EFFECTS OF PRUNING TIME, LUNGS, AND RESTING PERIOD ON TOTAL NON-STRUCTURAL CARBOHYDRATE RESERVES, REGROWTH AND YIELD OF TEA (*CAMELLIA SINENSIS* [L.] O. KUNTZE)

BY

JOHN KIPKOECH BORE

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN HORTICULTURE

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DECLARATION

This Thesis is my original work and has not been presented for a degree in any other university.

John Kipkoech Bore

Registration No. K34/0179/98

Signature_____ **Date** 31ST OCT. 2001

This Thesis has been submitted with our approval as university supervisors.

DR. D. K. ISUTSA

Signature_____

Date NOV. 1, 2001

PROF. FRANCIS M. ITULYA, PH.D.

Signature_____

Date November 1, 2001

HORTICULTURE DEPARTMENT

EGERTON UNIVERSITY, NJORO.

DEDICATION

To my Mother

ABSTRACT

Two experiments were conducted at Kipkebe Estate, Sotik, Kenya, which lies at 1740 m asl. The experiments were aimed at establishing the effects of pruning time, number of lungs, resting period and total non-structural carbohydrate (TNC) reserves on regrowth and yield of tea. In the first experiment, tea was lung pruned to leave 0, 4 and 8 lungs, while in the second experiment, tea was rested for 0, 45 and 90 days before pruning. Parameters assessed included regrowth period, diebacks, emerging buds, TNC and yields after pruning.

Results of the first experiment showed that, TNC was significantly ($P \leq 0.05$) affected by pruning time and number of lungs. October-pruned tea had the highest leaf TNC that ranged from 148 to 300 g/kg. Stem TNC were, however, lower and ranged between 60 and 90 g/kg, in tea pruned in March and October, respectively. Root TNC was higher than both leaf and stem TNC, but it declined immediately after pruning, and reached pre-pruning level after 3 months. There was no significant effect of pruning time and number of lungs on both diebacks and emerging buds.

The October-pruned tea bushes of the 1997 harvests had the highest significant yields, followed by June-pruned, and lastly, by March-pruned tea bushes. There were significant correlations between leaf TNC and regrowth period (r = -0.61), root TNC and regrowth period (r = -0.52), stem TNC and diebacks (r = 0.46), stem TNC and emerging buds (r = -0.54), leaf TNC and

yields (r = 0.39), stem TNC and yields (r = -0.57), and root TNC and yields (r = 0.62). However, r-values for root TNC and the assessed parameters were higher than for other TNC's and the assessed parameters.

In experiment two, October pruning increased leaf, stem, and root TNC. A longer resting period of 90 days improved leaf and root TNC to 294 and 230 g/kg, respectively. Generally, TNC declined after pruning and thereafter increased to non-significant levels. Resting for 90 days also reduced regrowth period to 100 days. Pruning in October produced higher amounts of diebacks and highest yields. Pruning time significantly increased yields during the pruning year, the following year and cumulative yields.

Root TNC significantly ($P \leq 0.05$) correlated with regrowth period (r = –0.39). Leaf and root TNC were positively correlated with diebacks (r = 0.48 and 0.91, respectively). Leaf, and root TNC correlated significantly with yield (r = 0.54, and r = 0.83, respectively).

Generally, the best number of lungs, resting period, and pruning time is between 4 and 8 lungs, 45 and 90 days, and October, if drought stress can be avoided, respectively.

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CHAPTER ONE

1. INTRODUCTION

Tea is believed to have originated from the Assam/Burma border in the west to China in the east, and from Burma/Thailand in the north to Vietnam in the south (Kingdon-Ward, 1950). This region has monsoon type of climate. From the origin, tea has been introduced to many countries of the world, and currently, it is grown in a wide range of climates that range from Mediterranean type to hot humid tropics. Its area of production extends from Georgia (42° N) to Argentina (27° S), and from sea level in Bangladesh (Barua, 1992) to as high as 2700 m asl in Kenya (Anonymous, 2000).

Tea was introduced to Kenya in the early 1900's from India and China. It was first planted around Limuru, followed by other suitable areas of the country. The tea introduced for commercial cultivation in Kenya only comprised of seedling plants that were low yielding, and its cultivation was hampered by lack of planting material (Wilson and Smithett, 1962). By then, the cheap and effective methods of vegetative propagation from cuttings were not fully developed. Tea seeds obtained from North India were used to set up the first plantations during the first quarter of the 20th Century (Cannel et al., 1977). The sources of these seeds comprised random open-pollinated natural hybrids between the Assam and China

varieties from Assam region (Cannel et al., 1977). The genetic base and genetic variation of these progenitors were unknown, and their seed provenances were not selected for both yield and quality (Banerjee, 1992). Consequently, the seedling populations were low yielding, and non-uniform (Cannel et al., 1977). These disadvantages led to the mass selection within the seedling populations.

The Indian hybrid seed provenance's, from which the seedling populations were established in Kenya, were mixed, random selections from popular races, and because they were open-pollinated, the seeds were polyclonal mixtures (Cannel et al., 1977). Therefore, early planters in Kenya began to visually select jats that were closely related to the *assamica* variety within their seedling populations, based on their vigour, plucking point density, and shoot size, and then used the selected jats to develop seed bearers.

The establishment of the Tea Research Institute of East Africa in 1951 (Anonymous, 1966), the forerunner of the Tea Research Foundation of Kenya, marked the beginning of tea improvements in East Africa. Several jat stocks from the original Assam hybrid seed provenance's, such as *Tingamira* and *Betjan,* adapted to the local growing conditions in East Africa, formed a basis of the local selection of improved assamica clones from seedling tea (Wilson and Smithett, 1962; Anonymous, 1966;

Cannel et al., 1977). Initially, 18 clones were phenotypically selected directly from seedling tea populations (Green, 1966; Green, 1969).

It was in this batch of improved clones that clone 6/8 was the most superior in yield and quality as compared to seedling tea (Green, 1969). The made-tea yield potential was 3000 kg/ha/yr as compared to 4,500 and 10,000 kg/ha/year of clones 31/8 and S15/10, respectively, which are currently used as control clones for yield performance (Seurei et al., 1997).

The selection criterion for yield potential is primarily determined by shoot numbers, shoot weight, rate of shoot regeneration and extension, which, though genetically controlled, are subject to environmental influences. These phenotypic traits have been used extensively in clonal selection. Other indicators of high yield potential include dry matter production and partitioning (Magambo and Cannel, 1981) and harvest index (Hay, 1995). The harvest index for tea ranges from 7% to 24% (Magambo and Cannel, 1981). Use of dry matter production, and harvest index in clonal selection of tea is not routinely practised, because it is destructive, laborious, tedious and time consuming.

In selection for quality potential, fermentability is an important characteristic and is easy to assess even in individual bushes of progeny trials (Sanderson, 1963). The chemical parameters which determine plain

tea quality comprise theaflavins and thearubigins, whose precursors (the green leaf flavanols) are genotype dependent and consists of (+)-gallocatechin, (+)-catechin, (-)-epicatechin, (-)-epigallocatechin, (-)-epigallocatechin gallate and (-)-epicatechin gallate (Robertson, 1992). The total green leaf polyphenol content is positively correlated with brightness, thearubigin content, total colour and sensory evaluation of plain tea quality (Obanda et al., 1992).

Valuation of black tea is correlated with theaflavin content (Ellis and Cloughley, 1981) and (-)-epigallocatechin is highly correlated with theaflavin level (Hilton and Palmer-Jones, 1973). The level of theaflavin-3, 3'-digallate and the theaflavin digallate of black tea relate strongly with sensory evaluation than total theaflavins (Owuor and Obanda, 1995). Owuor and Obanda (1997) recently showed that (-)-epicatechin gallate, (-)-epigallocatechin gallate and caffein were strongly correlated with sensory evaluation. These findings suggest that green leaf flavanols, particularly total polyphenols, (-)-epicatechin gallate, (-)-epigallocatechin gallate, green leaf caffein content, theaflavin content, and the levels of theaflavin-3, 3'-digallate and theaflavin digallate equivalents of black tea are reliable indicators of quality potential of plain black tea (Ellis and Cloughley, 1981; Robertson, 1992; Obanda and Owuor, 1997).

Various flavour indices for predicting black tea aroma have been

developed based on volatile flavour compounds. Aroma is complex and consists of 600 different compounds (Robinson and Owuor, 1992). In the past, four aroma indices were evaluated and they included those of Wickremasinghe-Yamanishi (Wickremasinghe et al., 1973), Yamanishi-Botheju (Yamanishi et al., 1978), Owuor's flavour index (Owuor et al., 1986), and Mahanta (Mahanta et al., 1988). Both Owuor and Wickremasinghe-Yamanishi indices exhibited significant relationships with sensory evaluation of black tea and, thus, can reliably be used in clonal selection (Owuor, 1992).

The tea industry in Kenya consists of four main sectors, which are 1) the small-holder sector under the umbrella of the government and the name Kenya Tea Development Authority (KTDA) until 30th June, 2000 and now under the Kenya Tea Development Agency, which is a private organization, 2) private estate sector under the Kenya Tea Growers Association (KTGA), 3) government sector, under the Nyayo Tea Zone Development Corporation (NTZDC), whose tea is manufactured by KTDA and managed by agents from the KTGA, and 4) propriety growers, who are private tea growers with tea farms ranging from 0.4 to 40 ha. The farms are managed by the owners and, in most cases, have management problems and greatly rely on tea research extension services. Also, some of the owners are members of KTGA, while others are out-growers of the

large tea estates.

Throughout the years, but especially after independence, there has been a lot of progress mainly in tea production by the small-scale farmers. Total tea area had reached 112,556 ha, yielding 244,525,160 kg by 1996. Expansion among large-scale farmers has risen from 17,921 ha in 1963 to 32,201 ha, yielding 105,579,709 kg in 1996, and among small-scale farmers from 3,527 ha in 1963 to 90,317 ha, yielding 153,855,368 kg in 1999 (Anonymous, 2000). Overall production has also increased from 18,000 tons of processed tea in 1963 to over 257,000 tons by 1996 (Ruto, 1997). Small-scale and large-scale growers account for 56% and 44%, respectively, of the national output. According to Ruto (1997), tea is the leading agricultural export crop and foreign exchange earner for Kenya. It employs over two million people, each with more than four dependants, and supports more than 300,000 small-scale farmers. The foreign cash earnings by the tea farmers in 1999 amounted to Ksh. 32,732,691,395 (US$ 419,649,889.68), which contributed tremendously to poverty alleviation (Anonymous, 2000).

With the increasing cost of farm inputs, continued economic production of tea will be achieved through intensive management of established tea bushes. This requires new initiatives in methods of plucking, pruning, and bringing tea into bearing and production, amongst

other management aspects (Magambo, 1983).

Pruning of tea bushes is done to maintain size and form, stimulate vegetative growth (Bald, 1965; Sharma and Murthy, 1989), keep bush frames healthy (Eden, 1976; Njuguna, 1976; Money, 1979; Nathaniel, 1982), prevent reproductive growth phase, and allow free accessibility (Ahmedullah, 1977; Kulasegaram and Kathiravetpillai, 1981).

The plucking table is formed at 50 to 60 cm within two years in a newly planted tea (Eden, 1976; Njuguna and Magambo, 1990). Annual table rise of 20 cm is acceptable in Kenya, although 10 cm is considered ideal. Plucking tables in Kenya reach an unmanageable height of 120 to 150 cm within three to four years, which necessitates pruning to reduce the height to a level on which plucking can easily be effected (Anonymous, 1986).

The time at which pruning is done is important in determining regrowth and performance of tea. A lot of research has been done in an attempt to elucidate the best time of pruning for maximum regrowth (Anonymous, 1964; Anonymous, 1968/69; Ahmedullah, 1977; Pethiyagoda, 1986). These attempts have yielded varying results that could be attributed to complex factors prevailing during pruning time (Odhiambo and Othieno, 1992). It is recommended that pruning should be done when reserve carbohydrates, and soil moisture are not limiting, and

when temperature is cool as in July/August, East of the Kenyan Rift Valley (Anonymous, 1968/69; Templer, 1978a).

1.1. Statement of the Problem

Pruning is an essential cultural practice in tea production; it is a way of renewing frames of tea bushes, and encouraging young shoots to grow. However, there is a controversy on the systems and the timing of pruning. Consequently, most tea farmers in Kenya prune irregularly, and at no specific or standard time. Although some research on tea pruning has been done, there exists a knowledge gap on some aspects that contribute to the regrowth of tea bushes and their ultimate performance. These aspects include seasonal quantification of carbohydrate reserves before and after pruning, resting of tea bushes, located at low altitudes, before pruning to alleviate carbohydrate shortage/deficiency, and closely monitoring environmental factors that clearly influence tea regrowth and performance. Investigations on these aspects may provide answers on how green tea leaf yields can be increased.

1.2. Significance and Justification of the Study

In Kenya, most people consume tea; other Kenyans earn income through the sale of green tea leaves. Pruning is a cyclic event that is carried out regularly after three to four years. Whenever this operation is done, it causes some destruction that depends on the magnitude or severity, and time of pruning. Despite the use of good agronomic practices, failure of regrowth after pruning is a major problem, because it causes partial or complete crop loss. Although pruning is an essential cultural practice, there is no information to-date on its relation to carbohydrate reserves in low altitude areas. Thus, there is a need to study the relationship between non-structural carbohydrates and regrowth after pruning, as well as the subsequent tea-leaf yields.

1.3. Hypotheses

This study was done to test the following hypotheses:

1) Pruning time affects regrowth and performance of tea.
2) Resting period before pruning influences regrowth and yields.
3) Carbohydrate reserves affect tea yields after pruning.

1.4. Objectives

The main objective of this study was to determine the time of pruning, severity of pruning and resting period that increase carbohydrates, shorten the regrowth period, reduce diebacks, and increase emerging buds and yield of tea.

The specific objectives established for this study were:

1) To determine the effects of season (time of pruning) and severity of pruning (number of lungs) on total non-structural carbohydrate reserves, regrowth period, diebacks, emerging buds and yields.

2) To determine the effects of season (time of pruning) and resting period before pruning on total non-structural carbohydrate reserves, regrowth period, diebacks, emerging buds and yields.

3) To make recommendations on proper and standard time for pruning tea grown in low altitude areas.

CHAPTER TWO

2. LITERATURE REVIEW

Tea is a tropical plant, which requires pruning to a reasonable height that allows continuous harvesting of tender shoots for manufacturing. Usually after 3 to 4 years, tea bushes are pruned down to maintain size and form; encourage growth of new shoots from lower frames, and to clean bushes (Njuguna, 1976; Nathaniel, 1982).

2.1. Types of Pruning

Commercial tea growers in Kenya and elsewhere practice a single type of pruning such as cut-across pruning, lung-pruning, down-pruning and skiffing, or their combination (Eden, 1976; Money 1979; Anonymous, 1986; Willson, 1992). The choice of a pruning technique is fully dependent on management by the estate concerned.

2.1.1. Cut-across Pruning

This is also known as clean pruning; it involves cutting tea bushes at a predetermined height from the ground. Cut-across pruning can be done manually, using a curved pruning knife that gives a clean cut, sloping towards the centre of the bush (Anonymous, 1986; Willson, 1992). However, due to labour shortage, mechanical pruning has been attempted

and found to prune effectively, especially at the 60 cm height (Grice, 1980). But, it is expensive, because removal of dead and diseased bushes cannot be done simultaneously with pruning (Willson, 1992).

During the standard cut-across pruning, all leaves are removed, thereby slowing regrowth through lowered reserves, which cannot be replenished. According to Kulasegaram (1986), tea bushes cut-across at 55 cm recovered and produced high yields quite early. This performance was attributed to the resulting large quantities of foliage, which allowed continuous photosynthesis. Nevertheless, regrowth from cut-across pruning varies, depending on the clone and pruning time (Othieno, 1972). In Uganda, it takes as long as 10.5 weeks from pruning to regrowth, when tipping is done (Bazirake-Ntawera, 1978a), while in Kenya, regrowth generally takes up to three months, and varies with site. At high altitudes, regrowth period is longer, whereas at low altitudes it's shorter.

In Kenya, a 5-cm rise from the previous pruning level is recommended universally (Anonymous, 1986). However, cut-across pruning in Kenya is done a little bit too low (less than 45 cm) compared to the standard recommended practice. Hence, predisposing cut surfaces to infection by Hypoxylon wood rot (Anonymous, 1986). Hypoxylon wood rot stresses and affects plants, causing reduced yields. In Kenya, most tea farmers practice cut-across pruning, but it may not be suitable for all areas

in the country, because of diverse environmental conditions. In Sri Lanka and India, cut-across is restricted to medium and high elevations (Money, 1979; Nathaniel, 1982; Kulasegaram, 1986).

2.1.2. Lung-pruning

In lung-pruning, a number of branches are left unpruned (Eden, 1950; Bald, 1965; Eden, 1976; Kulasegaram, 1986) and are variously called lungs, breathers, or kickers. Lungs assist pruned tea regrow (Kulasegaram and Kathiravetpillai, 1981; Nathaniel, 1982; Willson, 1992), and improve growth and yield of tippings (Nagarajah and Pethiyagoda, 1965). Eden (1950) reported that lung-pruning hastened re-growth after pruning, because lungs continue photosynthesizing and replenishing starch reserves. Kandiah et al. (1984) reported that tea without lungs exhibited root dieback due to poor or no carbohydrate supply to roots.

Although lung-pruning has positive results (Mwakha, 1990), the presence of lungs early in the pruning season delays bud break (Anonymous, 1953). Lungs also use some reserves and retard regrowth (Nathaniel, 1982; Mwakha, 1986). According to Mwakha (1986), yields decrease if lungs remain on pruned bushes longer than the tipping stage. Therefore, lungs are supposed to be removed after bud break.

According to Bazirake-Ntawera (1977 and 1978b) lung-pruning is laborious and does not seem to have any yield and plucker productivity advantage over standard cut-across method. In contrast, lung-pruning has been reported to result in increased yields within the pruning year and in subsequent years (Mwakha, 1986 and 1990; Anyuka, et al., 1992). In Sri Lanka and northeast India, yield increases occurred in lung-pruned bushes (Kulasegaram, 1986). In some cases, yield differences as influenced by the number of lungs indicated that yield increases are only observed in the first year after pruning, and yields increase with the number of lungs (Kroon and Bandaranayake, 1980). Nevertheless, the number of buds and growth were depressed in lung-pruned bushes (Bald, 1965; Nagarajah and Pethiyagoda, 1965; Nathaniel, 1982).

Lung-pruning increases yields in most cases, but the number of lungs to be left per bush seems to vary, depending on the type of lung-pruning. The number of lungs determines regrowth after pruning. The optimum rim-lung size to retain until tipping is 12 branches, because it improves yields, especially in the pruning year (Mwakha, 1990). Each branch should have between 250 to 300 leaves (Nathaniel, 1982). According to Wijeratne et al. (1996), tea bushes that were rim-lung-pruned at 50-cm height had a decreased number of buds per bush compared to bushes that were cut-across at a higher height of 65 cm.

The position of lungs within the pruned bush is important and determines plucker productivity. The main types of lung-pruning positions are rim-lung and "Savani". Rim-lung pruning has lungs left on the periphery of bushes; the arrangement is such that edges with lungs are adjacent in rows of tea, thereby facilitating plucking. This position is preferred, because centre or reverse lung-pruning makes the removal of unproductive wood difficult (Nathaniel, 1982; Kulasegaram, 1986). Comparative studies on different lung positions have indicated that rim-lung-pruning improves plucker speed, productivity, and yields (Bates, 1977; Mwakha, 1990).

On the other hand, "Savani" lung pruning is the type of pruning, where one-third of the central area of tea bushes is left unpruned (Templer, 1978). However, leaving 3 to 4 lungs at the centre results in side branches hindering field operations despite increasing yields (Templer, 1978b; Mwakha, 1986).

2.1.3. Down (reduction) Pruning (Cycle change)

At the end of each pruning cycle, the plucking table reaches a maximum height that reduces plucker productivity and necessitates down-pruning (Kulasegaram and Kathiravetpillai, 1981; Anonymous, 1986;

Kulasegaram, 1986; Willson, 1992). Down-pruning stimulates new shoots and wood, and renews maintenance foliage at lower levels (Eden, 1976; Kulasegaram and Kathiravetpillai, 1981). Chkhaidze (1972) observed that down-pruning to 10 to 15 cm results in higher shoot weight, but not shoot number. Grice (1981) reported that down-pruning to levels lower than 45 cm reduces yields, as evidenced by greater yields at 45 cm than at 30 cm.

Before pruning, tea plants should be supplied with nutrients and high carbohydrate reserves for regrowth and development (Willson, 1992). In Malawi, down-pruning is performed in early April to allow adequate time for bud break before cold and moisture stress begin (Grice et al., 1984).

The effect of down-pruning on yield of seedling tea can last long (Kaptich, 1985; Njuguna and Magambo, 1990). Down-pruned bushes take long to start producing tea leaves; crop loss occurs during the first two years followed by yield increase (Grice, 1981). In some countries such as Malawi (Grice, 1981), Sri-Lanka (Middleton, 1963), and South India (Bald, 1965; Money, 1979; Kulasegaram and Kathiravetpillai, 1981), yield of down-pruned bushes is greater than that of normally pruned bushes, and yield loss is compensated for in subsequent years. Low yields associated with down-pruning in some areas are perhaps due to poor, late, or totally failed regrowth, the time tea takes to regrow after pruning, and reduced plucking surface (Venkata-Ram, 1974; Kaptich, 1985; Njuguna and

Magambo, 1990; Amarasekera, 1996).

Down-pruning is often slow and expensive, because it involves cutting off thick wood (Kilavuka and Oigo, 1982). Based on these disadvantages, down-pruning is rarely performed compared to standard cut-across pruning.

2.1.4. Skiffing

Pruning intensity is classified as heavy or light, depending on the quantity of prunings removed. Skiffing refers to light pruning, and involves removing a little of top growth along with green or young red-brown wood (Dutta and Grice, 1966; Anonymous, 1986; Willson, 1992). The main reason for skiffing is to smoothen an out-of-control plucking table, prolong pruning cycle, and provide planting materials from bushes that have been under plucked (Nathaniel, 1982; Anonymous, 1986; Willson, 1992).

Skiffed bushes regrow quickly and result in higher immediate yields than bushes pruned by other methods, because most foliage is left on the bush (Dutta, 1964; Grice, 1964; Wettasinghe, 1973). Skiffing can be done repeatedly on healthy frames (Ahmedullah, 1977). Rahman (1978) recommended that light or medium skiffing be alternately done after deep skiffing to ensure continuation of maintenance foliage. Skiffing is sometimes followed by a heavy (flush), which is difficult to manage

plucking. Therefore, it is essential to plan on the availability of labour force for plucking (Congdon, 1977).

2.2. Effects of Pruning on Carbohydrate Reserves

The main objective of a tea grower is to promote continuous production of young shoot tips (flush), and maximize the potential of this flush for good quality tea. A requirement of sustained growth of tea is a continuous supply of food materials such as inorganic salts (nutrients), carbon (e.g. carbohydrates), and water (Larcher, 1995). Adequate supply of these materials to the harvestable plant portion leads to successful cultivation and production of tea.

Carbohydrates are products of photosynthesis and are the universal substrates for respiration, and starting points of a wide range of biosynthetic processes (Larcher, 1995). A proportion of photosynthesized carbohydrates has to be stored as long term fuel reserves for sustenance when photosynthesis is limited, especially after pruning. The pruned plant must use stored energy to build up its leaf area again. Storage can occur anywhere in the plant, but is commonest in roots, stems, and leaf bases (Forbes and Wartson, 1992). Different amounts of energy reserves are stored in plant roots, stems, and leaves. The commonest reserves are

sucrose and starch (Forbes and Wartson, 1992). Several studies on metabolism of carbohydrates in rose disclosed that glucose, fructose, and sucrose are the main soluble carbohydrates (Ichimura et al., 1999). However, their concentration decreased after stems were cut-off, but remained constant if sucrose was supplied.

Pruned tea bushes need stored food reserves to help them regrow, and support new shoots. Roots also use stored reserves for survival before the newly produced shoots start photosynthesizing. Carbohydrates assist tea to regrow after pruning (Kulasegaram and Kathiravetpillai, 1981; Wringley, 1982; Sharma and Murthy, 1989; Wilson, 1992). Pruned bushes require a certain amount of carbohydrate reserves to regrow; this amount is about 12% (Eden, 1976; Nathaniel, 1982). However, the carbohydrates decline after pruning (Kulasegaram and Kathiravetpillai, 1981; Mwakha, 1989). During pruning, the removal of most leaves and young wood reduces photosynthesis and replenishing of food reserves. Therefore, pruned tea relies on stem and root reserves to regrow.

According to Satyanarayana (1994), both current and reserve carbohydrates are used for growth and development. Current carbohydrates are used for growth of aerial parts and also for replenishment of reserves, whereas reserve carbohydrates are used for root growth and shoot regrowth after pruning. In carbohydrate surplus

situation, current carbohydrates are converted into reserve form, depending on soil, climate, season and internal factors (Satyanarayana, 1994), whereas in carbohydrate deficit situation, reserves are mobilized for growth, depending on the demand of bushes that are regrowing after pruning or stress (Satyanarayana, 1994).

Tea food reserves are stored in roots and utilized to support budbreak and growth after pruning; however, reserves tend to fluctuate with season (Wringley, 1982). Dieback following pruning has been associated with inadequate carbohydrate reserves; its incidence is much reduced where carbohydrate reserves build-up during winter for use in growth during spring (Kandiah, 1971; Eden, 1976; Willson, 1992). Presence of lungs in pruned tea bushes alleviates the strain on carbohydrate reserves, resulting in reduced diebacks (Nagarajah and Pethiyagoda, 1965). At low elevations, there is high utilization of carbohydrate reserves, because of high temperatures and respiration, which subject plants to poor regrowth after pruning (Venkata Ram, 1974; Wringley, 1982).

Regrowth after pruning depends on the time tea is pruned (Pethiyagoda, 1963; Eden, 1976; Anonymous, 1986; Obaga and Othieno, 1986; Mwakha, 1989), and the level of carbohydrate reserves stored during the previous season (Walters, 1954). Pethiyagoda (1963) reported

that tea pruned at different seasons showed varied regrowth rates, although no relationship between rate of regrowth and seasonal carbohydrate reserves in roots was found. Kandiah (1971) observed a decline of root reserves after pruning, and attributed it to failed mobilization from roots to stems, or root utilization. Reserves in stems and barks remained to assist pruned bushes regrow. This observation suggests that seasonal variation in regrowth of tea after pruning depends on levels of stem and bark carbohydrates. In contrast to Kandiah (1971), Sharma and Murthy (1989) observed that root-bark carbohydrate levels exhibited a strong correlation with regrowth.

According to Pethiyagoda (1966), dieback is prevalent if fertilizers are applied and immediately followed by pruning. There has to be an ample time for applied fertilizers to be taken up by plants before pruning. These results suggest that reserves are mobilized from roots to other parts of the plant.

Although pruning time affects bush regrowth and yields in the year of pruning, it is not clear how lungs and pruning time interact to influence yields, quality and regrowth after pruning. Lung-pruning is practiced in lowland tea growing areas of Sri Lanka to reduce incidences of die-back by increasing carbohydrate reserves (Satyanarayana, 1994). Lungs affect carbohydrate balance, especially in roots, and promote utilization of such

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reserves in bush regrowth after pruning. However, Nagarajah and Pethiyagoda (1965), Barua (1966), and Kandiah (1971), reported that lungs depressed bud development on bush frames.

Distribution of dry matter among different plant parts maintains functional structures (Cannel, 1971). Should any condition limit photosynthesis, most photosynthates are used by leaves and stems to grow more than roots, until the canopy is capable of producing adequate photosynthates (Hunt, 1975). On the other hand, if nutrients limit plant growth, photosynthates are not used in the canopy, but are translocated to roots, which then grow more than stems and leaves until roots start exporting nutrients to the canopy (Ichimura et al., 1999). This observation agreed with that of Lister et al. (1967), who observed that translocation of carbohydrates from shoots to roots was lowest when shoot growth was most active. Sanderson and Sivapalan (1966) found that water-soluble carbohydrates tend to increase with the activity and age of the leaf.

Most active tea shoots are plucked for commercial purposes, and carbohydrate quantity fluctuates with the management; that is, either plucking, pruning, or resting of bushes before pruning (personal observation). Consequently, carbohydrate movement can be bi-directional or uni-directional, depending on the time of the year. The direction of movement is influenced by the cropping pattern, health of maintenance

foliage, season and occurrence of banjhi shoots (small, dormant apical buds) (Satyanarayana, 1994). Maintenance leaves support the growth and development of crop shoots and replenish carbohydrate reserves depleted during regrowth after pruning.

Experiments on tea pruning in Kenya have not included quantitative carbohydrate determination, although its role in regrowth and yield is enormous. Earlier work in the 1950's was qualitative, and used iodine to show the presence, but not the quantity of starch.

2.3. Effects of Pruning Time on Tea Regrowth

Pruning time influences a complex number of factors that determine regrowth after pruning. They include food reserves, environmental conditions, and internal plant growth regulators. Although factors such as hormones may not directly affect regrowth, their influence cannot be underestimated (Manivel, 1981); hence their quantification and physiological effects are essential.

The best pruning time for quick regrowth and better yields is not known to-date, because earlier pruning trials in Kenya were not conclusive. It has been shown that timing of pruning is important in the

regrowth and ultimate performance of tea (Mwakha, 1989).

Despite several attempts to determine the best pruning time, results have varied from time to time. This variation has been attributed to environmental factors prevailing during pruning time and hormone levels in the plants (Odhiambo and Othieno, 1992). Although prevailing environmental conditions at the time of pruning determine regrowth period, they cannot be replicated each year, resulting in pruning trial inconsistencies. These inconsistent results make it difficult to decide when to prune. Hence, most estates decide independently of published research findings.

In some instances, pruned bushes fail or poorly recover, when dormant buds, lateral shoots, and frames are exposed to killing and scorching sun. Tea prunings are used to cover and protect cut bushes against sunscorch. Once the bush has recovered, these prunings are removed and left *in situ* to enrich soil with organic matter, regulate water loss, and suppress weeds (Anonymous, 1986; Grice and Malenga, 1987).

In Malawi, optimum yields are obtained from tea pruned in May at Mulanje, and in August at Thyolo when conditions were moist and warm, respectively (Ellis, 1975). In India, pruning in April-May, when moist and warm, results in quicker regrowth and higher yields than pruning in October, when it is dry (Dutta and Grice, 1966).

In Indonesia, Astika (1994) observed that pruning can be done whenever appropriate climatic conditions prevail. The climate of Indonesia has marked dry and wet seasons. During the rains, blister blight may adversely affect crop performance, and in the dry season, growth is slow due to soil moisture deficit. Thus, pruning is done from January to March and from October to December.

In Sri-Lanka, pruning is performed in April-May or in September-October, when soil moisture, carbohydrate reserves, and weather conditions are not limiting (Kulasegaram, 1986). In Western Kenya, tea recovered better when pruned in the moist and warm October-December months, although yields varied in subsequent years (Othieno, 1972; Obaga and Othieno, 1986). In contrast, Mwakha (1989) found that the moist and cool period prevailing from February to May is the most suitable for pruning tea in Kericho, Kenya.

2.4. Effects of Resting Period Before Pruning

Literature on the effect of resting period on tea regrowth is not available locally. In Sri Lanka, resting period had a significant effect only in the initial period following pruning (Watson and Gunasereka, 1986). Resting for 11 months lowered yields compared to resting for 8 months.

Moreover, the control had the highest yields, and hence, no advantage of resting period was observed (Watson and Gunasereka, 1986).

According to Wadasinghe and Gunasereka (1986), resting tea bushes for 16 weeks resulted in no significant differences in stem dry weights, but the stem thickness, measured at the pruning-cut level, was significantly higher in rested bushes. This indicates that more dry matter was accumulated during the resting period. However, bushes that were plucked continuously had better bud break. It was also observed that the number of buds developing into sprouts were similar in both treatments, indicating that there was more abortion of buds in tea bushes that were continuously plucked due to carbohydrate deficiency.

Resting period before pruning might have an effect on replenishment of carbohydrates used in regrowth of tea after pruning. Kathiravetpillai et al. (1989) reported that resting for longer periods of up to three months prior to pruning and delaying tipping increased carbohydrates and starch to 44% and 16%, respectively. Pre-prune starch levels in roots were high in rested tea bushes, compared to those that were plucked continuously. These levels were found to decrease with time after regrowth to non-significant levels (Navaratne, 1996). It is on the basis of these few observations that research on resting period before pruning was done to provide information on this important aspect in tea pruning in the low

altitude Kenyan conditions.

2.5. Weather and Tea Yields

Meteorological data are useful for most agro-ecological purposes. It is for this reason that Walter (1963) constructed climatic diagrams based on rainfall and temperature data. These diagrams facilitate comparisons among climates of different areas. Because evaporation is proportional to temperature, these diagrams give an indication of moisture levels of an area provided that plant and soil factors are held constant. Weather data are also important, because significant correlation's have been obtained between the yields of tea and both rainfall and air temperature (Sen et al., 1966).

2.5.1. Rainfall

Rainfall data have to be compared to crop production records as they give a true crop output or yield potential, provided that other factors of production are not limiting. Eden (1965) reported that for good tea yields to result rainfall should not be below 1300 mm per year. This amount is considered marginal for production of tea, whose monthly

rainfall average should not be below 50 mm (Eden, 1965). According to Rahman (1994), rainfall, soil moisture and atmospheric humidity are interrelated and tea growth is greatly affected if available soil moisture in the root-zone is less than 50%. In some tea estates of Uganda, high growth rates of tea, as shown by yields, were dependent on ready availability of water, calculated from meteorological data (Hanna, 1969).

Rainfall distribution is very important in maintaining uniform tea yields, although the quantity required varies depending on the environment, plant and soil factors (Ng'etich, 1995). Ng'etich (1995) observed that there may be localized variations in rainfall within an estate, resulting in uneven yield potential. At lower altitudes of about 1800 m above sea level, higher root depths accounted for 45% more dry matter when compared to higher altitudes. Also, higher evapotranspirational demand at lower altitude was a limitation to realization of yield potentials.

2.5.2. Temperature

The optimum temperature for tea growth varies with location, distance from the equator, and clone, among other factors. A fluctuation in the mean range of 18 to 29° C was found to be satisfactory for tea growth in Pakistan (Hasan et al., 1965). Tea growth may be adversely affected if

mean monthly temperature is lower than 13° C, or higher than 29° C (Eden, 1965). Went (1953) reviewed temperature effects on growth, but found no correlation between temperature and tea growth. However, there is no published research findings or information on the effect of controlled temperature on tea growth.

The few weeks before the onset of rains in a season of high temperature may directly inhibit growth (Went, 1953). Rapid growth occurs at about the same time when rains start, although this is believed to be an indirect effect of reduced temperature rather than an effect of precipitation. However, increased rates of growth are apparent under overhead irrigation, when soil moisture stress is absent (Fordham, 1971).

From the foregoing review, it is evident that there is a gap in knowledge on the relationship between the type of pruning method, pruning time, and resting before pruning and the level of total non-structural carbohydrates, regrowth and the ultimate tea performance after pruning.

CHAPTER THREE

3. MATERIALS AND METHODS

Two experiments were conducted at the same site from 1997 to 1999 and phase two repeated in 2000. This site lies at an altitude of 1740 m, and lies within latitude of 0° 17' S and 35° 3' E. According to Jaetzold and Schmidt (1983), the site is a tea-dairy zone (LH 1 p or two), with permanent cropping possibilities, and divisible into two variable cropping seasons. The soils were developed on acid igneous rocks (rhyolites), with volcanic ash admixture, and are well drained, deep to very deep, dark reddish brown, with friable and slightly smeary top soils (andoluvic phaeozems) (Jaetzold and Schmidt, 1983). The site receives an average of 1618 mm of annual rainfall (13 years average). The mean minimum temperature is 17.8° C, while the mean maximum is 20.5° C.

3.1. Experiment 1: Time of Pruning and Number of Lungs

The experiment was conducted at an estate/plantation owned by Kipkebe limited, Sotik. Tea plants of clone 11/4, released by the Tea Research Foundation of Kenya, and planted in 1969 at a spacing of 1.22 m x 1.22 m in a triangular plant arrangement was used in this experiment.

The tea plants had annually received 200 kg/ha of 25N:5P:5K:5S fertilizer, and were lung-pruned at a height of 61 cm, and tipped-in at

20.32 cm above the pruning height as per estate practice.

The experimental design was a Split-plot, arranged in Randomized Complete Blocks, each with three replications. Main treatments consisted of three pruning times (March, June and October). Subplots were number of lungs, comprising zero (control), four, and eight shoots left unpruned. Each subplot had 40 tea bushes, which were replicated three times.

After pruning, the rate of regrowth was determined as the number of days taken from pruning time to when more than 50% of foliage had developed at the first tipping time. The 50% foliage development was assessed when more than 20 plants in the subplot had developed foliage in half of their surface. The numbers of emerging buds were counted from 10 randomly selected bushes in each subplot. These bushes were also used to determine the number of diebacks.

Green tea leaves were plucked at a regular interval of 10 to 14 days in conformity with estate practice. The conventional harvest unit was the top two leaves and a bud. They were converted to kilogrammes of dry made tea (mt) per hectare per year (kg mt/ha/yr), using a conversion factor of 22.5%. For the purpose of standardization, the tea yields analyzed for each pruning time in 2000 pruning cycles were for four months post-tipping. However, the annual yields for 1997, 1998 and 1999 harvests were for 12 months beginning from their time of pruning.

3.2. Experiment 2: Time of Pruning and Resting Period

The site of this experiment was the same as that for experiment 1. Clone 11/4, of a similar age as that used in experiment 1, was used for experiment 2. The experimental design was a Split-plot, arranged in Randomized Complete Blocks. The main plot treatments consisted of three pruning times: March, June and October, whereas subplot treatments were resting periods of zero (control), 45, and 90 days. Each subplot had 40 bushes replicated three times. Tea bushes were left unplucked and allowed to freely grow for either 45 or 90 days. Control plots were plucked continuously until pruning time. After the three resting periods, pruning was done on the same day. After regrowth, the bushes were tipped-in at a height of 20.32 cm above the pruning level. The parameters measured were similar to those described in experiment 1.

3.3. Determination of Available Carbohydrates

Samples obtained from both experiments 1 and 2 of the 1997 pruning cycle and used to determine carbohydrates were for up to six months post-pruning, for each pruning time. The reason why samples were taken only up to six months post-pruning was that carbohydrates fluctuate much, especially when a plant is under stress. For all determinations, maintenance leaves, pencil thick stems, and roots were

sampled from each subplot. Root samples were dug out and soils removed by cleaning. Sub-samples were obtained from five randomly selected bushes, and then mixed before taking a representative, working sample. Sub-samples were obtained on the day of pruning (0), 0.5, 1, 2, 3, 4, 5, and 6 months after pruning. The sub-samples were oven-dried at 65° C for 48 hours to a constant weight, after which they were powdered, using a Willey Mill (Moulinex, type 505, Ireland) so as to pass through a 40 to 60-mesh screen. The non-structural carbohydrate analysis method used in this study is outlined below in detail, because it represents modifications of published methods.

The principle of the extraction procedure is that the available carbohydrate either in mature leaves, stems or roots is the sum of the starch and sugars expressed as "starch" (Gough, 1981). The mixture of glucose and maltose (reducing sugars), resulting from the enzymatic action of diastase (α-amylase) on starch is converted to glucose by hydrolysis (Gough, 1981). Total reducing sugars, in the protein-free hydrolyzate, are determined titremetrically with potassium ferricyanide solution; using methylene blue as an indicator.

The procedure was as follows: 0.5 g of ground sample was put into a 100-ml conical flask, moistened with 2 ml ethanol (90% v/v), and then 40 ml of water were added with occasional swirling. The contents were boiled

for 2 hours on a hot plate to gelatinize the starches (Dekker and Richards, 1971), cooled, brought to boiling, and cooled again.

One ml of 5% acetic acid and 0.2 g of diastase (α-amylase) were added and mixed; the walls of the flask were washed down with a minimum amount of water. One ml of toluene was added before the flask was covered with aluminum foil and incubated for about 18 hours at 37^0 C.

The flask was removed from the incubator and uncovered. The contents were boiled and filtered while hot, with gentle suction, through a Whatman number 42 filter paper supported by a Buchner funnel into a filter flask calibrated at approximately 80 ml. The incubation flask and the residue were washed with hot water into the filter flask until the total filtrate was approximately 80 ml.

The filtrate was quantitatively transferred into a 100-ml volumetric flask before adding 2 ml of zinc acetate solution, mixing and adding 2 ml of potassium ferrocyanide (10% m/v) solution. The mixture was diluted to 100 ml with water and filtered through a Whatman number 42 filter paper.

Eighty ml of the filtrate was pipetted into a 100-ml volumetric flask, 4.8 ml of 72% sulphuric acid added and mixed. The contents were gently boiled for two hours in a water bath, and cooled. A few drops (approximately 11 ml) of methyl red and sodium hydroxide solution were added until the red colour just changed to yellow. If a precipitate

appeared, it was redissolved by adding a few drops of 5-M hydrochloric acid. The solution was transferred to a 100-ml volumetric flask and diluted to 100 ml, using water. The solution was used to determine reducing sugars as follows:

Five ml of 50 mg/ ml potassium ferricyanide and 1.5 ml of sodium hydroxide (10% m/v) solution were pipetted into a 100 ml conical flask. The contents (solution) were boiled preferably on a hot plate, while stirring with a magnetic bar. Potassium ferricyanide solution was titrated with the prepared glucose solution, using a 25-ml burette until the yellow colour of the ferricyanide diminished. One drop of methylene blue (1% m/v) solution was added and the titration continued until the blue, then the red-blue colour disappeared, leaving a colourless or pale, straw-coloured liquid. The volume of the titre was recorded.

The weight of glucose (in mg), calculated as the volume of the reducing solution required to reduce X ml of ferricyanide solution, was obtained from the expression (20.12+0.035V)*8, where V is volume of ferricyanide solution and 20.12, 0.035 and 8 are constants (Gough, 1981). The ml of ferricyanide solution (X) were recorded and multiplied by 113.8 and divided by W*V*8, where W is weight of sample used. Thus, ml of ferricyanide = [(20.12+0.035V)*8*113.8]/W*V*8. The result gives the g/kg of available carbohydrate in the sample.

The amount of starch concentration was estimated as 0.9 x glucose concentration liberated from the sample (Rong et al., 1996). Total non-structural carbohydrates were calculated as the sum of soluble sugars and starch (Rong et al., 1996; Kool et al., 1996). Non-structural carbohydrates are considered as the reserves immediately available for plant use and growth (Volenec, 1986).

3.4. Meteorological Measurements

Meteorological data were used as a measure or indicator of tea performance. Meteorological measurements were obtained from Kipkebe estate office next to the experimental site. The rainfall and temperature measurements were taken daily at 09.00 and 15.00 hours local time.

Rainfall was recorded daily on a standard rain gauge. Maximum, minimum, wet bulb, and dry bulb temperatures were recorded daily, using mercury or alcohol-in-glass thermometer, as appropriate (Casella). These data were used to explain seasonal variations in tea growth and yield.

3.5. Data Analysis

For each of the parameters assessed, data were subjected to the analysis of variance (ANOVA), and where significant F-values ($P \leq 0.05$) resulted, mean separations were done using either the Least Significant Difference (LSD) or the Duncan's Multiple Range Test, depending on the number of means to be separated. Some parameters were transformed before subjecting them to the analysis of variance. Square root transformation ($\sqrt{(Y + 0.5)}$) was applied on counts, and arcsine transformation was applied on the percentage values. The transformed data were reconverted to the original form before reporting.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

Results for the two experiments are presented separately, and according to the parameters assessed. The parameters included total non-structural carbohydrates for 1997 (the pruning year) regrowth period, diebacks, emerging buds, annual and cumulative yields over the experimental period (1997-1999).

4.1. Effects of Time of Pruning and Number of Lungs on Tea Total non-structural carbohydrates (TNC), Regrowth Period, Diebacks, Emerging Buds and Yields

4.1.1. Total non-structural carbohydrates (TNC)

a) Leaf TNC

The amount of available leaf total carbohydrates was significantly ($P \leq 0.05$) affected by pruning time and number of lungs (Figure 1A). Pruning in October resulted in significantly higher leaf carbohydrates, at pruning time, two, five and six months after pruning, as compared to either pruning in June or March. However, it was not significant at half, one, three and four months after pruning. Leaf TNC in October-pruned tea bushes ranged from

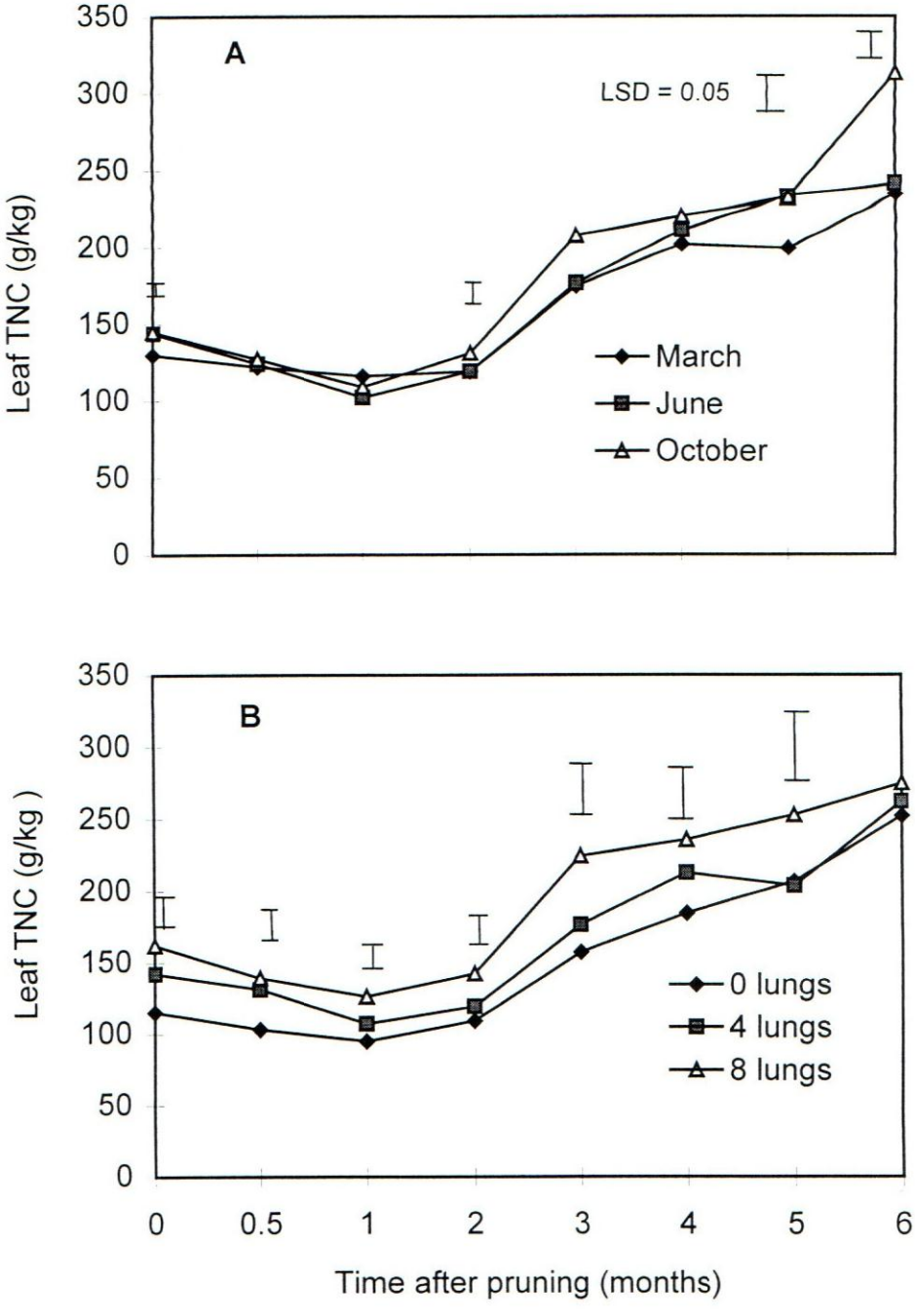


Figure 1. Effect of time of pruning (A) and number of lungs (B) on mean leaf total non-structural carbohydrates

148 g/kg at pruning time to 300 g/kg dm of leaves at six months after pruning. The leaf TNC ranged from 139 to 227 g/kg dm for March-pruned, and 143 to 250 g/kg for June-pruned tea bushes. The differences were also attributed to climatic factors (Figure 2). The leaf TNC, generally, decreased after pruning in all treatments, but began to increase after two months (Figure 1A).

Lungs significantly ($P \leq 0.05$) affected the leaf carbohydrates during all the sampling times after pruning, except at six months (Figure 1B). Pruning to leave 8 or 4 lungs improved the carbohydrate status of tea plants. At pruning time of June and March experiments, 8 lungs resulted in 4% and 8% more leaf TNC, respectively, when compared to control tea bushes.

The physiology of plants after defoliation has two distinct phases. The first one is a transient period during which previously stored reserves are used to rapidly replace lost tissues. The second phase is a readjustment of physiological activity when reserve pools are progressively replenished. According to some studies, the phase of reserve mobilization lasts about one week (Davidson and Milthorpe, 1996a). Leaf growth after defoliation or pruning depends on pre-defoliation reserves and then on post-defoliation assimilates. In this experiment, the levels of TNC initially declined due to carbohydrate remobilization to support growth of new leaves. The level rose

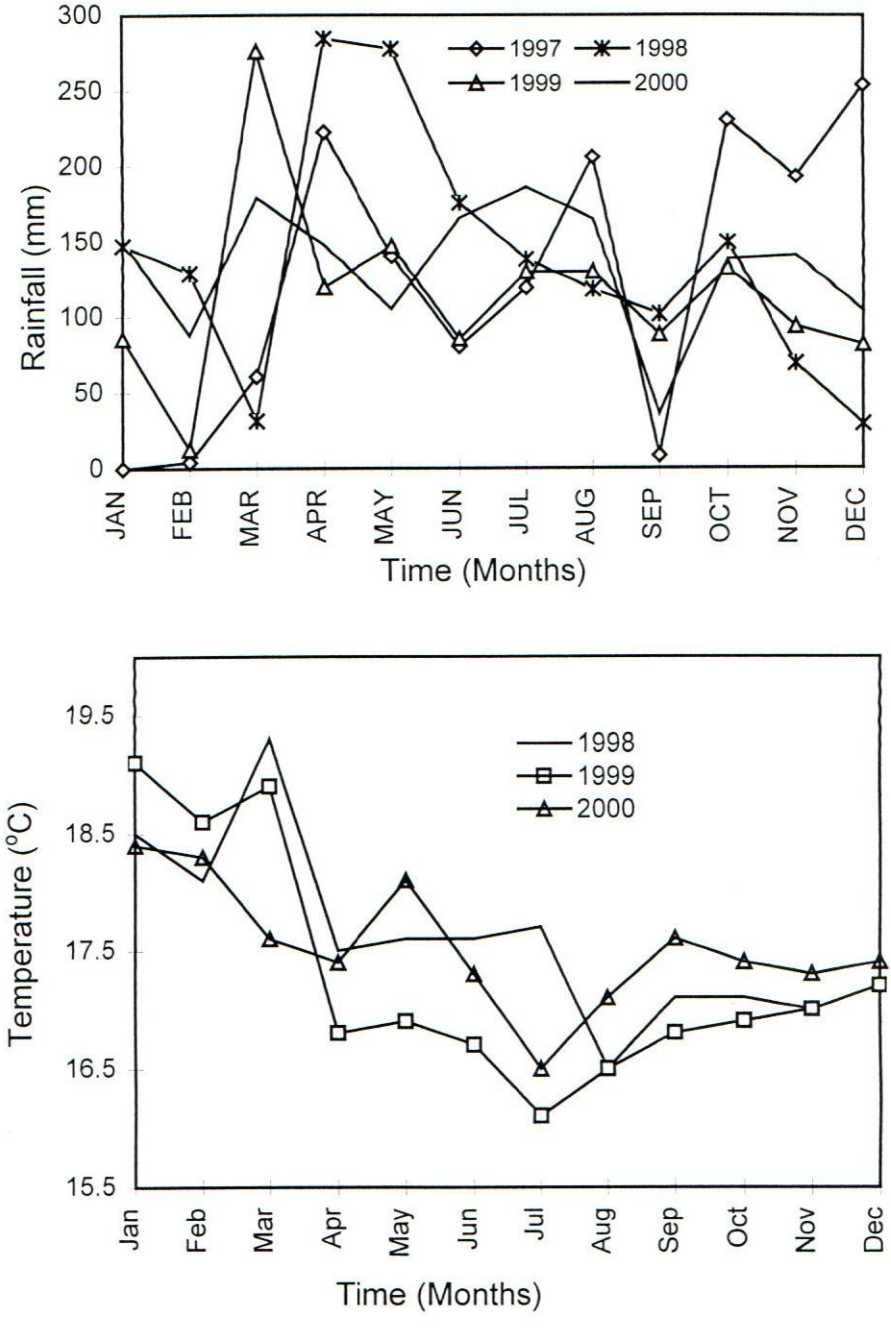


Figure 2. Rainfall and temperature data of the experimental site

again due to post-defoliation assimilates, resulting from photosynthesis by the newly developed leaves (Davidson and Milthorpe, 1996b).

Responses to defoliation have been characterized by plant types (Feeny, 1976). Bryant et al. (1983) proposed that plants be grouped by their leaf longevity. The central point of this argument is that evergreen plants are more sensitive to foliage loss than deciduous species, because evergreen foliage has a higher initial cost of production and lower rate of return per carbon (C) investment, and stores proportionately larger amounts of whole-plant Carbon. However, plants have compensatory responses to defoliation. Reich et al. (1993) found that rates of photosynthesis on residual or regrowth foliage increased more than in non-defoliated controls, and this was also observed in this experiment, as characterized by increased carbohydrates three months after pruning. Loescher et al. (1990) reported that loss of reserves might be of little consequence to trees, depending on the timing of defoliation or pruning. Webb (1975) reported that the extent to which foliage can be considered a storage organ for starch might be dependent on the age of the plant. Baur-Hoch et al. (1990) found that there is a close relationship between regrowth of white clover and carbohydrates, because a higher regrowth rate was observed in plants with high carbohydrate concentration.

On the other hand, TNC form the pool of reserve carbon that can be partitioned to growth when demand exceeds supply of currently produced photosynthates (Kramer and Kozlowski, 1979). In tea, excess carbohydrates are stored in the roots and stem as starch, depending on the quantity of active leaf and the new growth taking place (Goodchild, 1954).

b) Stem TNC

Stem carbohydrates were significantly ($P \leq 0.05$) affected by pruning time at all sampling times after pruning, except at three and five months after pruning, during which they were not significant (Figure 3A). At pruning time, October-pruning resulted in the highest TNC level, which declined immediately thereafter. The stem TNC in March and June-pruned tea also followed a similar pattern as those of October-pruned tea. The stem TNC was low as compared to both leaf and root TNC. Nevertheless, stem TNC was consistent (fluctuated within a narrow range) throughout the experimental period, as compared to leaf and root TNC.

The stem carbohydrates in October-pruned tea bushes drastically declined after pruning (Figure 3A). In this experiment, high carbohydrates were found in October-pruned bushes, which had low diebacks. However,

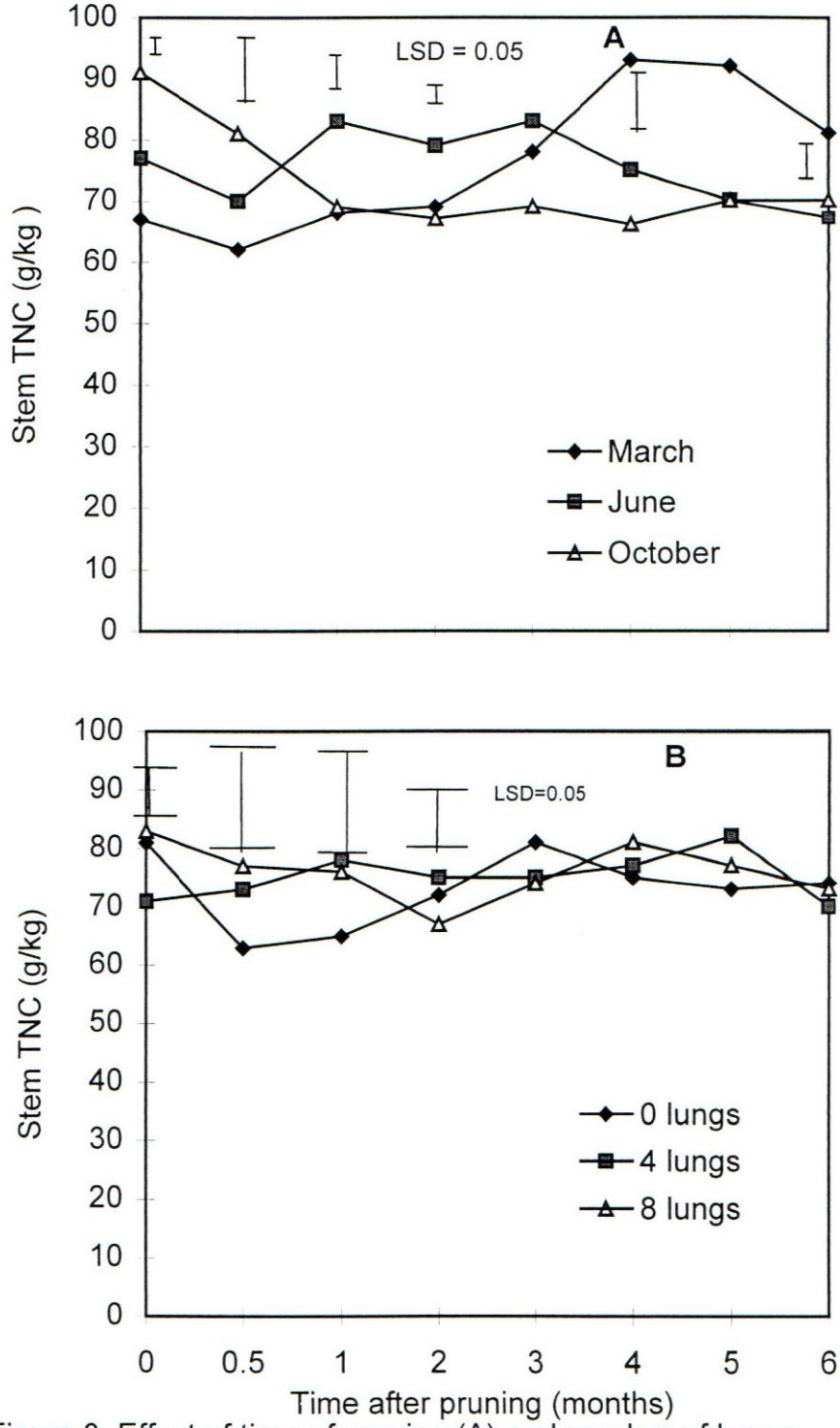


Figure 3. Effect of time of pruning (A) and number of lungs (B) on mean stem total non-structural carbohydrates

carbohydrates in March-pruned tea bushes, which had low stem TNC at pruning time, increased to a maximum of 90 g/kg, five months after pruning.

Stem TNC were significantly ($P \leq 0.05$) affected by the number of lungs, from pruning time until two months after pruning, beyond which they were not significantly affected (Figure 3 B). Lung-pruning slightly improved the overall mean stem TNC by more than one percent as compared to the control and exhibited very little fluctuation across the sampling times after pruning. This implies that lungs contributed carbohydrates, which were necessary for regrowth. Three months after pruning, the plants had produced adequate leaf area for manufacture of photosynthates.

c) Root TNC

Root TNC were significantly ($P \leq 0.05$) influenced by pruning time only at zero and two weeks after pruning (Figure 4A). However, from the second week after pruning there was a steady increase that had no characteristic pattern. For October-pruned tea bushes, there was a slight fluctuation in root TNC throughout the sampling period. The March and June-pruned tea bushes showed a constant increase.

Similarly, the number of lungs left at pruning time significantly ($P \leq 0.05$) affected root carbohydrates only at 2 weeks and two months after pruning (Figure 4B). There was a steady increase that showed that the

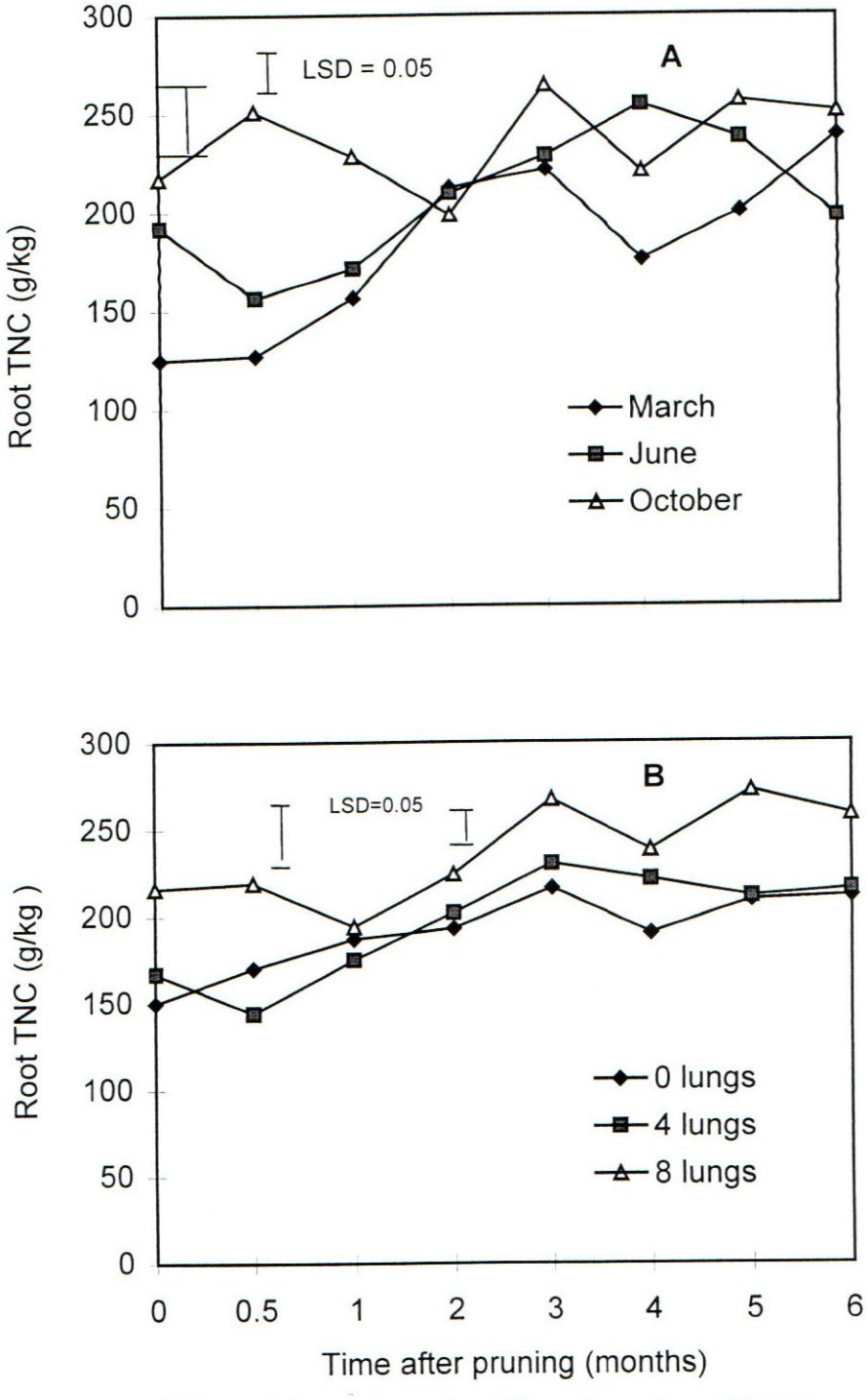


Figure 4. Effect of time of pruning (A) and number of lungs (B) on mean root total non-structural carbohydrates

more the lungs, the higher the root TNC. Pruning to leave no lungs (control), 4 lungs, and 8 lungs resulted in root TNC, which ranged from 149 to 190 g/kg, 170 to 200 g/kg and 200 to 250 g/kg, respectively.

After pruning, root TNC level decreased, depending on the pruning time (Figure 4A). There was a slight reduction in root TNC for March and June treatments (Figure 4B). However, there was an increase in TNC for one month for October-pruned tea bushes. The TNC later declined to an almost constant level. Root TNC increased four months after pruning in all treatments. This coincided with the period when most pruned teas had developed regrowth, implying that the newly developed leaves were photosynthetically active and were able to fix more than adequate TNC. Thus, some of it had to be stored in the roots. This phenomenon was reflected in the leaf and stem TNC as well.

Roots had higher TNC than both leaves and stems (Forbes and Wartson, 1992). Meohuachi et al. (1996) reported that sugar accumulation might take place because of three reasons, namely, higher rate of photosynthesis, alteration in the control of source-sink relationships and assimilate transport, and lower rates of dark and photo-respiration. Currently, it is difficult to evaluate the contribution of each process in the carbohydrate build up observed in pruned tea bushes.

According to Gholz and Cropper (1991), root carbohydrate concentration varies highly among species; analytical methods, and soil factors cause this variation (Adams et al., 1986). Also, the proportion of coarse to fine roots could influence the TNC results (Okano and Omae, 1996). However, the results of this experiment agreed with those of Okano and Omae (1996), who reported that 84% of total available carbohydrates were localized in the lignified roots of two-centimeter diameter.

Changes in sugar and starch concentration may partly reflect conversions between these compounds; seasonal changes in carbohydrate production, transport and utilization would also influence the observed pattern. Deans and Ford (1986) reported that reduction in starch during the growing season probably reflected carbohydrate use associated with the construction and maintenance of new tissues.

The low stem carbohydrates exhibited when plants were regrowing after pruning, suggests that there was translocation from shoots to roots. Although bi-directional carbohydrate movement was not considered or measured in this research, it is a pointer for future studies.

Emergence of many buds on October-pruned tea bushes was attributed to the amount of carbohydrates in plant leaves, stems and roots (Figures 1, 3, and 4). The levels of carbohydrates were adequate to trigger the onset of bud burst and subsequent shoot development. Apart

from the control plots (zero lungs), the number of emerging buds increased with increasing number of lungs. The lungs provided enough photosynthesizing leaf surface area to replenish carbohydrate reserves when it was most required.

In most previous pruning experiments, a lot of emphasis was placed on climatic variables, which may affect yields. For example, Dutta and Grice (1966) reported that pruning in India is performed from April to May, but not in October, which is a dry month. In Sri Lanka, it is done in April-May, or in September when the soil moisture content, availability of carbohydrates, and weather are not limiting (Kulasegaram, 1986). These observations imply that carbohydrates are dependent on the availability of moisture.

In this experiment, it was observed that more lungs (eight) and October-pruning resulted in the highest amount of carbohydrates in the plant parts sampled (Figures 1, 3, and 4). The implication is that the lungs provided adequate reserves, through their photosynthetic activities. Lungs continue photosynthesizing, as the plant regrows after pruning. The lungs, therefore, improve plant yields. Plants without lungs tend to have low yields, perhaps due to low and/or no carbohydrates (Kandiah et al., 1984). Although the presence of lungs is important, they also use some reserves,

thereby, retarding regrowth (Nathaniel, 1982; Mwakha, 1986). This is the reason necessitating their removal once plants attain full regrowth.

4.1.2. Regrowth Period

The effect of pruning time on regrowth period was significant (Table 1). October-pruning took the fewest number of days (102) from pruning time to first tipping time.

Lung-pruning significantly ($P \leq 0.05$) reduced regrowth period after pruning. Regrowth period decreased with increasing number of lungs from a mean of 122 days in the control plots to 116 days in 8-lungs plots (Table 1). The observation that lungs hastened regrowth concurred with that of Eden (1950), but contradicted that of Anonymous (1953), who concluded that the presence of lungs delays bud break

The second pruning cycle conducted in 2000 also showed that pruning time and lungs significantly affected the regrowth period (Table 1). Like in the 1997 pruning cycle, October-pruning resulted in the shortest regrowth period, followed by March, and then June-pruning. Lung-pruning also significantly ($P \leq 0.05$) reduced the regrowth period in such a manner that the more the lungs, the shorter the regrowth period.

Table 1. Effect of time of pruning and number of lungs on regrowth period (days)

Pruning time	Number of Lungs 0	4	8	Means
a) 1997 pruning cycle				
March	128^{ij**}	121^{j}	122^{j}	124^{a}
June	129^{ij}	135^{i}	132^{l}	132^{a}
October	110^{k}	104^{k}	93^{l}	102^{b}
Means	122^{e}	120^{ef}	116^{f}	
%CV	3.60			
b) 2000 pruning cycle				
March	118^{j**}	112^{l}	108^{n}	113^{b}
June	120^{i}	117^{k}	111^{m}	116^{a}
October	92^{o}	91^{p}	90^{q}	91^{c}
Means	109^{e}	106^{e}	103^{f}	
%CV	0.18			

**Values followed by the same letter within a pruning cycle and within a letter series are not significantly ($P \leq 0.05$) different according to the Duncan's Multiple Range Test (DMRT).

There were significant interactions between pruning time and number of lungs, implying that plants responded differently when pruned at different times. The results showed that pruning in October, and leaving 8 lungs resulted in quicker regrowth. Templer (1977) reported that most Kenyan teas are pruned at non-recommended seasons. Regrowth, therefore, often may have mild to disastrous effects on tea. Poor regrowth may reduce yields in the year of pruning or may even extend to an entire pruning cycle.

In this research, pruning time and number of lungs interacted, resulting in varied effects on tea regrowth. The quick regrowth in October-pruned tea bushes may have been due to the high amount of rainfall that was characterized by the *el-Nino* phenomenon in late 1997 (Figure 2). Earlier, in the same year, there had been a severe drought, which may have equally affected the regrowth of March and June-pruned tea bushes.

4.1.3. Diebacks

Neither did pruning time, number of lungs, nor their interactions significantly affect diebacks in the first pruning cycle (Table 2). The trend was that few diebacks resulted in October-pruned tea bushes.

The bushes pruned in dry months of March had a large number of diebacks. Eden (1950) reported that the only way to prevent dieback is through lung-pruning. However, the second pruning cycle in 2000 showed

Table 2. Effect of time of pruning and number of lungs on diebacks/bush

	Number of lungs			
Pruning time	0	4	8	Means
a) 1997 pruning cycle				
March	8*	15	14	12
June	15	24	19	19
October	9	9	7	8
Means	10	15	13	
%CV	13.07			
b) 2000 pruning cycle				
March	28*	17	13	19
June	20	17	21	17
October	21	17	12	17
Means	23[a]**	17[b]	15[b]	
%CV	30.47			

*Means not followed by a letter within a pruning cycle, are not significantly ($P \leq 0.05$) different according to the F-test

**Means followed by a letter within a pruning cycle and within a letter series are not significantly ($P \leq 0.05$) different according to the Duncan's Multiple Range Test

that although there was no significant effect of the pruning time, lungs significantly ($P \leq 0.05$) affected diebacks (Table 2). The control had the highest amount of diebacks (Table 2). Pruning and leaving lungs reduced the incidence of diebacks such that the more the lungs, the less the diebacks. This shows that lungs assisted the pruned plants to regrow, probably through photosynthates that were fixed by the foliage on the lungs. Diebacks are reduced during lung-pruning, because lungs provide leaf area, and hence the supply of carbohydrates used for regrowth. Pethiyagoda (1966) found that lung-pruning, as practised in lowlands of Sri Lanka, reduces diebacks.

The lower incidence of diebacks in October-pruned tea bushes could be attributed to the high leaf (Figure 1) and root carbohydrates (Figure 4). Diebacks following pruning have been associated with inadequate carbohydrates (Tubb, 1937). In this experiment, inadequate carbohydrates were not demonstrated, implying that harsh environmental conditions may have reversed the expected reduced diebacks in January to February.

Goodchild (1954) reported that dieback is a major cause of crop loss in tea; it is a slow insidious process that remains unnoticed until considerable damage to frames has occurred. Production of a larger number of shoots during the month before pruning increases the amount of diebacks (Tubb, 1937). This is attributed to an increase in the number of

shoots that compete for carbohydrates, with a resultant effect of reducing the carbohydrate reserves, hence causing diebacks.

Leaving lungs provides the plant with small quantities of carbohydrates, while the new growth is taking place. According to Goodchild (1954), several scattered lungs over the bush are better than one large one, because not all branches are directly connected with roots, and this partly explains why lung-pruning in some cases may not be of any assistance to the pruned plant. What needs to be established is how each branch is connected to most of the roots. This information can provide a physiological mechanism that will indicate the best positioning of lungs for the best plant regrowth and survival after pruning.

4.1.4. Emerging Buds

In both 1997 and 2000 cycles, pruning time had no significant effect on emerging buds. However, October-pruning resulted in more emerging buds than the other times tested (Table 3).

In the 1997 pruning cycle, lungs had a significant effect ($P \leq 0.05$) on emerging buds (Table 3), and it was observed that eight and four lungs resulted in the fewest emerging buds. Pruning without leaving lungs

Table 3. Effect of time of pruning and number of lungs on emerging buds/bush

Pruning time	Number of lungs			Means
	0	4	8	
a) 1997 pruning cycle				
March	188*	122	117	142
June	169	99	120	129
October	186	148	195	177
Means	181[a]**	123[b]	144[b]	
%CV	14.71			
b) 2000 pruning cycle				
March	161*	190	189	180
June	149	185	177	170
October	152	191	187	177
Means	154[b]**	189[a]	185[a]	
%CV	13.65			

*Values not followed by a letter within a pruning cycle, are not significantly ($P \leq 0.05$) different according to the F-test.

**Values followed by the same letter within a pruning cycle and within a letter series are not significantly ($P \leq 0.05$) different according to the Duncan's Multiple Range Test

(control) resulted in the highest emerging buds, developing to full size productive shoots (Table 3). In the 2000 pruning cycle, pruning to leave lungs exhibited a higher number of emerging buds, unlike in the 1997 pruning cycle. Generally, pruning exposes pruned branches to direct heat from the sun, hence sunscorch damage (Othieno, 1983). Blind branches are caused by sunscorch, which kills the buds on pruned branches suddenly exposed to direct intense heat from the sun.

The results obtained in this experiment seem to suggest that lung-pruning leads to development of more emerging buds as evidenced by the 2000 pruning cycle results. The observed differences in the two cycles may be accounted for by their different weather conditions. This implies that emergence of buds is dependent on environmental factors, which greatly dictate the performance of shoots in terms of regeneration and sustenance of green leaves.

Pruning of tea has an effect of stimulating new vegetative growth (Bald, 1965), and it is from then on that the plants are easily managed through constant plucking. Emergence of new shoots depends on the type of pruning method employed, and also the time of pruning. Carbohydrates that are either stored, or manufactured in the plant are used during the periods when photosynthesis is not actively taking place to supply adequate reserves. Pruned plants, hence, use stored reserves to supply energy

needed for bud break. These reserves are commonly stored in roots. Root supply of carbohydrates during regrowth period is vital for plant survival and regrowth (Nathaniel, 1982).

4.1.5. Yields

During the 1997 pruning cycle, pruning time had significant ($P \leq 0.05$) effects on only the 1997 harvests (Table 4). Yields obtained after pruning in the month of October were higher than those obtained after pruning in either June or March. These results are in agreement with those of Othieno (1983).

Number of lungs significantly affected the yields of tea pruned in 1997 only in the third year after pruning (1999 harvests). Mwakha (1986) had reported that although lung-pruning significantly affected yields, it was only during the pruning year. Also, Tubb (1937) reported that the decrease in yield in the first year of lung-pruning might be due to the temporary inability of the pruned branches to contribute to yields until much later. This response is counter-productive as far as yields are concerned, but it is quite beneficial in maintaining plant health.

In this study, yields increased with time after pruning. Satyanayarana (1994) found that age after pruning affects productivity. The proportion of

Table 4. Effect of time of pruning and number of lungs on yields (kg mt/ha/yr) of the 1997 pruning cycle

	Number of lungs			
Pruning time	0	4	8	Means
a) 1997 pruning cycle (1997 harvests)				
March	3357*	3193	3239	3263[b**]
June	3519	3501	3367	3462[b]
October	4640	4408	4442	4497[a]
Means	3839	3701	3683	
%CV	9.15			
b) 1997 pruning cycle (1998 harvests)				
March	5035*	5006	5081	5041
June	5127	5275	4845	5082
October	5354	5344	5434	5377
Means	5172	5208	5120	
%CV	7.61			
c) 1997 pruning cycle (1999 harvests)				
March	4915[g**]	5710[de]	5439[efg]	5355
June	5002[fg]	5212[efg]	5308[efg]	5174
October	5563[def]	5356[efg]	6073[d]	5664
Means	5160[h]	5426[gh]	5607[g]	
%CV	5.32			

*Values not followed by a letter within a harvest year are not significant ($P \leq 0.05$) different according to the F-test.

**Values followed by the same letter within a harvest year and within a letter series are not significantly ($P \leq 0.05$) different according to Duncan's Multiple Range Test

phytomass (yields) partitioned towards the crop increased from the first year to the third year after pruning. The pattern of yields in this experiment was similar to that of phytomass partitioning. Tea yields are normally low immediately after pruning, and then increase gradually to a peak, followed by a decline within the third year after pruning. Also, the third year after pruning is characterized by presence of smaller-sized shoots, which have a low dry mass content.

Previous work on tea pruning emphasized types of pruning and during that time, some aspects contributing to regrowth and performance of tea were not carefully addressed. Amongst the type of pruning methods, which improves yield is lung-pruning. Lungs assist in regrowth (Willson, 1992), and improve growth and yield (Nagarajah and Pethiyagoda, 1965). The main mechanism is attributed to the lung's continuity to photosynthesize and maintain carbohydrate supply.

Pruning time significantly ($P \leq 0.05$) affected cumulative yields (Table 4 a). Pruning in October resulted in significantly higher yields, probably due to the effects of favourable weather conditions in 1998, and in October 1997, when there was excessive rainfall (Figure 2). Usually, high yields resulting from high growth rate depend on availability of water (Hanna, 1969). Rainfall distribution is critical, because it affects yield performance and may cause 'carry over' effects (Figure 2).

Table 4a. Effect of time of pruning and number of lungs on cumulative yields (kg mt/ha/3yr) of the 1997 pruning cycle

	Number of lungs			
Pruning time	0	4	8	Means
a) 1997 pruning cycle (1997 to 1999 harvests)				
March	13308*	13908	13760	13659[b]**
June	13649	13987	13521	13719[b]
October	15558	15108	15949	15538[a]
Means	14171	14334	14410	
%CV	4.66			

*Values not followed by a letter are not significantly ($P \leq 0.05$) different according to the F-test.

**Values followed by the same letter within a letter series are not significantly ($P \leq 0.05$) different according to Duncan's Multiple Range Test.

During the 2000 pruning cycle, yields were not significantly ($P \leq 0.05$) affected by the time of pruning, but lungs had a significant effect on yields (Table 5). Generally, these yields were much lower than those of the previous pruning cycle in 1997. The varied yield responses of different pruning cycles in this experiment may be attributed to localized variations in rainfall (Figure 2). Ng'etich (1995) pointed out that localized variations in rainfall lead to uneven yield potential even within the same field or experimental site, as was observed in this experiment.

Table 5. Effect of time of pruning and number of lungs on yields (kg mt/ha/4 months) of the 2000 pruning cycle

	Number of lungs			
Pruning time	0	4	8	Means
March	1726*	885	996	1202
June	1493	892	950	1112
October	1290	857	1207	1118
Means	1503[a]	878[c]	1051[b]	
%CV	19.94			

*Values not followed by a letter are not significantly ($P \leq 0.05$) different according to the F-test.

** Values followed by the same letter within a letter series are not significantly ($P \leq 0.05$) different according to Duncan's Multiple Range Test.

4.1.6. Correlation between Total Non-structural Carbohydrates and Growth Parameters of Experiment 1

Both leaf and root TNC had significant negative correlations with regrowth period. For leaf TNC r = -0.610 (*P = 0.001*) and root TNC r = -0.519 (*P = 0.01*). This shows that a decrease in TNC will result in a long regrowth period. Regrowth after pruning can occur provided that TNC is not below 12% (Eden, 1976; Nathaniel, 1982). Carbohydrates are manufactured in the leaves, and those stored in the roots assist in regrowth. Stem TNC was, however, not significantly correlated to regrowth (Table 6).

Satyanarayana (1994) reported that current and stored carbohydrates are used for growth and development. Reserves from storage organs are mobilized in a deficit situation. Results obtained in this experiment agree with those of Sharma and Murthy (1989), but contradict those of Pethiyagoda (1963), who found no correlation between root carbohydrates and regrowth. Correlation analysis indicated that stem TNC was positively correlated (r = 0.457, *P = 0.001*) with diebacks, while leaf and root TNC were not significantly correlated with diebacks (Table 6). A decline in carbohydrates increases incidence of diebacks (Willson, 1992; Kandiah, 1971). Also at low elevations of Sri-Lanka, temperatures are high and respiration reduces stored carbohydrates, resulting in poor regrowth and high diebacks (Venkata-Ram, 1974).

Table 6. Correlation coefficients between total non-structural carbohydrates (TNC) and regrowth parameters of experiment 1

	Parameters			
TNC	Regrowth period	Diebacks	Emerging buds	Yield
Leaf	-0.610***	-0.124	-0.020	0.390*
Stem	0.246	0.457*	-0.540**	-0.573**
Root	-0.519**	-0.163	0.093	0.615***

*, **, *** Significant at P = 0.05, 0.01, and 0.001, respectively.

Critical values at P = 0.05, r= 0.38; at P = 0.01, r=0.4869; at P = 0.001, r= 0.5974.

In this experiment, no significant correlation resulted between emerging buds and either leaf or root TNC. With stem TNC, the number of emerging buds tended to be few where stem TNC was high (r = -0.540; *P* = *0.01*) (Table 6). The results agree with those of Lister et al. (1967), who observed that carbohydrate translocation from shoots to roots was lowest during active growth. Thus, most TNC was in leaves and not in stems, when bud emergence was highest.

The relationships between yields and all total non-structural carbohydrates were significant. The correlation coefficients for leaf, stem, and root TNC *versus* yields were r = 0.390, *P* = 0.05; r = - 0.573, *P* = 0.01; and r= 0.615, *P* = 0.001, respectively (Table 6). Evidently, root TNC is strongly correlated with yields and indeed, most of the TNC were contained in the roots. Roots are, therefore, the primary sources of TNC, which influence all other parameters and yield of pruned tea.

4.2. Effects of Time of Pruning and Resting Period on Total Non-Structural Carbohydrates, Regrowth Period, Diebacks, Emerging Buds and Yields

4.2.1. Total Non-structural Carbohydrates

a) Leaf TNC

Pruning time significantly affected leaf TNC at zero, two and four months after pruning (Figure 5A). October-pruning exhibited the highest amount of leaf TNC, followed by March and June-pruning. At pruning time, October-pruning resulted in leaf TNC of about 220 g/kg, whereas 196 and 148 g/kg resulted for June and March-pruning, respectively (Table 5A). Generally, the leaf TNC declined after pruning and increased slowly one month after pruning (Figure 5A). March-pruned tea bushes showed a slight seasonal fluctuation in leaf carbohydrates, unlike June-pruned tea bushes that showed a major fluctuation from the second month after pruning (Figure 5A). From June to July, the March-pruned plants had developed adequate maintenance foliage, which has been recognised as the source of carbohydrates (Barua, 1989). The utilization of assimilates by the growing shoots (sinks) helps sustain the rate of photosynthesis of maintenance leaves.

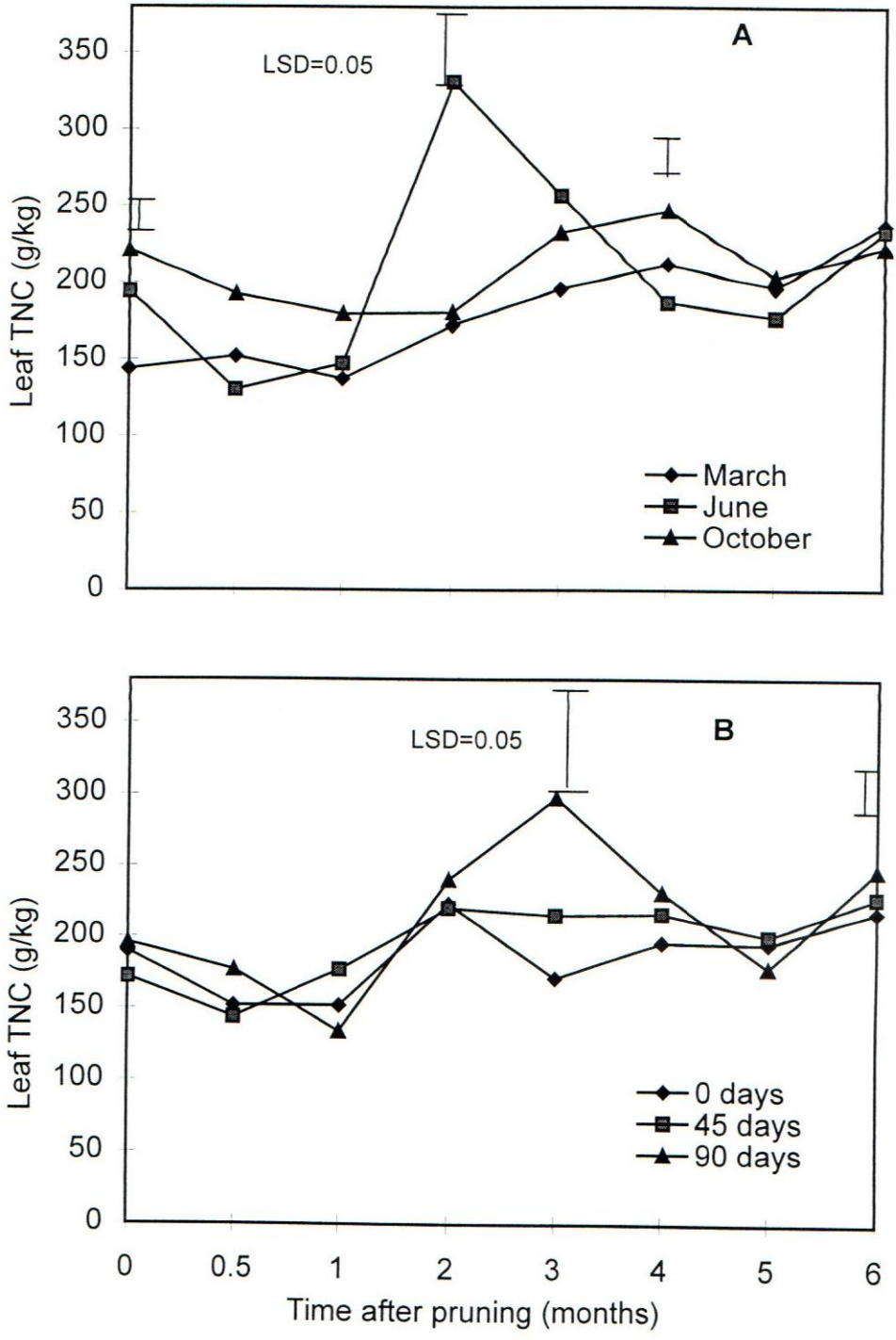


Figure 5. Effect of time of pruning (A) and resting period (B) on mean leaf total non-structural carbohydrates

Resting improved carbohydrate status of the tea plants. Resting period significantly ($P \leq 0.05$) affected leaf TNC only at three and six months after pruning. The TNC level also declined after pruning and peaked up again one month after pruning and attained pre-pruned TNC level after two months post-pruning. Longer resting periods increased leaf TNC, which, however, declined after the pruned plants started regrowing. The amount of leaf TNC decreased after pruning to 120 g/kg then increased to 294, 160 and 180 g/kg for 90, 45 and 0 days resting periods, respectively (Figure 5B). The overall mean leaf TNC for 90 days resting period increased by 4% after pruning in March, followed by 3% after pruning in October and 2% after pruning in June.

Marimuthu et al. (1994) reported that about 40% of photosynthates are mobilized to growing shoots, and 20% to dormant banjhi shoots. It is, therefore, essential to remove banjhi buds, because the dormant phase limits the economic yield of tea (Marimuthu et al., 1994). Flush shoots are considered stronger sinks, contributing dry matter accumulation that supports productivity and growth rate of shoots. Flush shoots receive more photosynthates, which explains the high amount of TNC observed in the leaves (Figure 5A). Flush usually occurs in the month of October, hence the observed high leaf TNC in tea bushes pruned in this month (Figure 5A).

b) Stem TNC

Stem TNC were significantly ($P \leq 0.05$) affected at zero, three and five months post-pruning. Only stem TNC of March-pruned tea bushes declined sharply after pruning, whereas TNC of both June and October-pruned tea bushes showed a non-significant increase, except at three and five months after pruning (Figure 6A).

Resting period did not significantly affect stem TNC in all sampling periods, except at three and five months post-pruning (Figure 6B). At pruning time, control (no resting period) resulted in 80 g/kg, which immediately declined and increased half a month later. The TNC of both the 45 and 90 days resting periods was lower than that of the control only at pruning time. Stem TNC of experiment 2 was similar to that of experiment 1.

The pattern of stem TNC fluctuation was similar to that of leaf and root TNC. However, stem TNC were lower than both leaf and root TNC. This implies that stems do not store a lot of carbohydrates and mainly act as conduits, for carbohydrate translocation from either roots or leaves.

c) Root TNC

Pruning time significantly ($P \leq 0.05$) influenced root TNC, except at two weeks after pruning. October-pruning resulted in the highest root TNC,

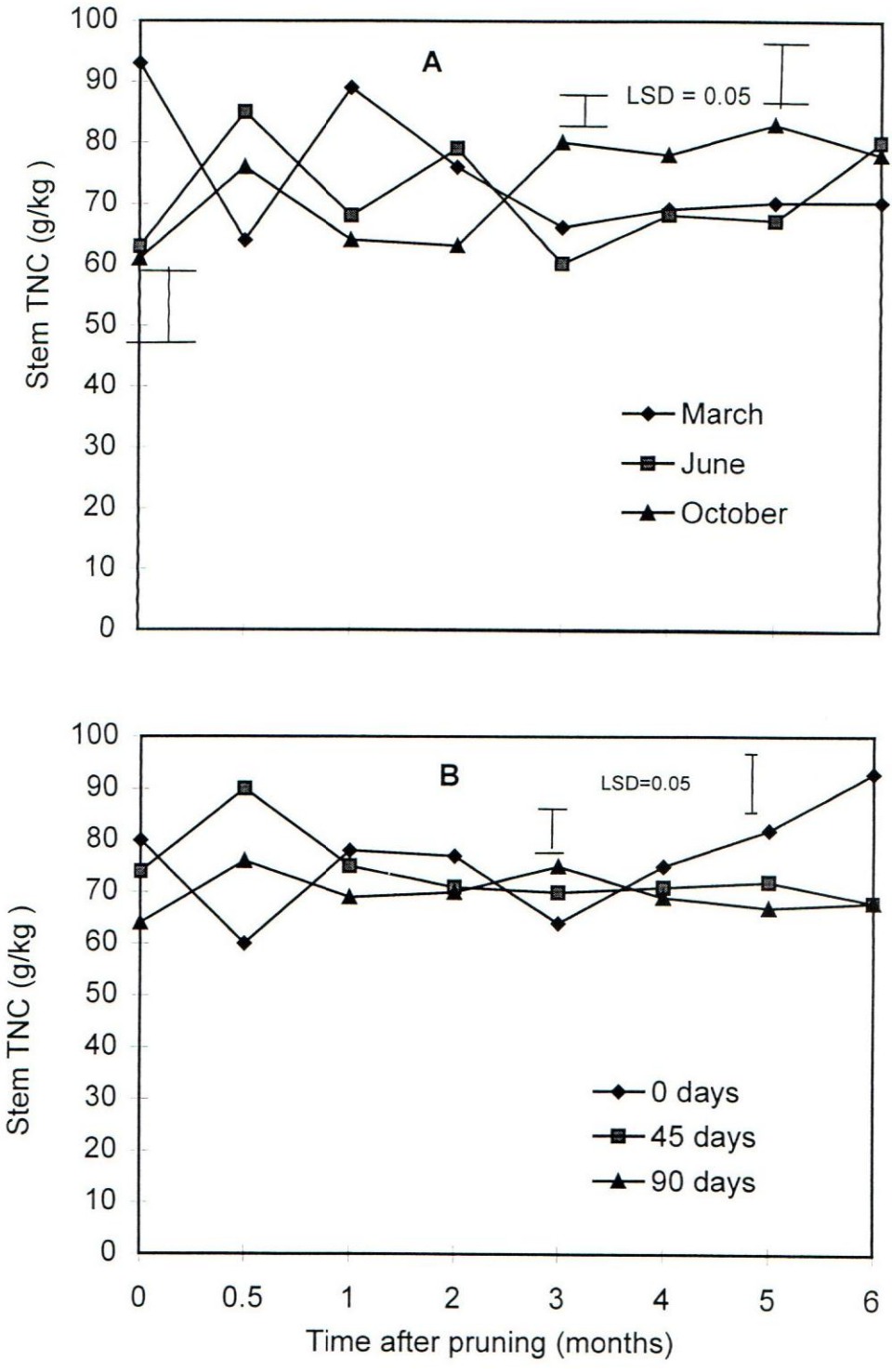


Figure 6. Effect of time of pruning (A) and resting period (B) on mean stem total non-structural carbohydrates

which declined immediately after pruning, but sharply increased from one month after pruning and then declined again from the second month post-pruning. At pruning time, the level of root TNC was 360, 155, and 145 g/kg for October, June and March-pruning, respectively (Figure 7A). March-pruning resulted in lower TNC than other pruning times, because adverse environmental conditions prevailed just before pruning (Figure 2). The temperatures were slightly high and accompanied by a dry spell. A significant reduction in root TNC occurred as shoot growth resumed in May and August, following pruning in March and June, respectively (Figure 7A).

Resting had a significant influence only at pruning time and at six months post-pruning (Figure 7B). Although resting for 90 days resulted in low root TNC of 185 g/kg, at pruning time, that level increased after pruning (Figure 7B). Resting significantly affected the initial carbohydrates in the roots. Thereafter, root TNC fluctuated within a narrow range, although un-rested (control) plants had a higher initial carbohydrate level of 240 g/kg (Figure 7B). Eventually, longer-rested tea bushes had higher final amounts of root TNC (Figure 7 B).

According to Rong et al. (1996), defoliation induced changes in starch depletion-reaccumulation in roots of birdsfoot trefoil (*Lotus corniculatus* L.) and sweet clover (*Melilotus officinalis* L.).

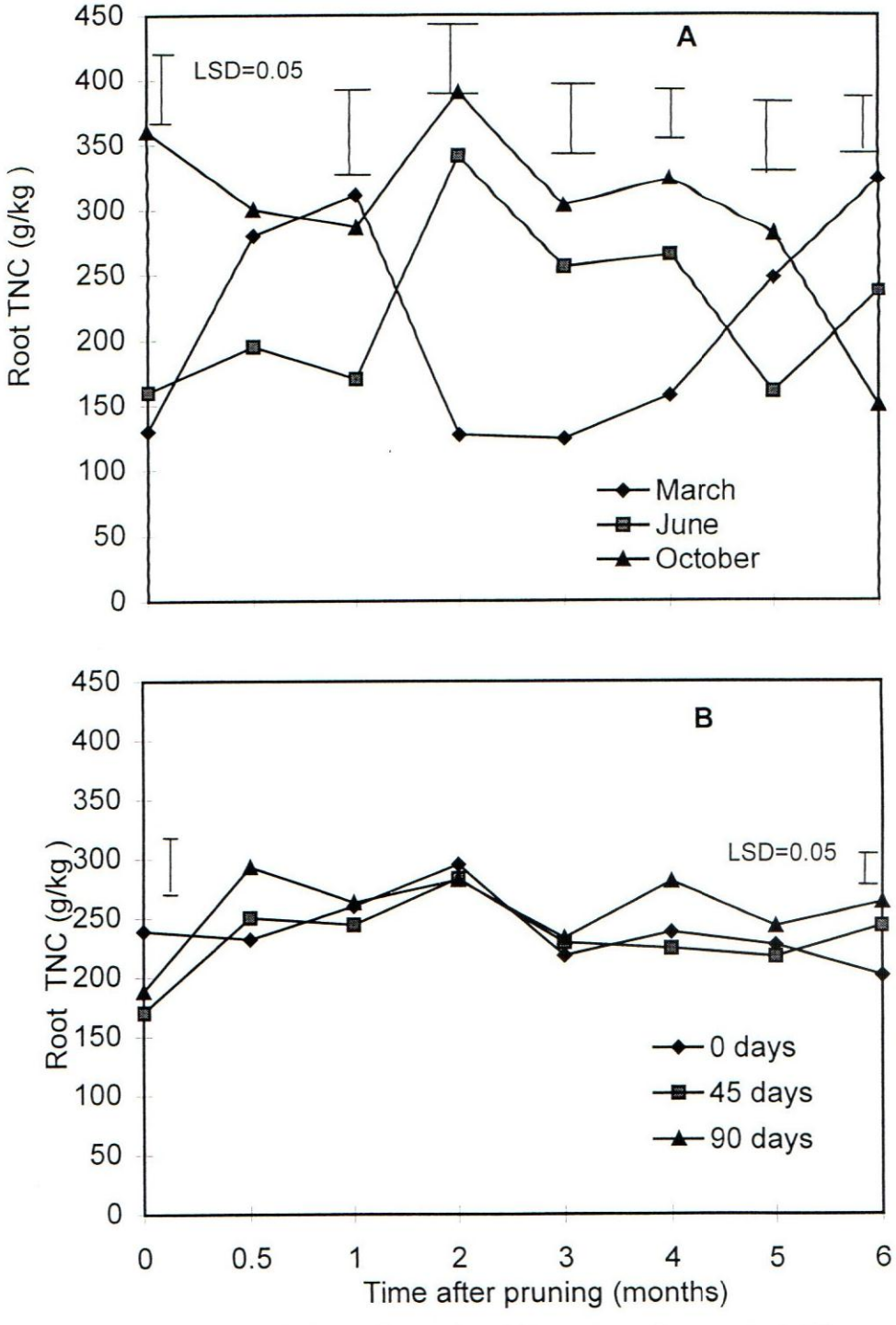


Figure 7. Effect of time of pruning (A) and resting period (B) on mean root total non-structural carbohydrates

High levels of root TNC are believed to be necessary for forage-legume survival when they are defoliated or under stress (Smith, 1962). For tea, root TNC may play a role in yield, diebacks and shoot regrowth after pruning. October-pruned tea bushes mostly had the highest amount of root carbohydrates (Figure 7A). These carbohydrates are made available to the plant for use during regrowth.

In this experiment, the increased carbohydrate levels after resting confirmed results of Kathiravetpillai et al. (1986), who concluded that resting for up to three months before pruning increases carbohydrates by 44%. However, the decline of carbohydrates to non-significant levels after the tea plants had fully recovered showed that an equilibrium had been established between photosynthesis, utilization and storage of reserves.

Resting slightly increased all carbohydrates in the tissues sampled and Kathiravetpillai et. al (1989) had observed a similar increase in carbohydrates with increasing resting period. However, the root TNC results obtained showed that there was no significant benefit of resting and concurred with those of Watson and Gunasereka (1986), who found that resting for 11 months before pruning lowered yields more than resting for 8 months.

4.2.2. Regrowth Period

Both resting and time of pruning significantly ($P \leq 0.05$) reduced regrowth period (Table 7). Pruning in October resulted in the shortest regrowth period of 100 days in the tea that was pruned in 1997. Longer resting for 90 days resulted in the shortest regrowth period of 108 days (Table 7). However, no significant interaction between pruning time and resting period resulted, implying that each variable had an independent effect on pruned tea bushes.

The 2000 pruning cycle showed that pruning time alone had significant ($P \leq 0.05$) effects on regrowth period (Table 7). As in the 1997 pruning cycle, October-pruning resulted in the shortest regrowth period. June-pruning resulted in the longest regrowth period, while regrowth period for March-pruning was between that for June and October-pruning (Table 7). However, March-pruning in the 2000 pruning cycle had a slightly longer regrowth period than in the 1997 pruning cycle.

The shorter regrowth period for the tea bushes pruned in October may be attributed to environmental factors. The average rainfall was above 100 mm and temperature was 17.3° C at the time when the October-pruned tea bushes were regrowing (Figure 2). According to Othieno (1983), tea bushes pruned in seasons with low cumulative potential soil moisture deficits took a few days to regrow after pruning. Tea bushes pruned at peak growing

Table 7. Effect of time of pruning and resting period on regrowth period (days)

	Resting period (days)			
Pruning time	0	45	90	Means
a) 1997 pruning cycle				
March	110*	103	92	102[b]
June	146	151	141	146[a]
October	110	100	90	100[b]
Means	122[e**]	118[e]	108[f]	
%CV	7.90			
b) 2000 pruning cycle				
March	114*	112	111	112[b**]
June	121	120	126	122[a]
October	96	95	95	95[c]
Means	110	109	110	
%CV	2.29			

*Values not followed by a letter within a pruning cycle are not significantly ($P \leq 0.05$) different according to the F-test.

**Values followed by the same letter within a pruning cycle and within a letter series are not significantly different ($P \leq 0.05$) according to the Duncan's Multiple Range Test.

conditions take a shorter time to regrow. This explains why regrowth was faster in October treatments,a period associated with flush.

Factors that determine regrowth include food reserves, and environmental conditions (Odhiambo and Othieno, 1992). Their variation leads to differences in regrowth and yield performance. In Malawi, optimum yields are obtained from tea pruned in May to August, when it is warm and moist (Ellis, 1975). Also in India, tea bushes pruned in April/May, when it is moist and warm, result in quick regrowth (Dutta and Grice, 1966).

Pruning when it is dry results in poor regrowth due to moisture deficiency (Astika, 1994). This may cause the pruned plant to die off or if it regrows partially, it does not produce adequate photosynthates to maintain the plant. At low altitudes of Sri-Lanka, there is high utilization of carbohydrate reserves due to high temperatures and respiration, which leads to poor regrowth of pruned plants (Venkata-Ram, 1974; Wringley, 1982).

Pruned tea regrows at a rate that depends on the level of previously stored carbohydrates, and pruning time (Walter, 1954). In Uganda, regrowth takes about 10.5 weeks (Bazirake-Ntawera, 1978a), while in Kenya, it takes longer at high altitudes and shorter at low altitudes and seems to depend on temperature. Tea growth is adversely affected if temperature falls below 13° C, or rises above 29° C (Eden, 1965).

4.2.3. Diebacks

In the 1997 pruning cycle, only pruning time had a significant ($P \leq 0.05$) effect on diebacks. Resting period and interaction had no significant ($P \leq 0.05$) influence (Table 8). March-pruned tea bushes had the fewest diebacks, and the highest incidence of diebacks was in October-pruned tea bushes.

The explanation for the observed phenomenon is that October-pruned tea bushes recovered into a dry season. These results, however, contradict those of the first experiment on lung-pruning and pruning time. This contradiction could have resulted because of the treatment effects. In this experiment, tea bushes were cut-acrossed hence the plants had to depend on stored TNC, which were however, not replenished immediately. In all the three pruning times of the 1997 pruning cycle, not resting (control) tea bushes, resulted in the fewest diebacks, although not significant.

In the 2000 pruning cycle, pruning time and resting period had no significant effects on diebacks (Table 8). However, resting for 90 days, resulted in the fewest diebacks, although not significant. Eden (1950) reported that where there is a marked seasonal resting period, the severity of diebacks, because of carbohydrate shortage is likely to be less noticeable. Dieback after pruning has been associated with inadequate carbohydrate reserves. Its incidence is much reduced where carbohydrates build up during winter for use in growth during spring (Kandiah, 1971; Eden, 1976; Willson, 1992).

Table 8. Effect of time of pruning and resting period on diebacks/bush

	Resting period (days)			
Pruning time	0	45	90	Means
a) 1997 pruning cycle				
March	7*	10	9	9[b]**
June	7	11	12	10[b]
October	19	22	21	21[a]
Means	11	14	14	
%CV	32.33			
b) 2000 pruning cycle				
March	22*	22	21	22
June	16	21	16	18
October	23	17	14	18
Means	20	19	17	
%CV	24.6			

*Values not followed by a letter within a pruning cycle are not significantly ($P \leq 0.05$) different according to the F-test.

**Values followed by the same letter within a pruning cycle and within a letter series are not significantly different ($P \leq 0.05$) according to the Duncan's Multiple Range Test.

4.2.4. Emerging Buds

Pruning time and resting period had no significant ($P \leq 0.05$) effect on emerging buds in both pruning cycles (Table 9). However in both pruning cycles, the number of emerging buds increased with increasing resting period (Table 9). This shows that the dry matter that accumulated during resting period was used to promote bud emergence (Wadasinghe and Gunasereka, 1986).

Although not significant, pruning in June promoted a high number of emerging buds, followed by pruning in March and October (Table 9). The few emerging buds in tea bushes pruned in October may be accounted for by the fact that October is usually associated with flushing. Flush shoots receive more photosynthates, and are thus stronger sinks, which drain a lot of accumulated photosynthates, denying emerging buds the opportunity to develop adequately. Also, regrowth of October-pruned tea bushes occurs during a dry season, which may adversely affect plants. Some of the buds are either aborted or do not develop at all, making the pruned plant to be partially covered with leaves. This incident may result in low to poor green leaf production and often the affected plants die if there is more stress. The results of the second experiment, showing the non-significant effect of pruning time on emerging buds corroborated those of the first experiment.

Table 9. Effect of time of pruning and resting period on emerging buds/bush

Pruning time	Resting period (days) 0	45	90	Means
a) 1997 pruning cycle				
March	111*	109	112	110
June	107	119	119	115
October	103	98	114	105
Means	107	109	115	
%CV	15.96			
b) 2000 pruning cycle				
March	172*	155	185	170
June	179	187	178	181
October	134	171	160	155
Means	162	171	174	
%CV	10.78			

*Values not followed by a letter within a pruning cycle are not significantly ($P \leq 0.05$) different according to the F-test.

4.2.5. Yields

Yield results showed that pruning time had significant ($P \leq 0.05$) effects during the first and second years after pruning, but not during the third year (Table 10). During the first and second years after pruning, October-pruning resulted in the highest yields compared to pruning in either June or March (Table 10). Resting period did not have a significant ($P \leq 0.05$) effect on all annual harvests (Table 10).

Pruning time had a significant effect ($P \leq 0.05$) on cumulative yields (Table 11). Increased resting period resulted in increased cumulative yields although not significant (Table 11).

In the 2000 pruning cycle, neither pruning time nor resting period had a significant effect on yields (Table 12). Nevertheless, in both the 1997 and 2000 pruning cycles, there was no significant interaction between pruning time and resting period, implying that each factor had independent effects on yield of pruned tea bushes (Tables 10 and 12). Resting of tea bushes before pruning is mainly aimed at improving carbohydrate reserves of the plant. This has been confirmed to increase dry matter accumulation, if done for up to 16 weeks (Wadasinghe and Gunasereka, 1986).

Table 10. Effect of time of pruning and resting period on yields (kg mt/ha/yr) of the 1997 pruning cycle

	Resting period (days)			
Pruning time	0	45	90	Means
a) 1997 pruning cycle (1997 harvests)				
March	1972*	1214	1459	1548[b]**
June	2625	2285	2313	2408[a]
October	2530	2636	2646	2604[a]
Means	2376	2045	2139	
%CV	15.19			
b) 1997 pruning cycle (1998 harvests)				
March	5151	5139	5222	5171[b]
June	6055	6024	6744	6274[a]
October	6113	6892	6737	6581[a]
Means	5773	6018	6234	
%CV	8.64			
c) 1997 pruning cycle (1999 harvests)				
March	5826	5422	5415	5554
June	5684	5816	5841	5780
October	4884	5262	5117	5088
Means	5465	5500	5458	
%CV	8.26			

*Values not followed by a letter within a harvest year are not significantly ($P \leq 0.05$) different according to the F-test.

**Values followed by the same letter within a harvest and within a letter series are not significantly different ($P \leq 0.05$) according to the DMRT.

Table 11. Effect of time of pruning and resting period on cumulative yields (kg mt/ha/3yr) of the 1997 to 1999 harvests

	Resting period (days)			
Pruning time	0	45	90	Means
March	12949	11774	12095	12273[b]
June	14365	14125	14898	14463[a]
October	13527	14790	14500	14272[a]
Means	13614	13563	13831	
%CV	8.73			

*Values not followed by a letter are not significantly ($P \leq 0.05$) different according to the F-test.

**Values followed by the same letter within a letter series are not significantly ($P \leq 0.05$) different according to Duncan's Multiple Range Test

Table 12. Effect of time of pruning and resting period on yields (kg mt/ha/4 months) of the 2000 pruning cycle

	Resting period (days)			
Pruning time	0	45	90	Means
March	4058*	3928	3589	3858
June	3709	2957	2609	3092
October	2712	3019	2672	2801
Means	3493	3301	2956	
%CV	10.80			

*Values not followed by a letter are not significantly ($P \leq 0.05$) different according to the F-test.

These results indicate that although no significant effect of resting period on yields was obtained in the 1997 pruning cycle, there was a "carry over" effect, which may be attributed to environmental factors. Also, this observation implies that treatment effects may not be realised within the year of experimentation, and hence a long-term period is required before any conclusive recommendations can be made.

4.2.6. Correlation between Total Non-structural Carbohydrates and Growth Parameters of Experiment 2

Correlation analyses were done between TNC and regrowth duration, diebacks, emerging buds and yield to determine their relationships. The results showed that the correlation coefficient between regrowth and root TNC was significant ($r = -0.385$, $P \leq 0.05$) and it was not significant for leaf and stem TNC (Table 13). This shows that root TNC is more important in regrowth after pruning (Table 13), although, the influence of environmental conditions is also important in plant growth and development. However, in this study, regrowth after pruning was not significantly correlated with rainfall ($r = 0.23$) and temperature (0.29). Othieno (1983) had earlier observed similar results.

In the case of diebacks and TNC, there was a significant positive correlation. The values were $r = 0.482$ ($P \leq 0.05$) and $r = 0.906$ ($P \leq 0.05$)

Table 13. Correlation coefficients between total non-structural carbohydrates (TNC) and regrowth parameters of experiment 2

	Parameters			
TNC	Regrowth period	Diebacks	Emerging buds	Yield
Leaf	0.103	0.482*	0.240	0.539**
Stem	0.046	-0.170	-0.095	-0.239
Root	-0.385*	0.906***	-0.176	0.827***

*, **, *** Significant at P = 0.05, 0.01, and 0.001, respectively.

Critical values r = 0.38 at P = 0.05; r = 0.4869 at P = 0.01; r = 0.5974 at P = 0.001.

for leaf and root TNC, respectively (Table 13).

However, there was no significant relationship between diebacks and stem TNC, proving that both leaf and root TNC are the main determining carbohydrates in reduction of dieback incidence.

In this experiment, no significant relationship between all total non-structural carbohydrates and emerging buds resulted, unlike in the first experiment (Table 13). These results imply that resting period did not influence emerging buds through influencing TNC.

There was a highly significant (P = 0.05) positive relationship between yields and either leaf or root total non-structural carbohydrates. The values were r = 0.539 (P = 0.01) and r = 0.827 (P = 0.001) for leaf and root TNC, respectively (Table 13). These relationships indicated that increased leaf and root TNC would concomitantly increase yields. The results concur with those of Wadasinghe and Gunasereka (1986), who observed that increased dry matter accumulation in leaves and roots increases yields. Since resting did not significantly influence annual and cumulative yields, these results show that resting only improves the TNC status of pruned tea bushes, and hence, influences other parameters such as yields that depend on carbohydrates. The effect of resting on yield can, therefore, be termed as indirect.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

Based on this study, the following conclusions can be made:

1. The amount of total non-structural carbohydrates significantly depends on the pruning time and the number of lungs. October-pruning results in the highest TNC as compared to other pruning times. Most TNC are in the roots and leaves, while stems have the lowest.

2. The concentration of carbohydrates is initially high before pruning and sharply declines immediately after pruning and peaks up again to non-significant levels.

3. October-pruning and 8 lungs results in the shortest regrowth period.

4. The effects of pruning time and number of lungs on yields, diebacks and emerging buds depend on the pruning cycle.

5. Although October-pruning resulted in the highest yields, the problem is that regrowth occurs into a dry period, which may end up stressing most tea plants.

6. Resting increases TNC at pruning time, but that TNC declines and increases again post-pruning, as plants re-grow.

7. Resting decreases the regrowth period and its effects on incidence of diebacks after pruning depends on the pruning cycle.

8. Long restting periods increase cumulative yields, although not significantly. However, the benefits of resting do not follow a fixed pattern. This is because resting has indirect or carry-over effects through TNC, regrowth, diebacks and emerging buds.

9. There is a significant relationship between total non-structural carbohydrates and either regrowth period, diebacks, or yields. Root total non-structural carbohydrates are more correlated with yields than are other total non-structural carbohydrates.

The following recommendations can be made based on the findings of the two experiments:

1. Lung-pruning (4 to 8) should be done at any pruning time, because it improves the carbohydrate status, regrowth period, and yield of tea plants.

2. Tea bushes should be rested for 45 to 90 days before pruning, because it improves their general performance and yields.

3. Although pruning in October mostly realized the highest carbohydrates and yields, the pruned plants regrow into a dry season and may experience drought stress. However, it is recommended if water stress can be mitigated.

4. Since resting mostly improved the carbohydrate content and yields of pruned tea bushes, an economic analysis should be done to provide an insight on whether its benefits over-ride those of the foregone yields.

5. Further investigation should be conducted to assess treatment effects on radiation levels and correlation with carbohydrate accumulation.

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