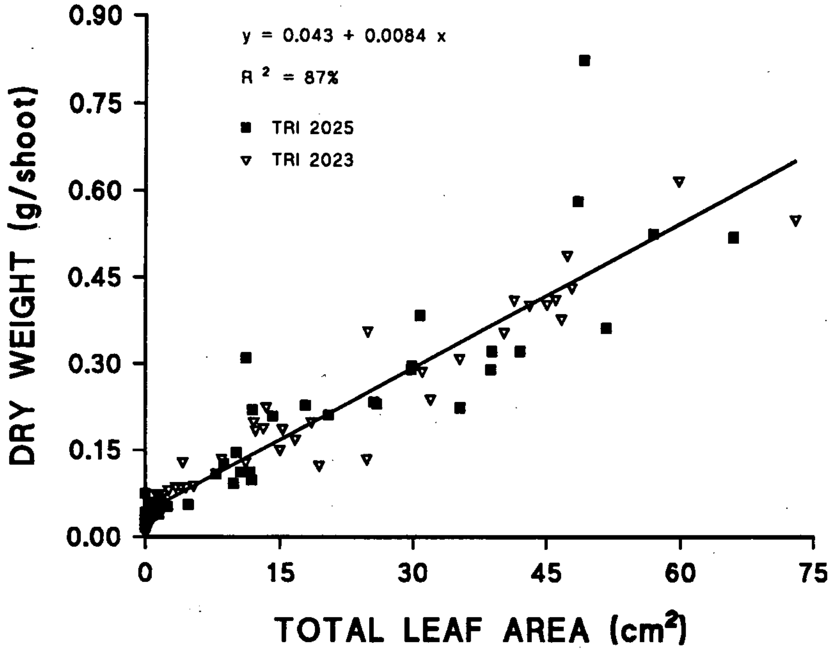


Fig. 3.4-Weight gain of a tea shoot in relation to leaf expansion

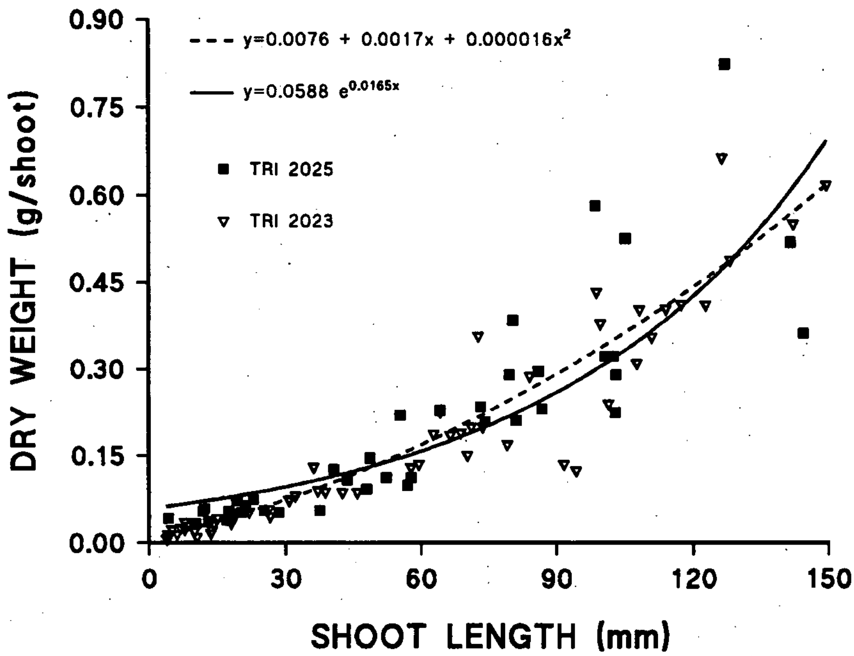


Fig. 3.5-Weight gain of a tea shoot in relation to shoot extension

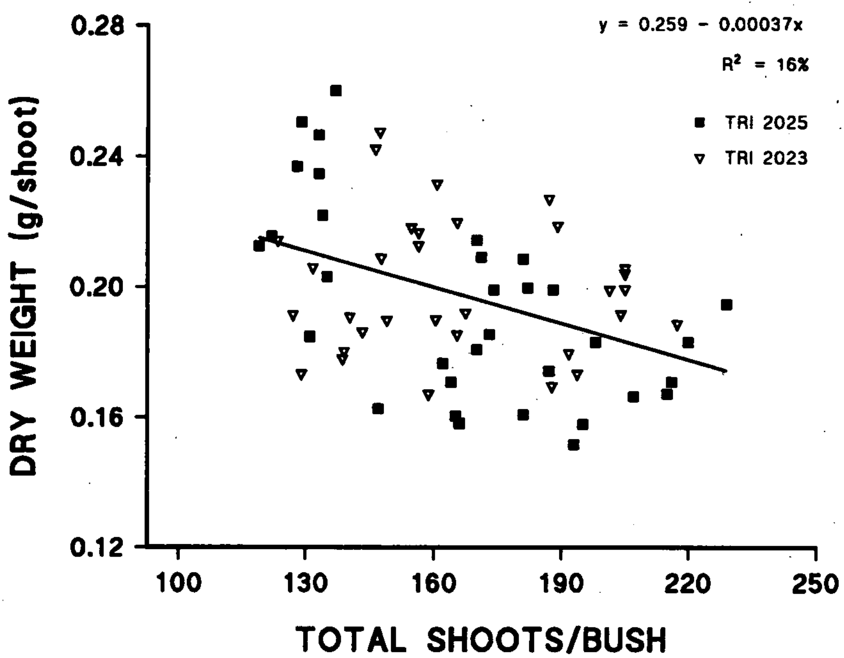


Fig. 3.6-Relationship between shoot density and mean shoot weight

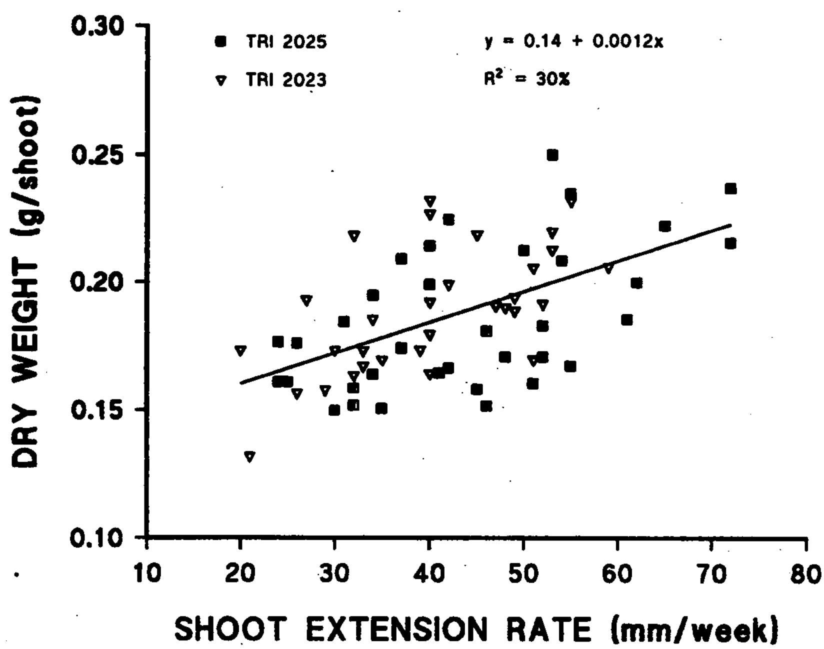


Fig. 3.7-Relationship between shoot extension rate and mean shoot weight

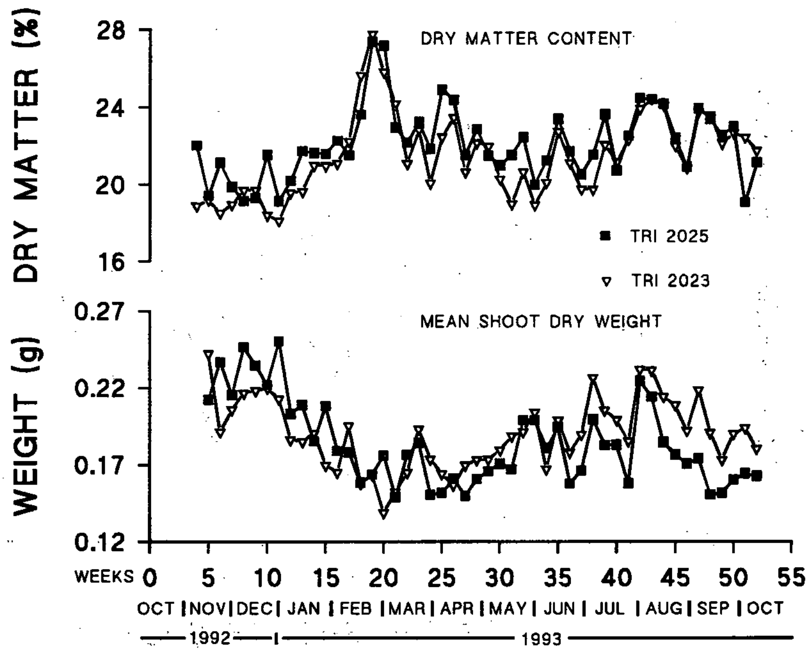


Fig. 3.8 - Variation in mean weight and dry matter content of a tea shoot (February and March were dry months.)

shoot extension rate is greatly hindered by dry weather conditions, it is less sensitive to dry weather than leaf expansion. Nevertheless, the shoot extension rate of some tea clones in Sri Lanka has been reduced from about 49 mm/week to about 35 mm/week due to dry weather (Wijeratne and Fordham, 1996). Moreover, the reduction in the rate of shoot extension in response to the development of plant water deficit is more in drought tolerant clones than in drought susceptible ones. This is also an adaptation of drought tolerant clones to successfully tide over a dry period. The day length has also been shown to have an influence on shoot growth. A number of scientists have shown that the growth of tea shoots depresses when the day length is less than about 11 hours (Laycock, 1964; Herd and Squire, 1976; Fordham, 1970; Tanton, 1982). Barua (1969) found that there is a greater tendency for tea shoots to become dormant when the day length is shorter than 11 hrs and 10 minutes. As tea cultivation is principally an agro-based enterprise that depends mostly on natural resources and weather, plucking policies should vary according to the changes in weather pattern.

3.4.1. Temperature dependent shoot growth

Most biological processes are temperature dependent. Experimental observations have revealed that there is a minimum temperature (base temperature) below which no active growth of tea occurs and an optimum temperature above which growth rate declines. Although the base temperature for shoot extension is generally considered as 12-13°C (Carr and Stephens, 1992), it can vary from 7°C (Obaga *et al.*, 1988) to about 15°C (Stephens and Carr, 1990). In the low-country tea growing regions in Sri Lanka, shoot extension rate is reduced when the temperature rises above 26°C (Wijeratne and Fordham, 1996). However, the analysis of yield and meteorological data over 2 decades has shown that the highest tea yield in Sri Lanka was obtained around 22°C (Amarathunga *et al.*, 1999). Various reports on growth and yield of tea in other countries have implied that the optimum temperature for growth of tea is in the range of 23-30°C (Carr, 1972; Carr and Stephens, 1992; Rahman, 1988; Smith *et al.*, 1993; Squire, 1979; Tanton, 1982 and 1992). Hence, the mean optimum temperature for growth of tea can be considered as 26°C. A linear increase in rate of growth (shoot extension rate) has been found in response to increasing temperatures between the base and optimum temperature. However, the coefficients of the relationship can vary with the presence of other limiting factors such as moisture stress and high vapour pressure deficit (Fig. 3.11).

There is an apparent variation in the rate of shoot growth with respect to altitudinal changes (Squire, 1990; Balasooriya, 1996). This is the result of decreasing ambient temperatures with the rise in altitude. Shoot extension rates at an altitude of 1860 m in Kenya was 1.87 mm/day compared to 1.22 mm/day at 2180 m amsl. Some tea growing regions experience both cooler and warmer climates. Under such conditions, carbohydrates are mostly partitioned to the roots during cooler climate as there is less or no active shoot growth. Later, these carbohydrates are re-translocated to the developing shoots when weather conditions are favourable (Fordham, 1972; Rahman and Dutta, 1988; Squire, 1977). These findings show that the variation in temperature modifies the balance between shoot and root growth.

The temperature dependent growth of tea shoots has been used for modelling and prediction of tea yield. The available daily temperature for shoot growth is the difference between base and mean daily temperatures provided that the mean temperature does not exceed the optimum temperature. The integral of this temperature difference over the period during which time a growth process occurs is termed as thermal time. Thermal time is given as degree-days (°C d). Detailed studies have demonstrated that an accumulation of a minimum number of degree-days is required for completion of most of the growth processes in the plant kingdom. According to this concept, it is possible for tea growers to predict some of the important harvesting policies such as plucking rounds (*see* Chapter 5.6) for different periods of the year based on the temperature variation. For example, a growing tea bud needs to accumulate about 450-500°C d to produce a tea shoot with two leaves and the thermal time for the period between initiation of successive leaves is about 150°C d in Kenya (Squire, 1990). However, under average growing conditions in Sri Lanka, the number of degree-days accumulated for producing a harvestable shoot with 3 leaves by clone TRI 2025 is estimated to be 330-370 in the high elevation (mean temperature-19°C) and 500-600 in the low elevation (mean temperature-26°C). Similarly, thermal time for successive initiation (opening) of leaves (clone TRI 2025) is estimated to be 30-40°C d in the high elevation and 60-70°C d in the low elevation (estimates were based on

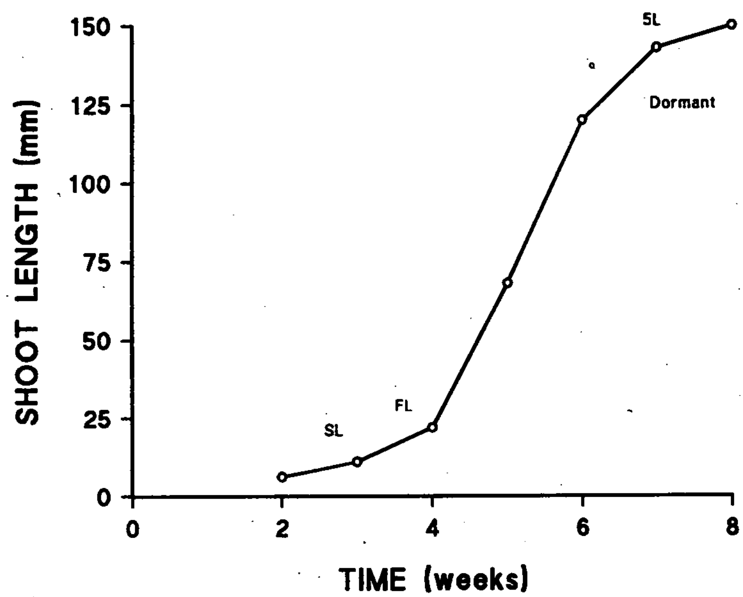


Fig.3.9 - Extension of a tea shoot (SL, FL and 5L are the appearance of scale leaves, fish leaf and 5[th] normal leaf, respectively.)

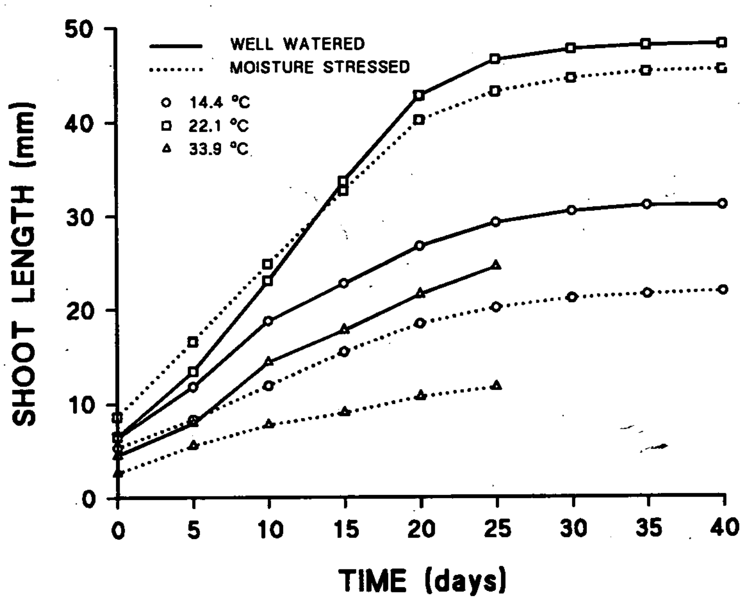


Fig. 3.10-Effect of temperature and soil moisture on shoot extension

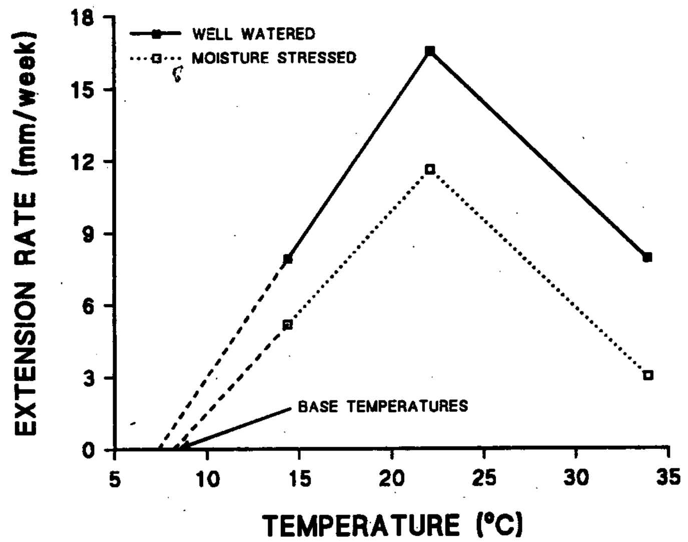


Fig.3.11-Effect of temperature on shoot extension rate

data reported by Ekanayaka, 1992 and Wijeratne, 1994 with a base temperature of 12.5^{0}C). The variation in degree-days recorded in these two elevations in Sri Lanka could be due to the presence of temperature above the optimum in the low-country or changes in the rate of plant response to temperature following the acclimation to the environment. Hence, more investigations are needed to adopt harvesting policies based on degree-days. Nevertheless, growers can easily estimate thermal time requirement for growth of tea shoots in their region or location using field observations and meteorological records.

The success of such predictions depends to a greater extent on the precision of the base temperature and the absence of other limiting factors such as lack of soil moisture and high vapour pressure deficit. The other practical implication limiting the use of the degree-day concept for deciding plucking rounds is the presence of a mixture of clone in a tea field. This is because the base temperature and thermal time requirements may vary among different clones. It has also been shown that under tropical weather condition, the ambient temperatures can rise above the optimum. Therefore, such cases should be carefully evaluated for the necessary corrections in the temperature model before predictions are made.

3.5 Dry matter content

As the marketable product of tea is the dried leaves, the dry matter content of tea shoots is of great importance to tea producers. Dry matter content of shoots varies with the weather pattern. Wijeratne (1994) reported varying dry matter contents between 18 per cent in wet weather and 28 per cent in dry weather with an annual mean of 21 per cent for TRI 2023 and 22 per cent for TRI 2025 in the low-country tea growing regions in Sri Lanka (Fig. 3.8). Similar variations of dry matter content have also been reported in East Africa (Stephens and Carr, 1994).

4. PARTITION OF DRY MATTER

4.1 "Source" and "Sink" relationship

The "source" of dry matter production is the mature foliage. When there are a large number of growing buds in the canopy, the majority of carbohydrates produced by leaves are diverted to the growing buds. In contrast, they are mostly stored in roots when the shoot growth is hindered. Hence, roots and growing buds are called the "sink". Of them, growing buds and *arimbu* (younger shoots) constitute the major sink for assimilated carbohydrates. The sink capacity is greater in the elongating bud compared to an expanding leaf (Barua, 1987). Manivel and Hussain (1986) found that the sink capacity of the first, second and third leaf from the apical bud, declined in the order 70, 40 and 30 per cent respectively of that of the apical bud. It is therefore, clear that the elongating buds and younger shoots (*arimbu*) on the plucking table are the strong sinks for assimilates. If the total sink capacity of a tea bush reduces, the production of carbohydrates by the foliage (source) may also reduce due to affected removal (partitioning) of carbohydrates from the source. In contrast, if there is no efficient source, the growth of bud and root is affected due to inadequate supply of food materials. Hence, it is necessary to maintain a balanced growth between the source and the sink in order to sustain tea yield.

It has been reported that the tea bush is sink limited (Tanton, 1979 & 1992). Magambo and Cannel (1981) also showed that plucking limits dry matter production. As per their estimates, free growing bushes produce 36 per cent more dry matter than harvested bushes. Unlike the harvested bush, most of the extra production of dry matter in the free growing bush is partitioned to stems and roots. Frequent removal of immature tea shoots by plucking has been identified as the major limiting factor for increasing the productivity of the tea bush. However, selective harvesting, that removes standard shoots leaving younger shoots *(arimbu),* minimizes the deterioration of the sink capacity of the tea bush. Harvesting policies therefore, affect the balance growth of shoot and root of the tea bush that determine its productivity and survival.

4.2 Harvest index of tea

In commercial plantations, the tea plant is confined to a low grown bush. It has the ability to produce a large amount of dry matter, part of which is harvested as tender shoots. Some of the carbohydrates produced by mature leaves are lost in respiration. Some are partitioned to various components of the bush namely, growing buds, stems and roots, as already discussed. The respiratory loss of assimilated carbohydrates is comparatively higher than that retains in the bush. It has been estimated to be about 60-70 per cent (Barbora and Barua, 1988; Rahman 1988; Tanton, 1979). Of the total dry matter that remains in the bush, the fraction harvested is called as the harvest index. The harvest index of tea is reported to be about 14-26 per cent, depending on cultivar and plant density (Burgess, 1992; Tanton, 1979; Magambo, *et al.*, 1988).

4.3 Dry matter partitioning to shoots and harvested proportion

Growing buds and younger shoots soon after bud break are unable to produce sufficient carbohydrates for their growth. Therefore, they depend on canopy leaves that are exporting carbohydrates and or starch reserves in bark and roots for their energy requirement. Experiments conducted in the low-country Wet Zone of Sri Lanka (Wijeratne, 1994) have shown that the mean weekly dry matter partitioning to shoots of a weekly harvested tea bush (high yielding clone planted at 1.2 x 0.6m) is in the range of 16-20 g/bush/week (Fig. 4.1). These studies have also shown that the dry matter partitioning to shoots is affected by weather conditions. Accordingly, dry matter partitioning to shoots has been reduced by about 25-35 per cent during dry weather. Increase in vapour pressure deficit above 1.2 kPa and soil moisture deficit above 50 mm has been responsible for such reductions.

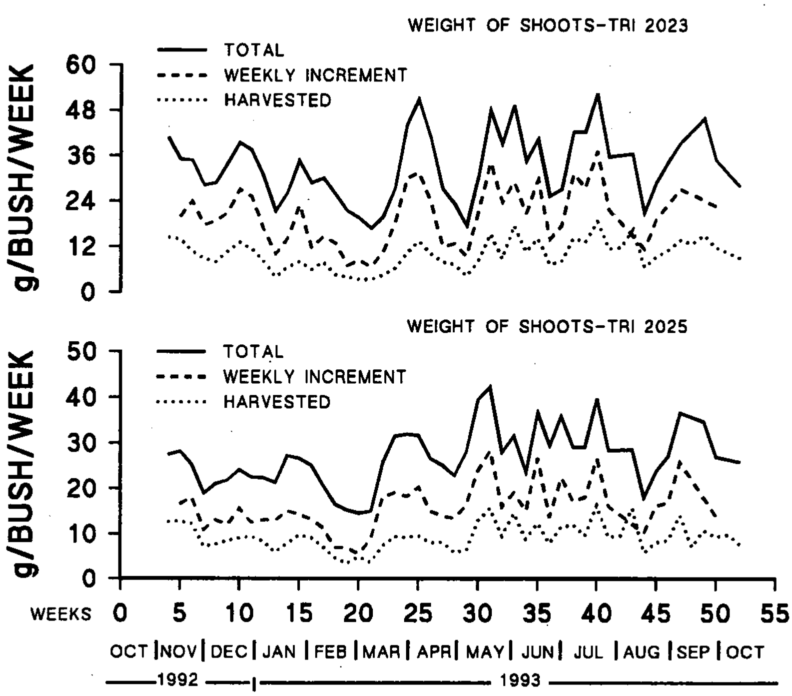


Fig. 4.1-Variation in dry matter partitioning to shoots.

Under average growing conditions in the low country Wet Zone of Sri Lanka, level plucking (mixture of single leaf and fish leaf plucking) at 7-day intervals (plucking rounds) removes about 30 per cent of the total shoot dry mass above the plucking surface. This amount corresponds to about 45 per cent of the dry matter partitioned to shoots after the previous plucking round (that is over a period of one week). Of a tea shoot with three leaves, about 40 per cent of the dry mass is removed by single leaf or mother leaf plucking (Chapter 5.5). However, this can be as high as 80 per cent for fish leaf plucking. Therefore, harvesting policies, mainly severity and standard of harvesting, have a great impact on the size of harvested crop and that of canopy (bush). In addition, there are apparent clonal differences in the harvestable proportion of a shoot. This is due to the differences in the shoot characteristics, mainly the inter-nodal length and size of leaves. Wijeratne (1994) reported that the harvested proportion of a tea shoot with longer inter-nodes (TRI 2023) is less than that of a shoot with shorter inter-nodes (TRI 2025), that is about 53 per cent and 67 per cent, respectively for mother leaf plucking on a shoot with 3 leaves. The amount of dry matter partitioned to shoots of TRI 2023 is 22 per cent more than that of TRI 2025. Therefore, a clone, which partitions a greater dry mass to shoots, may not necessarily give a higher yield.

5. HARVESTING (PLUCKING) POLICIES

Harvesting policies include methods, standard, severity and frequency of harvesting. These policies can vary from field to field depending on age and clone or *jat.* They also differ from one estate to the other depending on the availability of resources (labour *etc.*) and the type of tea produced in the factory (market requirements). Furthermore, harvesting policies may change from one region to the other depending on weather and climatic conditions. Nevertheless, the best harvesting policy is one that gives the highest productivity at a low cost while ensuring the good quality of the end product and vigour (health) of the tea bush.

5.1 Methods of harvesting

There are two methods of harvesting namely, manual and mechanical. The manual harvesting of shoots can be done either selectively or non selectively. Mechanical methods are mostly non-selective or partially selective details of which are discussed in a subsequent chapter.

5.2 Manual harvesting

5.2.1 Selective harvesting

When harvesting is selective, one or two older generations of shoots (Chapter-2.2) are removed. However, younger generations of shoots (*arimbu*) are left unplucked to enhance the "sink" capacity of the bush and also to harvest them as heavier units in the subsequent rounds. Selective harvesting not only gives a higher and a sustainable yield but also ensures a maximum exploitation of shoot growth and production of good quality made tea.

5.2.2 Non selective harvesting

Under this system, as many generations of shoots as possible are harvested without any selection. When no shoots are left on the bush and the plucking table consists of only mother leaves, it takes a dark green in colour. Therefore, it is known as "Black Plucking". This practice not only adversely affect the source:sink balance of the bush but also delays bud break and shoot regeneration due to release of immature axillary buds for re-growth (Chapter 2.3). A system of non-selective harvesting gives a marked reduction in yield due to adverse effects on shoot production and assimilation (Chapter 5.7). Moreover, the health and vigour of the tea bush deteriorates, thereby reducing its life span. The mean weight of a harvested shoot is also less under the system of non-selective harvesting due to removal of *arimbu*. Some other adverse consequences of non-selective harvesting are the production of dormant shoots and formation of "*mudichchi*" (Crow's feet condition), that is, a clump of shoots and stalks originating from one base (Fig 5.1). When shoots are continuously hard plucked, the gap between new shoots tends to narrow and the distance between two consecutive plucking points is also reduced due to short inter-nodes below the fish leaf, thereby resulting in the formation of a shoot clump. The harvested crop with no selectivity consists of shoots with varying degrees of maturity. Hence, non-selective harvesting creates problems in tea processing leading to the production of poor quality tea.

5.3 Shoot (leaf) standard

In order to produce good quality tea, it is necessary to supply tender shoots without coarse (mature) leaves to the factory. The shoot (leaf) standard to be fixed by the management (depending on the required quality of made tea) may vary with the type of tea manufacture and the method of harvesting. Generally, the standard shoots should only have 2-3 tender leaves and a bud. Immature dormant shoots with one leaf are also acceptable for processing. Tea shoots with coarse (mature) leaves and stalks and *arimbu* are considered to be sub-standard shoots for good quality tea manufacture. However, it is not practically possible to harvest 100 per cent acceptable (standard) shoots owing to varying field conditions and other constraints. Usually, presence of more than 75 –80 per cent good leaf (acceptable shoots) ensures a better quality end product.

5.4 Plucking (harvesting) standards

This is one of the most important aspects of harvesting policies. The plucking standard indicates the size of shoot (number of leaves) harvested. This can be classified into three categories, namely, fine, medium and coarse. Usually, these three categories have been identified based on the proportion of harvested shoots with varying number of leaves (Hudson *et al.,* 1997; Arunachalam, 1995; Kulasegaram, *et al.,*1989; Watson, 1986a). However, the classification can be easily done based on the number of leaves harvested. Accordingly, removal of shoots with 2 leaves is called fine plucking. If shoots with 3 leaves are harvested, it is considered as medium plucking. Coarse plucking implies the removal of shoots with more than 3 leaves and or coarse leaves. The quality of the end product and the cost of manufacture are greatly influenced by the standard of plucking. Fine plucking gives a low yield due to harvesting of smaller shoots (with less weight) and the extension of shoot replacement cycle (Chapter 2.3). It is also costly to maintain a fine plucking standard, as intake per plucker (weight of shoots harvested by a worker per day) is less than the other two standards. This is because the plucker needs to collect more shoots with 2 leaves (fine plucking) than those with 3 or more leaves (medium-coarse plucking) to form one kilogram. Sometimes, the 3rd leaf and inter-node immediately below the 3rd leaf can be more fibrous (coarse) in slow growing seedling tea than in the fast growing VP tea clones. Hence, a higher proportion of shoots with 2 leaves can be harvested from such fields to minimize any adverse effect on the quality of the end product. While the medium plucking provides an acceptable leaf standard for producing better quality tea at a low cost, coarse plucking adversely affects the quality of the end product. Nevertheless, changes in whether pattern may also warrant manipulation of plucking standards. Accordingly, the adoption of fine plucking is preferred during non-cropping months or periods of moisture stress to minimize the inclusion of coarse materials in the harvest (Chapter 5.7).

5.5 Severity of plucking

Severity of plucking determines the point at which a shoot is harvested. Although this becomes very useful for manual harvesting, its importance in the harvesting policy is negligible under a mechanical harvesting system as the point of plucking for individual shoots cannot be precisely set by a machine. If a shoot is plucked leaving the oldest normal leaf (true leaf above the fish leaf), it is called "single leaf plucking" (Fig. 5.2). The remnant leaf is known as the mother leaf, as it nourishes the subsequent growth of its axillary bud. Hence, this style is also known as "mother leaf plucking". Mother leaf plucking adds foliage to the bush in lieu of older and dying leaves at the bottom of the canopy and is considered to be the lightest and healthiest form of harvesting. While plucking to the fish leaf is termed "fish leaf plucking", plucking below the fish leaf is called "*janam*" leaf plucking" (Fig. 5.2). The latter two systems are known to be hard plucking.

5.6 Frequency of harvesting (Plucking round)

This refers to the length of period (number of days) between successive harvests. A plucking round can be defined as the time taken by the majority of shoots remained after the previous round (*arimbu*) to become ready for harvesting (harvestable). Accordingly, the decision to harvest a particular field is taken by field observations. However, such field observations cannot be used for predictions and planning purposes because of its wider variation with environmental factors.

With the results of detailed studies on shoot growth, the plucking round has been scientifically defined. Accordingly, an ideal plucking round is the number of days between successive opening of leaves, known as leaf period or phyllochron. In the absence of moisture and other stress conditions, the rate of leaf appearance is governed by the ambient temperature. Hence, the leaf period can be predicted using the thermal time (degree-day) concept, if the base temperature of clone and the daily mean temperature are known.

$$\text{Leaf period (plucking round)} = \frac{\text{Thermal time for a phyllochron}}{\text{(Mean temperature - Base temperature)}}$$

The thermal time for a phyllochron can be estimated by field observations. However, the prediction of leaf period should be validated under varying field conditions before accepting it as a general rule or routine practice. Further, such field observations and validations need to be carried out when bushes are at normal flushing and not under any stress conditions limiting growth. The clonal variation in base temperature (Chapter 3.4.1) should also be taken into consideration.

Plucking rounds are generally shorter during wet weather and are extended by dry weather. The frequency and standard of harvesting are to a greater extent, independent variables. However, extended plucking rounds, which increase the weight (size) of harvested shoots, may reduce yield due to the harvesting of a lesser number of shoots for a given period (Fig. 5.3). Moreover, it will adversely

Fig. 5.1-A *mudichchi* (Crow's feet)

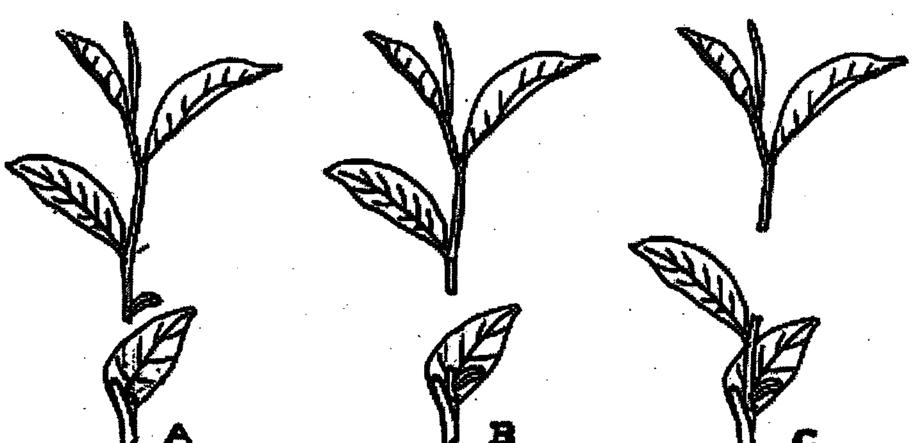


Fig. 5.2 - Severity of harvesting (A: Janum Plucking, B: Fish Leaf plucking, C: Mother leaf plucking)

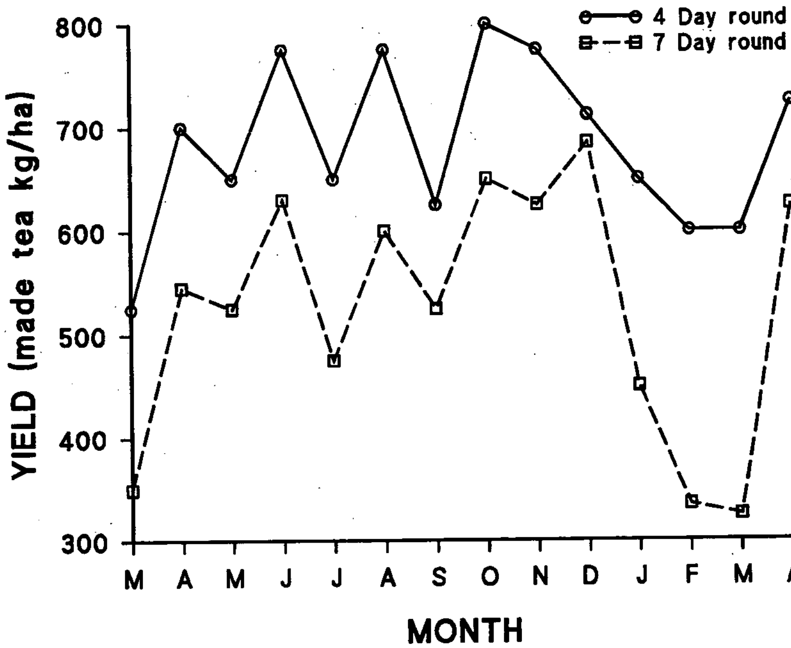


Fig. 5.3-Plucking rounds and yield of tea

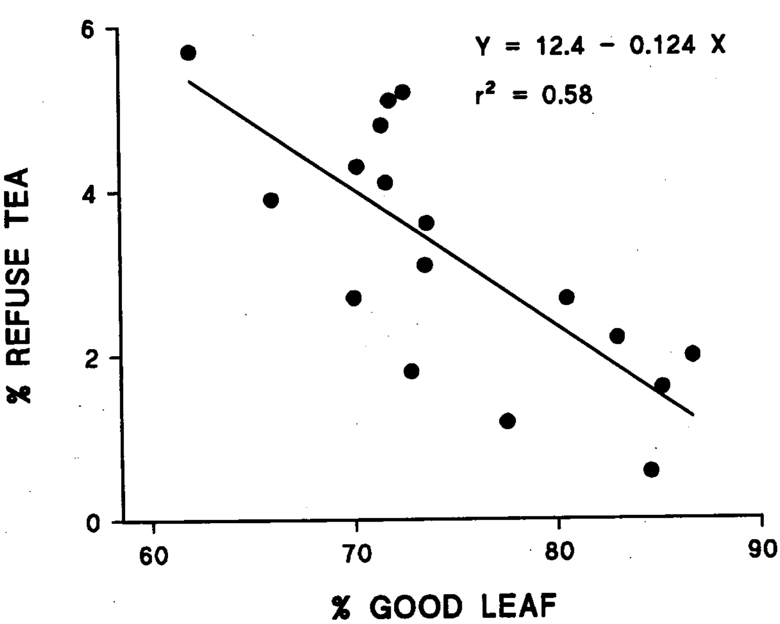


Fig.5.4 - Relationship between leaf standard and refuse tea content of processed tea (Galahitiyawa, 1998)

affect the quality of the end product due to the presence of more fibrous tissues (coarse leaf) in the harvest (Fig. 5.4). Hence, in a proper harvesting policy, there should be a logical balance between plucking round and plucking standard in order to secure a higher yield and good quality.

5.7 Plucking and vigour of the tea bush

Under single leaf plucking (light plucking), a fair amount of shoot dry mass is added to the canopy at every round of harvesting. Part of them is leaves. When the fish or *janam* leaf plucking (hard plucking) is done, an adequate number of leaves is not added to the canopy. However, as a result of harvesting a greater proportion of the shoot dry mass (Chapter 4.3), hard plucking gives a higher yield at the early stages of its introduction. Moreover, the fish leaf plucking can give a higher shoot replacement ratio that is more than 1:1 (Chapter 3.2). Nevertheless, at the latter stages of continuous fish leaf plucking, productivity of tea bushes declines due to lack of maintenance foliage and production of *mudichchi.* Non-selective harvesting of shoots (black plucking) always gives a lower yield (Fig. 5.5). With the presence of *mudichchi*, bushes tend to reduce shoot production and also produce smaller shoots that become dormant early. Therefore, continuous hard plucking reduces the productivity of tea bushes.

The rate of assimilation of tea leaves increases with leaf expansion. It becomes maximum when the leaves are fully expanded and is reduced with the subsequent ageing of leaves (Rajkumar *et al*, 1998; Watson, 1986b). Moreover, older leaves at the bottom of the canopy are shaded by younger leaves added on the top. As a result, older leaves always receive less sunlight than younger ones. This further reduces the photosynthetic efficiency of older leaves. Generally, adequate

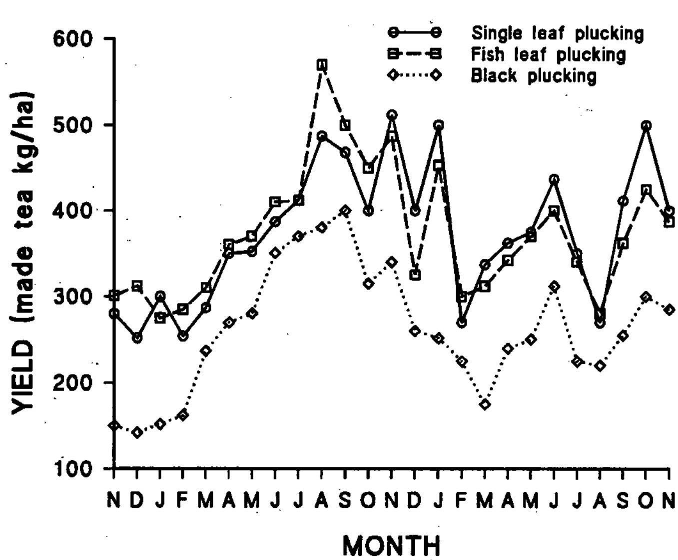


Fig. 5.5-Severity of harvesting and yield of tea

assimilates for export are available until tea leaves are about 6-8 month old (Rajkumar *et al*, 1998). Hence, addition of a fresh layer of canopy leaves (mother leaves) at every 6-8 months is a must to sustain the productivity of bushes. However, continuous addition of new leaves by adopting mother leaf plucking throughout the year is not necessary. This is not only a waste of harvestable shoot dry mass but also a cause of unmanageable rise in the plucking table. Experimental evidence has shown that the solar radiation is fully intercepted by a 25 cm deep canopy of tea leaves (Rajkumar *et al*, 1998; Watson, 1986b). Hence, the maintenance of a thick canopy (more than 25 cm) is not beneficial. Moreover, continuous addition of leaves can delay bud break due to shading or covering of the axillary buds by canopy leaves.

In order to maximize the yield preserving the health and vigour of the tea bush, it is necessary to adopt a mixture of fish leaf and single leaf plucking. This alteration of plucking system can be coupled with the changes in weather conditions. Usually, the cropping pattern of tea goes in parallel with the rainfall pattern in the tropics. The peak cropping months fall during wet weather while the trough (drop) in production sets in with the commencement of dry season (Fig. 5.6). Accordingly, a higher proportion of fish leaf and medium plucking can be advocated during wet weather when the bushes are in full production and shoots are more succulent. With the presence of more fibrous tissues during less-cropping (dry) periods, it is necessary to adopt a higher proportion of single leaf and fine plucking. Adoption of such a mixture of plucking will not only maximize the harvesting of dry matter partitioned to shoots without affecting the growth of the bush but also regulates the rise in plucking table to a manageable height while ensuring the addition of new leaves to the canopy. This combination also maintains a good quality of the end product.

5.8 Plucking after tipping and bringing into bearing

The importance of the depth of maintenance foliage has been discussed in the previous section. The tea bush soon after bringing into bearing and tipping does not have sufficient maintenance foliage. Moreover, ground cover is very poor under such conditions. Hence, it is necessary to build up a healthy canopy by adopting a light plucking system (mother leaf plucking) during early stages of bringing into bearing and tipping. The period of light plucking depends on the condition of the canopy. Under average growing conditions in Sri Lanka, light plucking for a period of one year after bringing into bearing and about 6 months after tipping is preferred. Moreover, the spread of tea bushes can be enhanced by leaving the horizontally growing branches or side shoots unplucked when they are actively growing.

5.9 Rush crop

Tea yield varies with the changes of weather conditions. Rainfall has been identified as the most influential factor in the tropics. Majority of tea plantations in Sri Lanka receives rain from both Southwest and Northeast monsoons. Usually, wet months are characterized by high yield (Fig. 5.6). Although harvesting is

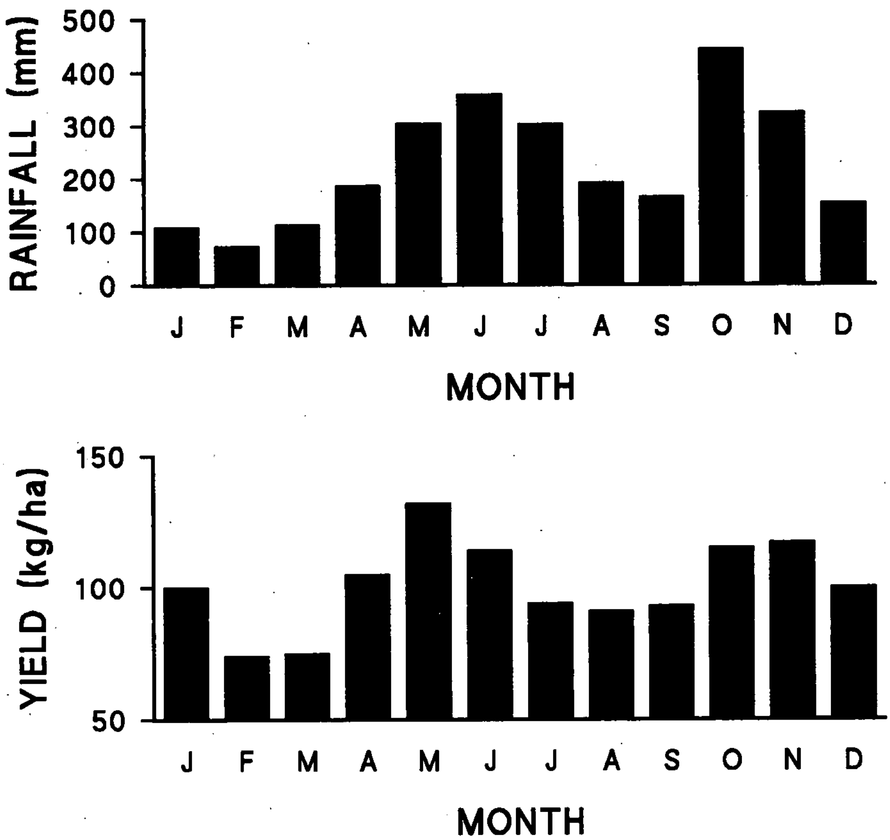


Fig.5.6 - Monthly variation in rainfall and made tea yield (Low-country Wet Zone of Sri Lanka.

continued during dry weather, axillary buds exposed for re-growth remain dormant or will have a slow rate of growth due to stress conditions. The growth of these buds is activated with the first few showers of inter-monsoon or monsoon. This synchronized growth of shoots leads to an increase in shoot population. Moreover, favourable climatic conditions during monsoons enhance the rate of growth of shoots, thus forming a peak in yield known as rush crop (Chapter 3.1). A similar phenomenon can occur due to seasonal variation of temperature.

During the peak cropping months, labour requirement for harvesting is comparatively high due to abundance of harvestable shoots and adoption of closer plucking rounds. However, several other agronomic practices such as pruning, planting, fertilizer application, weeding, lopping of shade trees, nursery practices, *etc.,* are also planned during the wet period. Therefore, many estates face problems of labour distribution for different field operations. The situation is aggravated, when the outturn of workers is declined owing to social activities such as festivals, falling mostly during the peak cropping months (e.g. Sri Lanka). As the majority of the annual production comes from the rush crop, proper planning of available resources is essential to obtain the maximum benefits.

5.10 Management of rush crop

Tea shoots should be harvested before they are over-matured or become coarse for manufacture. Therefore, harvesting policies should be adjusted to match the availability of labour for harvesting, taking into consideration of the harvestable extent, plucking rounds and plucker intake. Following strategies can be adopted to ease the problem of labour shortage during the rush crop period.

5.10.1 Reduction of plucking fields

During the rush crop, it may not be possible to harvest the entire extent of harvestable fields without having extended rounds. In such situations, resting (stop harvesting) of tea fields earmarked for pruning becomes very useful. This not only reduces the extent to be harvested but also improves the health and vigour of the bushes to be pruned. Moreover, the plucker intake is low in such fields and the quality of harvested shoots is also poor. The high cost of harvesting in the fields earmarked for pruning also favours the practice of resting tea before pruning. Presently, many estates delay pruning until the end of the cropping season (rush crop) and continue harvesting until pruning in order to maximize the crop. This can lead to poor recovery and debilitation of tea bushes after pruning due to the exhausted condition of the bush (lack of starch reserves) after producing the rush crop and subsequent recovery into dry weather after pruning (Kulasegaram *et al.,* 1989; Kulasegaram, 1986).

Commencement of harvesting before the bushes have adequately re-foliated after pruning, that is, at 4-5 leaf stage (known as plucking-in) also opens more fields, for harvesting during the cropping months. The practice of tipping (cutting of shoots with 8-10 leaves to a level, leaving 4-6 leaves per shoot) not only reduces pluckable extent during the rush crop period but also enhances frame development and vigour of the tea bush. Hence, proper pruning policies such as resting before pruning, timely pruning and tipping help management of the rush crop to a greater extent.

5.10.2 Extension of plucking rounds

Plucking rounds are closer during heavy cropping months due to the faster rate of growth. Under such conditions, maintenance of proper plucking rounds can be difficult if adequate workers are not available. Hence, it will be useful if tea shoots can be harvested at extended rounds without affecting the quality of shoots. This can be done to some extent by adopting partial black plucking by removing a generation of *arimbu* shoots, which is usually left on the bush. The degree of removal of *arimbu* determines the length of subsequent rounds. However, this should not be continued as a routine practice or as a substitute to normal plucking, because it deteriorates the source:sink balance and debilitates the health of the tea bush.

5.10.3 Increase in plucker intake

Labour requirement for harvesting can be reduced by increasing the output of workers. This can be done by introducing a suitable mechanical harvester. In this strategy, the use of harvesting shears or machines becomes necessary (Chapter 6). Labour productivity can be enhanced by providing various incentives to workers. Attractive "over-kilo rates" (payment of an extra rate per kg of leaf harvested over and above the fixed norm) and "cash plucking" (harvesting of extra crop outside normal working hours) in the morning hours increase the daily output of workers and coverage of harvestable fields. The incentives granted to workers based on their attendance are also effective in minimizing absenteeism of workers. The success of such incentive-based harvesting policy greatly depends on the quality of supervision and education of the labour force. Postponement of sundry works such as maintenance of roads and buildings, fencing, desilting of drains, *etc.,* to non-cropping months and deployment of those workers for harvesting will also ease the problem of labour shortage during the rush crop period.

In the context of labour shortage and rising wages, it will be beneficial to arrive at the optimum labour requirement for harvesting. This can be worked out based on three key factors namely, yield, plucking intake and made tea outturn (Annex. 1). This model is of a generic nature and needs to be modified for use by individual units in keeping with management policies, estate practices, agro-climatic differences and other relevant features (Sivaram, 2000).

5.11. Maintenance of plucking table

The plucking table that consists of mother leaves and shoots indicates the level of estate management and its productivity. It also gives a good appearance to the estate. The shape of the plucking table varies from flat to dome in shape, depending on the method of plucking adopted. Usually, bushes that are manually harvested have a flat surface of plucking in parallel with the slope of the land, while some machines and shears favour a dome shaped plucking surface along tea rows. The evenness of the plucking table not only improves the harvesting efficiency but also determines the efficacy of foliar-applied nutrients and other chemicals. Moreover, bud break and assimilation could be affected due to the uneven distribution of sunlight over a poorly managed plucking table. The maintenance of an even plucking table should therefore, be a routine operation in the field. Although this is automatically maintained by machines, it needs more attention when shoots are harvested manually. It is a common practice of workers in some tea growing regions to use a straight stick of about 2m kept on the plucking table, to harvest tea bushes to a level. The harvestable shoots above the stick are removed to the level while those below the stick are left without harvesting.

In the practice of maintaining the plucking table, some shoots need to be removed with mature leaves and inter-nodes (coarse leaves). These fibrous parts are not suitable for manufacture and hence removed to standardise the crop. This operation is known as "Break back". When plucking rounds are unduly extended more "break back" is necessary to standardise the harvested crop. This not only reduces the plucker intake but also causes loss of yield. The maintenance of plucking table also involves the removal of *mudichchi.* If, however, *mudichchies* have been accumulated, cleaning of the plucking table (removal of *mudichchi)* needs to be phased out at several rounds of harvesting because the removal of large clumps of shoots from its base can open up the plucking table, thereby reducing the subsequent production of shoots.

Some estates break the continuation of plucking table at every other row and make paths along the inter-rows by cutting peripheral branches of the bush. These paths made for easy movement of workers in the field are known as plucking or spraying lanes. Although the existence of such lanes are reported to increase the productivity of workers, the use of additional labour for cutting and maintenance of lanes, reduction of area of plucking table, enhanced growth of weeds are negative features of plucking lanes.

5.12 Quality of harvested shoots

It has been highlighted that the maturity of harvested shoots greatly influences the quality of the end product. A good leaf standard can be maintained by manipulating the frequency and standard of harvesting. The quality of made tea can nevertheless be affected by the physical condition of shoots reaching the factory. Hence, it is necessary to minimize the physical damages to tea shoots while harvesting and transportation. Shoots can be damaged (crushed or bruised) when too much of shoots are retained in the plucker's hand during manual harvesting. Frequent charging of the leaf collecting basket not only minimizes the physical damage to shoots but also improves selectivity of shoots by free movement of fingers. The use of machines and shears minimizes the leaf handling by hand. There is also a greater chance of damaging shoots at the time of bulking them into baskets or bags and during transportation. Too much of crop should not be rammed and pressed into a basket or a bag when bulking. In addition, several bags should not be stacked on the top of each bag in the vehicle because poor aeration and heat break down the chlorophyll and, subsequently, the shoots become brown in colour. Such shoots are unsuitable for manufacture. Harvested shoots can be spread on a clean floor under a shade if bulking or transportation is delayed.

Tea shoots should not be contaminated with agro-chemicals used for weeds, pest and disease control because chemical residues retained in the made tea are hazardous to human health. Hence, growers must take care either to bulk shoots from chemically treated fields adequately with those from untreated fields or withhold harvesting for a stipulated period of time, as recommended by the research institutes or chemical manufacturers.

6. MECHANICAL HARVESTING

Harvesting of tea is best done by hand. This will, in particular, ensure harvesting of shoots of required maturity (standard) to produce best quality tea and preserve the health and vegetative vigour of the tea bush. However, manual harvesting requires a large number of workers. It is well known that the workers of younger generation do not like to go for manual harvesting which is often considered to be a fatigue field job. The wage difference between estate and non-estate jobs also contributes to the shortage of workers in plantations. Consequently, the availability of manual workers for field operations in tea plantations has drastically declined in the recent past (e.g. low country tea growing regions in Sri Lanka), forcing some fields to be temporarily or permanently abandoned. The shortage of workers is greatly felt during cropping months and festival seasons. Although incentive based harvesting policies can to some extent improve labour performance, there is no permanent solution for absenteeism and declining labour force. Therefore, tea growers are compelled to look for alternatives of manual harvesting to ensure that the entire plucking fields are timely harvested.

Mechanization of field operations has offered an attractive solution for the labour shortage in many agricultural enterprises. Therefore, new machinery is being developed and continuously upgraded for different field operations. However, the use of machines has not been common in some of the tea producing countries (e.g. Sri Lanka, India), mainly due to the belief that mechanical harvesting would lead to poor quality of the end product and damage the bush.

A socio-economically acceptable system of mechanical harvesting should have the following attributes.

- -high worker output
- -low harvesting cost
- -harvesting shoots of acceptable quality
- -preservation of health and vigour of the bush
- -least impact on the environment
- -worker comfort

There are two types of mechanical devices used for harvesting tea. They are:

- -shears and
- -motorized machines

6.1 Shears

Varying types of plucking shears are used in different tea growing countries. Most of them are modified garden shears with long handles and a leaf-collecting tray or bag. Some have varying heights of steps above which the shoots are sheared to the collecting tray (Fig. 6.1). They weigh about 750 - 1500g and have either self-sharpening (concave type) or hot-tempered steel blades with long lasting cutting edges. The blades and trays are about 20-30 cm long and bolted using permanent rivets, screws or adjustable nut and bolts.

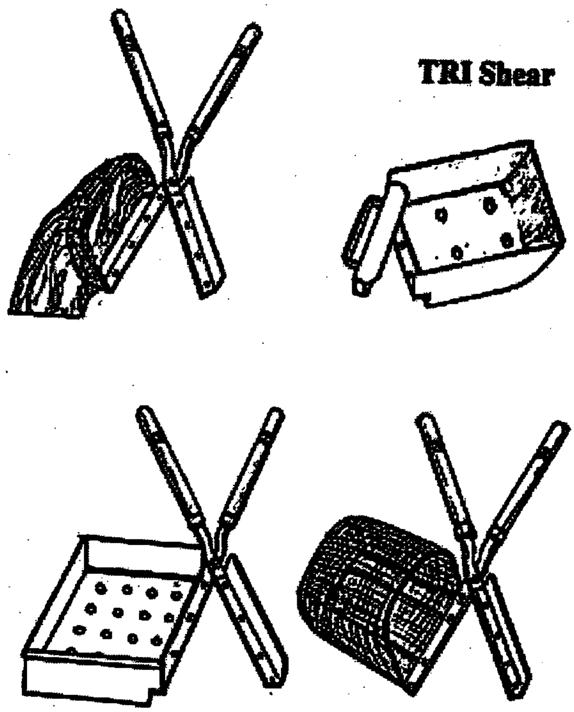


Fig. 6.1-Different models of tea harvesting shears

In Sri Lanka, the Tea Research Institute has developed a selective harvesting shear (TRI Selective Tea Harvester) without long and prominent handles (Plate 6.1). It weighs less than 400g. A leaf collecting tray with perforations and the handle are made of plastic. Two steel blades are fixed about 2.5 cm above the bottom of the leaf-collecting tray. One is fixed to the leaf-collecting tray and the other to the handle. The handle has a protruding edge about 2.5 cm above the blade to guide and push shoots towards the leaf-collecting tray.

6.1.1 Output of shears

The output of mechanical devices used for harvesting depends on the yield potential and the topography (terrain) of the field. When the growth of shoots is synchronized by pruning and weather, the entire crop for the year can be harvested within a few rounds (e.g. Japan). Under such conditions, the output of shears is very high, that is about 60-100kg/day. In South Indian tea plantations, the manual harvesting intake is about 20-30 kg/day compared to about 40-60 kg/day with shears. However, the use of similar type of shears in Sri Lanka has given an output of about 20-30 kg of green leaf per day (6.5 working hours) which is comparable to manual harvesting intake. The relatively low output has been due to non-selective harvesting, inconvenient operation in the field and lack of training. Nevertheless, most of these disadvantages have been overcome following the introduction of the selective type TRI shear without long handles. This has the potential of doubling worker output.

6.1.2 Yield and quality

In Sri Lanka, the continuous use of ordinary (non-selective) shears had brought about a 25-35 per cent yield reduction compared to manual harvesting. This was mainly due to the non-selective harvesting and affected shoot growth. However, the TRI shear has not brought about a significant drop in yield due to the selective harvesting of shoots. Although other shears give about 10-15 per cent more coarse leaves, the leaf standard of the TRI shear is comparable to that of manual harvesting. Because of minimum handling, the shoots harvested by plucking shears are found to be of better physical condition than those manually harvested. This is an added advantage of shear harvesting.

6.2 Motorized machines

Harvesting machines range from hand-held portable harvesters (Plate 6.2) to tractor-mounted types. Depending on their size, the weight of machine varies from about 10 kg to several tons. Although there are many kinds of motorized harvesters, their common feature is non-selectivity in the harvesting of tea shoots. They require good ground conditions, even growth of shoots (less number of generations) and trained canopies for better performance. Therefore, the use of motorized machines is greatly limited by the field conditions and pattern of shoot growth (cropping pattern).

In tea growing countries such as Sri Lanka and India, tea has been planted either in contour rows or along the slope (up and down planting), mostly at a spacing of 1.2m x 0.6m or wider. The majority of tea fields also lie on steep slopes. The plucking table of these bushes is flat and follows the slope of the land. Such tea fields often do not favour mechanical harvesting with motorized machines. The requirement of a greater percentage of tender shoots with 2-3 leaves for manufacturing of good quality tea has also been a limiting factor for the use of plucking machines. Under tropical climatic conditions, tea shoots grow throughout the year and about 5-6 shoot generations are present in the plucking table. As a result, machines need to be modified for selective harvesting or bushes stimulated to have synchronized growth of shoots with a fewer number of generations so that only the standard shoots are harvested.

In order to successfully undertake mechanical harvesting, it is important that the bushes are especially trained for motorized harvesters. This has to be done initially at the time of planting. Bushes then need to be continuously trained at every pruning by cutting of recovering shoots at several occasions depending on their rate of growth. This is necessary because the formation of a plucking table with many plucking points is a primary requirement of mechanical harvesting. Double hedgerow planting allows easy movement of workers and machines in the field. Moreover, the hedgerows can easily have a dome shape-plucking surface with a larger surface area of plucking table. Accordingly, many tea growing countries where mechanical harvesting is done have their tea lands planted and trained to suit mechanization. Synchronized growth of tea shoots with climatic changes in such countries also favours mechanical harvesting.

Plate 6.1- Harvesting of tea with the TRI shear (Selective Tea Harvester)

Plate 6.2-Harvesting of tea using a motorized machine

6.2.1 Classification of plucking machines

Tea plucking machines can be classified based on:

- -movement of blades
- -length of blades
- -source of power and mode of power transmission

Some of the plucking machines have horizontally reciprocating (hair clipper type) or turning blades while others have cylindrically arranged (mower type) blades. In the case of hand-held machines, the length of blades usually varies from about 30-100 cm. Harvesting section (blades) of plucking machines can be driven by engine or electricity. The engine can be a knapsack type with a flexible shaft or directly coupled with the harvesting section. The electrically driven machines have a generator or batteries. In addition, there are new models of tea harvesting machines powered by pneumatic pressure. Once the shoots are cut, they are air-blown or automatically guided by moving blades to a leaf-collecting bag.

6.2.2 Output of motorized machines

The output of machines largely depends on the length of blades (harvesting section), the longer blades giving a higher output than the shorter ones. Further, the output varies with the yield potential and topography (mainly slope) of the tea land. It can vary from about 2000 kg/day for a tractor- mounted machine to about 400 kg/day for a small hand held machine in Japan. However, under average field conditions in Sri Lanka, smaller hand held machines having about 30cm blades have given an output of about 150 kg/day. This has been as high as 400 kg/day for a larger machine with 100 cm blades. The crop harvested by machines contains about 15-20 percent more coarse leaves than that manually harvested. The output differences between tea growing countries are attributable to the differences in the pattern of shoot growth, style of planting, method of training of tea bushes and presence of drains, bunds, shade trees, *etc* in the field.

The labour requirement for mechanical harvesting also varies with the style of planting, topography of the field and the presence of other obstacles as mentioned above. Generally, a smaller machine requires one operator and larger machine (100 cm) two operators. An additional worker is required to hold and guide the leaf-collecting bag on sloping terrain where tea is originally planted for manual harvesting with a flat plucking table. Under such conditions, the output of machines per manday becomes comparatively low.

The extent of tea land harvested by a machine primarily depends on the field conditions. It can be as high as several hectares in countries where tea has been originally planted for mechanical harvesting (e.g. Japan) or less than a hectare on slopes where tea is planted and trained for manual harvesting (e.g. Sri Lanka). Hence, topography of land, the style of planting and training of tea bushes influence the area covered by a machine. Although fuel consumption varies with the engine capacity, it is reported to be about 3-5 l/day (6.5 working hours) for a hand-held machine.

6.2.3 Yield and quality

By and large, mechanical harvesting gives a less yield than manual plucking. However, when the growth of shoots are seasonal as in Japan, the yield reduction is minimum due to the presence of a few shoot generations. Under the Sri Lankan field conditions, continuous mechanical harvesting has resulted in a yield reduction of around 50 per cent. When harvesting machines are used only during peak cropping months (rush crop periods only), the yield loss could be minimized to about 20-30 per cent. The loss of yield under mechanical harvesting is a combined result of non-selective harvesting of shoots, damage to *arimbu* and maintenance foliage and extended plucking rounds. Inclusion of coarse leaves also reduces the yield of standard (acceptable) shoots.

Machine harvesting usually gives poor quality shoots compared to manual harvesting. The crop harvested by machines consists of sub-standard shoots such as coarse leaves and younger shoots *(arimbu)*. The presence of shoots of varying degrees of maturity and with a wider range of moisture affects tea manufacture and results in poor quality end product. When mechanically harvested crop is processed (orthodox manufacture), the amounts of refuse tea and off-grade tea are increased while that of good quality main grade tea is reduced. The production of refuse tea can be minimized by sorting out of coarse leaves and other extraneous materials in the harvest before manufacture. But this practice is a labour consuming process and reported to be uneconomical (Watson *et al.*, 1982). Due to the adverse effects on growth, yield and quality of tea, mechanical harvesting has not been considered as a substitute to manual harvesting. Nevertheless, if machines are to be used as an effective alternative to manual harvesting, it is necessary to adjust policies of tea harvesting and processing to suit mechanical harvesting. Moreover, workers and tea bushes should be trained for harvesting machines. Hence, a system of mechanical harvesting cannot be introduced as a single device or as a quick solution for labour shortage but as a total package for enhancing worker productivity.

REFERENCES

Amarathunga, M.K.S.L.D., Jayaratne, K.P.S.C. and Wijeratne, M.A. (1999). Effect of ambient temperature and evaporation on yield of tea in Sri Lanka. *Proceedings of 55th Annual sessions, Part 1,* SLAAS, Colombo, Sri Lanka 99-100.

Arunachalam, K. (1995). *A hand book on Indian tea.* Arunachalam Associates, Nilgiris, India.

Balasooriya, J. (1996). Effect of altitude on shoot development of clonal tea with special reference to clonal selection and harvesting intervals. *Sri Lanka Journal of Tea Science.* **64 (1/2):** 51-62.

Barbora, A.C. and Barua, D.N. (1988). Respiratory losses and partition of assimilates in tea bushes (*Camellia sinensis* L.) under plucking. *Two and a Bud,* **35:** 75-82.

Barua, D.N. (1969). Seasonal dormancy in tea (*Camellia sinensis* L.) . *Nature.* **224:** 514.

Barua, D.N. (1987). Tea. In: Sethuraj, M.R. and Raghavendra, A.S. (eds.) *Tree crop physiology.* Elsevier, Amsterdam, 225-246

Barua, D.N. and Das, S.C. (1979). Mechanisms of growth periodicity in tea. *Two and a Bud,* **26:** 36-40.

Bond, T.E.T (1942). Studies in the vegetative growth and anatomy of the tea plant (*Camellia thea* Link.) with special reference to the phloem. I. Flush shoots. *Annals of Botany,* **6:** 607-629.

Bond, T.E.T. (1945). Studies in the vegetative growth and anatomy of the tea plant (*Camellia thea* Link.) with special reference to the phloem. II. Further analysis of flushing behaviour. *Annals of Botany,* **9:** 183-216.

Burgess, P.J. (1992). Dry matter production and partitioning by clone 6/8. *Ngwazi Tea Research Unit, Quarterly Report,* **No.9:** 11-16.

Carr, M.K.V. (1970). The role of water in the growth of the tea crop. In: Luckwill, L.C. and Cutting, C.V. (eds.) *Physiology of tree crops,* Academic Press, London. 287-304.

Carr, M.K.V. (1972). The climatic requirements of the tea plant: A Review. *Experimental Agriculture,* **8:** 1-14.

Carr, M.K.V. and Stephens, W (1992). Climate weather and the yield of tea. In: Willson, K.C. and Clifford, M.N (eds.), *Tea: Cultivation to consumption,* Chapman and Hall, London. 87-135.

Ekanayake, P.B. (1992). Report of the Agronomy Division, *Annual Report for 1990, Tea Research Institute of Sri Lanka, Talawakelle, Sri Lanka*: 45-57.

Fordham, R. (1969). The physiological responses of tea to moisture stress and irrigation. *Quarterly Newsletter, Tea Research Foundation Central Africa,* **No. 13:** 13-15.

Fordham, R. (1970). Factors affecting tea yields in Malawi. *Annual Report, Tea Research Foundation of Centra Africa,* Mulanje, Malawi. 71-130.

Fordham, R. (1971). Stomatal physiology and the water relations of the tea bush. In: Carr, M.K.V. and Carr, S. (eds.) *Water and the Tea Plant.* Tea Boards of Kenya, Uganda and Tanzania Tea Authority. 89-100.

Fordham, R. (1972). Observations on the growth of roots and shoots of tea (*Camellia sinensis*) in southern Malawi. *Journal of Horticultural Science,* **47:** 221-229.

Fordham, R. and Palmer-Jones, R.W. (1977). Simulation of intra-seasonal yield fluctuations of tea in Malawi. *Experimental Agric*ulture, **13:** 33-42.

Galahitiyawa, G. (1998), Effect of tea leaf standard on net outturn of made tea in the low-country. *Personal communication*

Goodchild, N.A. (1968). Growth of tea shoot following pruning. *Annals of Botany,* **32:** 567-572.

Herd, E.M. and Squire, G.R. (1976). Observations on the winter dormancy in tea. *Journal of Horticultural Science,* **51:** 267-279.

Hoshina, T., Kosuge, N., Kozai, S. and Honjo, U. (1983). Influence of air temperature on nitrogen uptake by the tea plant. *Study of Tea,* **64:** 24-28.

Hudson, J.B., Durairaj, J., Muraleedharan, N., and Dhanakumar, V.G. (1997). *Guidelines on tea cultivation in South India.* UPASI-KVK, India.

Kulasegaram, S. (1986). Pruning. In: Sivapalan, P., Kulasegaram, S. and Kathiravetpillai, A. (eds.) *Hand book on tea.* Tea Research Institute of Sri Lanka, Talawakelle, Sri Lanka: 82-87.

Kulasegaram, S. and Kathiravetpillai, A. (1972). Effect of nutrition and hormones on growth and apical dominance in tea (*Camellia sinensis* (L.) O. Kuntze). *Journal of Horticultural Science*, **47**: 11-24.

Kulasegaram, S. and Kathiravetpillai, A. (1983). Effect of shade water supply and nitrogen on the distribution of mineral nutrients and total carbohydrate resources in young tea (*Camellia sinensis* (L.) O. Kuntze). *Tea Quarterly*, **52:** 21-30.

Kulasegaram, S., Kathiravetpillai, A. and Shanmugarajah, V. (1989). Approaches to higher productivity through proper bush management. In: Sivapalan, P. and Kathiravetpillai, A. (eds.) Proceedings of the regional tea (Scientific) Conference. Tea Research Institute of Sri Lanka, Talawakelle, 157-164.

Laycock, D.H. (1964). An empirical correlation between weather and yearly tea yields in Malawi. *Tropical Agri*culture, **41:** 277-291.

Magambo, M.J.S. and Cannell, M.G.R. (1981). Dry matter production and partition in relation to yield of tea. *Experimental Agriculture*, **17:** 33-38.

Magambo, M.J.S., Omolo, J.G. and Othieno, C.O. (1988). The effect of plant density on yield, harvest index and dry matter production. *Bulletin, United Planters Association of South India*, **No.40:** 7-14.

Manivel, L. and Hussain, S. (1982). Photosynthesis in tea: Direction of movements of photosynthates. *Two and a Bud,* **29 (2):** 49-52.

Manivel, L. and Hussain, S. (1986). Relative sink capacity of developing tea shoots. *Two and a Bud,* **33 (1-2)**: 30-38.

Mwakha, E. (1985). Tea shoot growth in the Kenya Highlands. *Tea,* **6:** 5-13.

Nathaniel, R.K. (1976). Some observations on the growth of clonal tea under low country conditions in Sri Lanka. In: *Proceedings of the twenty second scientific conference, Bulletin, United planters association of Southern India,* **No. 33:** 173-183.

Obaga, S.M.O., Squire, G.R. and Langat, J.K. (1988). Altitude temperature and the growth rate of tea shoots. *Tea,* **9:** 30-35

Odhiambo, H.O., Nyabundi, J.O. and Chweya, J. (1993). Effect of soil moisture and vapour pressure deficits on shoot growth and the yield of tea in the Kenya Highlands. *Experimental Agriculture,* **29:** 341-350.

Pethiyagoda, U. (1964). Some observations on the dormancy of the tea bush. *Tea Quarterly,* **35:** 74-83

Rahman, F. (1988). Physiology of the tea bush. *Two and a Bud,* **35:** 1-14.

Rahman, F. and Dutta, A.K. (1988). Root growth in tea. *Journal of Plantation Crops,* **16:** 31-37.

Rajakumar, R, Manivel, L and Marimuttu, S (1998) Longevity and factors influencing photosynthesis in tea leaves. *Photosynthetica,* **35 (1):** 41-46.

Ranganathan, V., Raman, K. and Natesan, S. (1983). Nutritional and physiological interactions with length of plucking rounds and banjhiness. *Bulletin, United Planters' Association of Southern India,* **No. 38:** 67-89.

Sivaram, B (2000). Labour Management and Planning. In: Sivaram, B. (ed.) *Plantation Management in the New Millenium,* National Institute of Plantation Management, Sri Lanka. 349-374.

Smith, R.I., Harvey, F.J. and Cannell, M.G.R. (1993). Clonal responses of tea shoot extension rate to temperature in Malawi. *Experimental Agriculture,* **29:** 47-60.

Squire, G.R. (1977). Seasonal changes in photosynthesis of tea (*Camellia sinensis*). *Journal of Applied Ecology,* **14:** 303-316.

Squire, G.R. (1979). Weather physiology and seasonality of tea (*Camellia sinensis*) yields in Malawi. *Experimental Agriculture* **15:** 321-330

Squire, G.R. (1990). *The physiology of tropical crop production.* CAB International, U.K.

Stephens, W. and Carr, M.K.V. (1990). Seasonal and clonal differences in shoot extension rates and numbers in tea (*Camellia sinensis*). *Experimental Agriculture,* **26:** 83-98.

Stephens, W and Carr, M.K.V. (1994). Responses of tea (*Camellia sinensis*) to irrigation and fertilizer. IV. Shoot population density, size and mass. *Experimental Agriculture,* **30:** 189-205.

Tanton, T.W. (1979). Some factors limiting yield of tea (*Camellia sinensis*). *Experimental Agriculture,* **15:** 187-191.

Tanton, T.W. (1981a). The banjhi (dormancy) cycle in tea (*Camellia sinensis*). *Experimental Agriculture,* **17:** 149-156.

Tanton, T.W. (1981b). Growth and yield of the tea bush. *Experimental Agriculture,* **17:** 323-331.

Tanton, T.W. (1982). Environmental factors affecting the yield of tea (*Camellia sinensis*). II. Effect of soil temperature, day length and dry air, *Experimental Agriculture,* **18:** 53-63.

Tanton, T.W. (1992). Tea crop physiology. In: Willson, K.C. and Clifford, M.N. (eds.) *Tea: Cultivation to consumption.* Chapman & Hall, London. 173-199.

Watson, M. (1986a). Plucking. In: Sivapalan, P., Kulasegaram, S. and Kathiravetpillai, A. (eds.) *Hand book on tea. Tea Research Institute of Sri Lanka, Talawakelle, Sri Lanka*: 78-81.

Watson, M. (1986b). Report of the Agronomy Division (Low-country). *Annual Report-1985,* Tea Research Institute of Sri Lanka, Talawakelle, Sri Lanka: 37-44

Watson, M., Bandaranayake, J.I.H. and Wettasinghe, D.T. (1982). Use of plucking machines for harvesting tea. *Tea Quarterly.* **51 (2)**: 58-66.

Wijeratne, M.A. (1994). Effect of climatic factors on the growth of tea (*Camellia sinensis* L.) in the low country wet zone of Sri Lanka., *PhD Thesis,* Wye College, University of London, UK.

Wijeratne, M.A. And Fordham, R. (1996). Effect of environmental factors on growth and yield of tea (*Camellia sinensis* L.) in the low country wet zone of Sri Lanka. *Sri Lanka Journal of Tea Science,* **46**: 21-34.

Annexure 1: Estimated monthly labour demand (mandays) for plucking

Up-country (>1200m amsl) and Mid-country (600-1200m amsl) tea growing regions yielding 2000 kg of made tea /ha/yr

MONTH	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Yield (kg/ha)	180	150	140	180	210	220	140	120	160	150	170	180
Plucking Mandays	41	41	40	34	40	42	35	33	40	34	35	37

Low-country (0-600m amsl) tea growing regions yielding 2250 kg of made tea /ha/yr

MONTH	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Yield (kg/ha)	209	135	135	202	248	202	202	158	158	180	207	214
Plucking Mandays	38	34	34	37	40	37	32	32	35	34	38	38

Source: (Sivaram, 2000)