

This book is written for undergraduate students who follow the subjects related to the Agronomy and Physiology of latex production of the Rubber tree (*Hevea brasiliensis*). In this book, author compiled valuable information collected through an extensive literature review and findings of her research related to the girth at opening on growth and yield of *Hevea*. Therefore the book will serve as a valuable source of information not only to undergraduates but also to postgraduate and professional research workers in the field of agriculture.



HKLK Gunasekera

# Latex Physiology and Exploitation of Rubber Tree (*Hevea brasiliensis*)

Special reference to the Estimation of Gas exchange  
Parameters and Photosynthetic Capacity of *Hevea*

Author of this book is Dr. (Mrs.) H. K. L. K. Gunasekera, Senior Lecturer at the Department of Agricultural and Plantation Engineering, Faculty of Engineering Technology, The Open University of Sri Lanka.



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brasiliensis*)**

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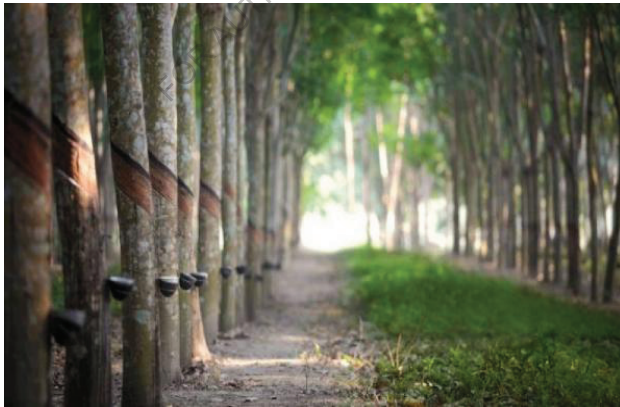
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# **Latex Physiology and Exploitation of Rubber Tree (*Hevea brasiliensis* Muell. Arg.)**

**By**

**Dr(Mrs). HKLK Gunasekera**



## Preface

This book is written for undergraduate students who follow the subjects related to the Agronomy and Physiology of latex production of the Rubber tree (*Hevea brasiliensis*).

The book offers comprehensive knowledge on Anatomy, physiology, latex yield determining parameters, canopy photosynthetic estimation and related gas exchange parameters concerning the exploitation of *Hevea*. In addition to that, this book has brought information on the possibility of exploiting rubber trees at a relatively early growth stage than recommended while minimizing the immature period and injury to the plant.

In this book, author compiled valuable information collected through an extensive literature review and findings of her research related to the girth at opening on growth and yield of *Hevea*. Therefore, the book will serve as a valuable source of information not only to undergraduates but also to postgraduate and professional research workers in the field of agriculture.

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## CHAPTER ONE

### INTRODUCTION

*“Rubber has become very much a part of life of the modern man. The world now rides on rubber, walks on rubber, lands on rubber, sits on rubber and sleeps on rubber”*

Rubber (*Hevea brasiliensis* Muell. Arg.) is a latex producing species belonging to the Euphorbiaceae family that originated from the Amazonian rain forest (Wycherley, 1992). It was introduced to the tropical Asia in 1876 through Kew Gardens. Sri Lanka was the first Asian country to acquire a stock of rubber planting material. Hence, Sri Lanka has a unique place in the history of the world's natural rubber industry. However, out of 95 per cent of the world rubber requirement provided by the South East Asian countries, the island's contribution is now only two per cent (Tillekeratne and Yogaratnam, 2000).

*Hevea* latex found in the latex vessels of the plant is harvested from the main trunk by systematic tapping. Tapping is an important agronomic practice determining the productivity of both rubber plantations and smallholdings (Wimalaratna, 1973).

Natural rubber is biosynthesized initiating from the end product of the photosynthetic process of the rubber tree. Latex is synthesized in the latex vessels found in the phloem tissue of the rubber tree (Tupy, 1985). The supply of sucrose, the end product of photosynthesis to the latex vessels is an important factor determining the latex metabolism and rubber yield. The total sugar content and starch level of

latex are considered as two important physiological parameters determining the rubber yield and the energy reserves of the tree. To harvest the potential yield of a rubber plant, it is important to make good use of its bark and also programme the harvesting process of latex over the whole economic life cycle in a systematic way.

Rubber tree is regarded as tappable with continuous excision method once it attains a girth of 50 cm, measured at a height of 120 cm from the highest point of the bud union. The tapping technique adopted should be capable of giving the highest biologically possible yields for the longest possible period of time (Peiris and Fernando, 1983).

Tapping is a critical agronomic practice determining the sustainable supply of natural rubber to the industry. The actual rubber yield in each tapping depends on the clone, age of the tree, the tapping system, stimulation and the depth, slope and length of tapping cut (Lee and Tan, 1979). The main yield determining parameters of a rubber tree is the initial flow rate, length of tapping cut, plugging index and dry rubber content. These main components are also influenced by some anatomical, physiological and environmental sub-components (Sethuraj, 1981).

Introducing high yielding genotypes is a major way of improving productivity of rubber lands. The clone indicates the plant's genetic constitution and determines its inherent ability to grow and produce latex within the environment provided. Hence, with the same effort of management a higher performance is always obtained from a genetically improved clone than from a genetically inferior clone (Attanayaka, 1998).

Even though, high yielding clones are introduced to the industry, to realize their full yield potential, it is important that both clones and recommended agronomic practices are correctly adopted. Amongst the different agronomic practices, tapping is an important factor governing productivity.

There is no single tapping system that will give the best performance on all cultivars under all conditions. The best tapping system has been defined as one which gives the highest yields at the lowest tapping cost with the best growth and bark renewal and the lowest rate of bark diseases (Peiris and Fernando, 1983). In Sri Lanka, the widely adapted exploitation system for the currently recommended clones is  $1\frac{1}{2}S$  d/2 tapping. Anyhow, this system results in a higher tapper requirement.

Rubber industry is currently experiencing a shortage of skilled tappers. Therefore, survival of the industry is being threatened by the scarcity of skilled tappers. Hence, the potential yield from the  $1\frac{1}{2}S$  d/2 system of tapping is not harvested in the majority of plantations and smallholdings due to vacant blocks and unskilled tappers. Use of unskilled tappers to overcome tapper shortage results in both immediate and long term crop losses (Nugawela, 1998).

In low rubber price and high wage scenarios, the yield per tapper is of greater importance than the yield per unit land area. Hence, tapping systems which give a higher yield per unit of labour are of considerable economic importance under such situations (Nayagam et al., 1993). Tapping cost is the largest single cost item in the cost of production at plantation and smallholder levels (Wesgarth and Narayan, 1964).

Use of yield stimulants for conservation of bark and reduction in labor inputs and costs is looked into by all rubber growing countries. Since the use of yield stimulants increases yield, it is seen as an ideal way to reduce labor costs as the tree needs to be tapped less regularly, reducing the tapper requirement (Gomez, 1983). One of the major outcomes of these efforts is the practice of low intensity tapping later referred to as low frequency of tapping (Vijayakumar et al., 1990). In low frequency tapping systems, judicious yield stimulation could be employed to enhance productivity and reduce labor input (Sivakumaran and Hashim, 1985; Gohet et al., 1991; Zarin et al., 1991). The low frequency tapping systems are more economical and help reduce the requirement of tappers. In countries like Malaysia, low frequency tapping coupled with higher task size has led to a marked reduction in tapper requirement whilst decreasing the cost of tapping (Vijayakumar et al., 2000).

The long immature phase of the rubber tree is considered as one of the major constraints when compared with other cash crops. It is a serious disadvantage especially to the resource-poor farmer. The period between planting and opening for tapping generally varies from 5 to 7 years. During this gestation period costs accumulate without any returns. Hence, it is important to look at all possible methods to reduce this unproductive period by early opening of trees for tapping with no reductions in the long term yields. Girth forms the best and the most practicable criterion to determine tappability (Girst and Menz, 1995). If rubber trees can be tapped at lower girths than practiced currently, it will enable the grower to earn an income earlier while reducing the immature cost.

Previous studies show that, commencing tapping at a lower girth results in relatively lesser yields. Nevertheless, in these trials trees of different girths were selected simultaneously from a clearing. Therefore, relatively lesser yields in lower girth trees may have been due to differences in growth vigour of planting material used. Generally, the dry rubber yield (grams per tree per tapping) increases with increase in girth class within a clone. Trees that reach a higher girth class later, yield less than trees reaching the same girth earlier (Anon., 1999). Therefore, attempts are now being made to define an age and a minimum girth for the commencement of tapping of modern *Hevea brasiliensis* clones.

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# CHAPTER ONE

## ANATOMY AND PHYSIOLOGY OF LATICIFERS OF RUBBER (*Hevea brasiliensis*)

The *Hevea* tree is exploited commercially for its latex by a systematic excision of the external tissues of the trunk, i.e. the bark. The latex vessels are articulated branched type, interconnected laterally to form a network structure and arranged in definite concentric rings in the bark (Thomas et al., 2002). Within each ring, they are vertically and laterally connected, resulting in a continuous network. Vessels run at an angle of  $2.5 - 7^\circ$  to the vertical in a counter-clockwise direction in most cultivars. The internal diameter of the latex vessels varies within the same tree and also differs between trees of a clone (Gomez et al., 1972). However, as a rough approximation, one may take  $30\text{ }\mu\text{m}$  as a typical value for the internal diameter of a productive vessel (Southorn, 1969).

The number of latex vessel rings in a plant is a clonal characteristic, but it is also influenced by the rate of growth of the tree, i.e. slow growing clones with large number of latex vessel rings and fast growing clones with a small number of rings (Sanderson and Sutcliffe, 1929). A ten year old tree of a modern *Hevea brasiliensis* clone would have about 30 latex vessel rings at a height of 150 cm from the union on virgin bark and something like 15 latex vessels per millimeter in each of the rings. A half spiral cut reaching up to 1 mm of the cambium would sever about 60% of the total latex vessels (Gomez, 1983).

When considering the spatial organization of the laticiferous tissue in the bark of *Hevea*, two zones can be distinguished, i.e. the inner soft bark and outer hard bark. The laticifers are found mostly in the inner soft bark (Riches and Gooding, 1952). Laticifers are the specialized cells which contain latex. These tubular structures are usually non lignified and thin walled (Gomez, 1982).

Latex vessels in the soft bark are functionally active while those in the hard bark are less active or shriveled (Boblioff, 1923). Due to the rhythmic activity of the cambium, the new latex vessel rings produced are pushed progressively and become non-functional leading to variation in the number of rings according to season (Thomas et al., 2002).

Normally tapping is commenced once the trees reach maturity, which is normally about 5 to 7 years after planting. At this age a tree would reach a girth of 50 cm at a height of 120 cm from the bud union. Tapping involves the periodic cutting of the bark on the trunk, and hence severing latex vessels. It is best done at a 25 – 30° angle to the horizontal, from high left of the tree to low right, exposing the maximum number of latex vessels per length of incision (Vijayakumar et al., 2000). The most active latex vessels are near the vascular cambium. Towards the outside they are old, disorganized and inactive. But vessels in the 1 mm adjacent to the vascular cambium (about 40% of the total active latex vessels) cannot be tapped for fear of injury to the cambium (Nugawela, 2001). During tapping, a thin layer of bark consisting of the entire hard bark and a major part of the soft bark is removed. The immediate effect of tapping is shrinkage of the outermost cells on the wounded surface of bark which undergoes necrosis (Panikkar, 1974).

### **Physiology of latex production**

Physiologically, the production of rubber in latex is determined by two constraining factors, i.e. latex flow after tapping and latex regeneration between two tappings. The dry rubber yield of a rubber plant is determined by the type of clone, plant age, season of the year and local agroclimatic conditions (Kekwick, 1989). The important physiological requirements of a rubber tree with regard to high productivity are a high net assimilation rate and a high ratio of partitioning of assimilates into latex biosynthesis (Templeton, 1969).

The rate of latex production in the latex vessels of *Hevea* has been related to the supply of sucrose from the adjacent sieve tubes of the phloem tissue. This suggests that economic yield of this crop may be closely linked to photosynthetic capacity, the primary source of sucrose. This possible link has promoted examination of the potential of selecting higher yielding clones by screening for higher photosynthetic capacity (Nugawele et al., 1995).

The potential dry rubber yield of a clone depends on the girth, number of latex vessel rings and plugging index. High yielding clones generally have a low plugging index and an efficient latex regeneration system with partitioning of assimilates more favorable for latex production (Jacob et al., 1989). Therefore, any high yielding tree must have the ability for a high rate of girthing so as to produce a large trunk. Rate of girth increment on commencement of tapping is generally less in clones of higher productivity, indicating that rubber biosynthesis and growth processes compete with

each other. Biosynthesis of rubber is a high energy consuming process which could lead to depression of growth after tapping (Bonner, 1967; Chau, 1967).

### **Physiology of latex flow**

Latex is a specialized form of cytoplasm containing a suspension of rubber and non-rubber particles in an aqueous serum (Archer et al., 1969). Latex vessels are filled with viscous latex under hydrostatic pressure usually between 10 -15 atmospheres in the early hours of the day.

Turgor pressure is regarded as the main driving force behind latex flow (Jacob et al., 1986). Immediately after tapping, the pressure of vessels is exposed to atmospheric pressure and hence latex flows out. Water will enter the latex vessels to compensate for the losses and the latex thus gets diluted (Southorn, 1969). This dilution reaction makes the latex less viscous resulting in an enhanced flow rate. The flow rate of latex after tapping is gradually decreased due to lowering of turgour pressure within latex vessels and finally the flow ceases (Nair, 2000). The complete cessation of latex flow after tapping is due to the formation of a plug in the cut vessels (Southorn, 1969).

### **Yield components in *Hevea***

The yield of rubber from a tree on tapping is determined by the volume of latex and the percentage of rubber it contains. Sethuraj (1981) derived the following relationship of yield with its main components as,

$$Y = F \cdot I \cdot (\text{DRC}) / P$$

Where,

$$Y = \text{latex yield (rubber tree)}^{-1} \text{ tap}^{-1}$$

$$F = \text{latex flow rate per cm of tapping cut during the first five minutes after tapping (i.e. initial flow rate)}$$

$$I = \text{length of tapping cut (cm)}$$

$$P = \text{the plugging index, which is a measure of the extent of latex vessel plugging (Milford et al., 1969).}$$

$$\text{DRC} = \text{the dry rubber content (\% by weight)}$$

These main components are also influenced by a complex combination of anatomical, physiological, biochemical and environmental parameters.

### 1) Plugging Index

The plugging index is a measure of the rate of plugging of latex vessels and is therefore a measure of the time over which latex will flow after commencement of tapping. The plugging index is determined by using the following formula, as described by Milford et al. (1969),

$$\text{Plugging index} = \frac{\text{Mean flow rate (ml min}^{-1}\text{) during the first five minutes after tapping}}{\text{Total latex volume (ml)}} \times 100$$

When a rubber tree is tapped, the flow begins to decline soon after tapping and ceases completely after some time when all the vessels are plugged. The rapidity of

plug formation is an important physiological and clonal characteristic. Hence, it is genetically determined. In a clone where plugging is rapid, the rate of latex flow declines sharply and stops completely in a relatively shorter period after tapping. In clones where plug formation is slower the latex flow rate decreases very gradually resulting in a prolonged latex flow (Waidyanatha and Pathiratne, 1971).

Clonal variation in plugging index has been well established (Milford et al., 1969; Paardekoooper and Somosorn, 1969; Saraswathy Amma and Sethuraj, 1975). Though a strong clonal character, plugging index is easily influenced by environmental factors, especially soil moisture content (Milford et al., 1969; Saraswathy Amma and Sethuraj, 1975;). It is negatively correlated with yield and incidence of dryness (*brown bast*) and positively correlated with girth and dry rubber content of latex. It also determines the clonal response to a particular tapping system. In clones with a higher dry rubber content and hence a higher viscosity, flow of latex is slower resulting in more rapid plugging and consequently a greater response to stimulation (Gomez, 1983).

Sub-components influencing the rate of plugging are stability of rubber and lutoid particles, flocculation potential of lutoid serum, dilution reaction after tapping, drainage area, whole tree water relations and mineral composition of latex (Sethuraj, 1992).

## **2) Initial flow rate**

Initial flow rate is influenced by the number of latex vessel rings actually cut, diameter and other anatomical characteristics of latex vessels and the turgor pressure at the time of tapping (Sethuraj, 1992). The influence of initial flow rate on yield has been established although its relative importance as a factor determining yield is less than that of the plugging index (Sethuraj et al., 1974; Yeang and Paranjothy, 1982).

Seasonal variation in initial flow rate, which is also related to variation in yield in different clones, has been reported by Saraswathy Amma and Sethuraj (1975). Though the correlation is not as strong with the plugging index, the initial flow rate is positively correlated with the total yield. For a given clone and exploitation system, latex yield from a tapping depends on initial flow rate and the duration of latex flow (Rao et al., 1990).

## **3) Dry rubber content**

The quantity of rubber present in latex is expressed as the dry rubber content of latex (DRC). The amount of dry rubber in grams present in 100 g of latex is its dry rubber content. Latex DRC usually ranges from 28 to 45%. Factors influencing the dry rubber content are rate of biosynthesis of rubber and intensity of exploitation (Sethuraj, 1992).



Plate 1. Collecting latex after tapping

The rubber content of latex, at each time the tree is tapped is determined basically by the period elapsed after the previous tapping as well as the inherent regeneration capacity of the laticiferous cells. The rubber content tends to be lower in clones with low plugging because more latex is lost every time the tree is tapped. Rubber content is a factor determining yield. Anyhow, the differences encountered in rubber content are much smaller than the differences in the volume of latex obtained on tapping. A negative correlation between yield and dry rubber content has been established (Paardekooper and Sookmark, 1969). This indicates that the high yielding character of a clone is a consequence of low plugging. The DRC of latex tends to become higher during the lowest yielding months. A higher DRC and a total solid content are observed with longer intervals between two tapplings (Ng et al., 1969).

#### **4) Length of the tapping cut**

Length of tapping cut is determined by the girth of the tree for a given system of tapping (Peiris and Fernando, 1983). Length of the cut is related to the initial flow rate of latex (Sethuraj, 1981). When length of tapping cut increases, a large area of bark is

exposed. This results in increasing the drainage area (Gomez, 1982) and consequently a higher initial flow rate which is positively correlated to the yield.

Length of the tapping cut is highly variable among and within clones (Paardekooper et al., 1975; Sethuraj, 1981). As the length of cut is a component of yield, optimal growth of the tree should be ensured to achieve high and sustained yields. Sub components influencing the length of cut are average annual biomass increment and partitioning of photosynthetic assimilates between growth and latex production (Sethuraj, 1992). For a given system of tapping, girth of a tree determines the length of cut. Clonal differences for yield are also due to different lengths of cut (Frey-Wyssling, 1933).

High yielding trees have larger drainage areas which in turn will result in a lower response to increase in length of tapping cut. Variation in yield due to different lengths of cut also varies with season (Vijayakumar et al., 2000).

### **Exploitation of rubber**

Exploitation of *Hevea* tree for latex is through controlled wounding and excision of the external tissues of trunk bark, a process known as tapping (Gomez, 1982). The aim of tapping is to cut open the latex vessels and the rubber yield depends on the number of functional latex vessels that were cut open (Templeton, 1969) and on the total number of latex vessels of the tree.

Trees are normally tapped once every two or three days. The tapping cut is usually in the form of a spiral and the length of a cut is predominantly a half spiral. The same cut is opened by the removal of a thin shaving of bark at each tapping. The main target during tapping is to get as much latex as possible from the tree with the thinnest excision of bark (Maclaren, 1913).



Plate 2. Exploitation (Tapping)

Tapping is a very important aspect determining the productivity of rubber plantations. Tapping should be commenced at dawn for better yield because the latex flow is highest during the early hours of the morning (Gomez, 1983).

The best yield can be obtained by tapping as close as possible to the cambium but without injuring these delicate cells. High yield coupled with smooth and even

renewal of tapping panels are good indications of correct depth of tapping. Yield is not enhanced further with the increase in thickness of the bark shaving (De Jonge and Warriar, 1965).

Latex production of the tree depends upon the total annual biomass increment, the partitioning ratio (harvest index) and the efficiency at which dry weight is converted to rubber (Simmond, 1982). However, the loss in biomass in a tapped tree, compared to that of an untapped tree, may vary almost seven times between clones for comparable rubber yield (Templeton, 1969). The harvest index in most agricultural crops is a function of genetically determined factors. For rubber, harvest index can be altered at will, by changing the exploitation system or by using yield stimulants. However, a tree may be trained by regular tapping for continuous rubber regeneration leading to a high cumulative yield. Therefore, a suitable tapping system should be adopted depending on clone and tapper availability (Abraham and Tayler, 1967).

### **Evaluation of tapping systems**

The ancient method of latex harvesting was by random wounding of trees. This was followed by various incision methods. These methods usually damage the vascular cambium and much of the latex flows off the incision at various points and hence latex gets wasted.

The development of modern methods of tapping followed the invention of excision tapping in 1889 by Ridley. He showed that the rubber tree can be continuously exploited by shaving the bark at regular intervals without damaging the cambium. Notation of tapping was introduced by Guest (1939). Tapping systems

differ in length of the tapping cut, frequency of tapping and number of cuts. Length of tapping cut is an important factor determining the yield. In the standard system of tapping the length of cut is a half spiral.

The results of Dutch scientists (De Jonge, 1919; Mass, 1925; Bobilioff, 1923) who carried out many tapping experiments and studies on anatomy and physiology of *Hevea brasiliensis* helped to formulate tapping systems on a scientific and rational basis. Thus, modern systems slowly evolved from the early tapping systems largely by reducing the number of cuts and the frequency of tapping.

There is no particular tapping system which is best suited for all clones under all conditions. They are clone-specific and have been devised to harvest the highest possible yields, i.e. economic yields during the entire tapping cycle. For most clones the half spiral alternate day system of tapping, i.e. 100% intensity, is found to be satisfactory from the commencement of tapping (Peiris and Fernando, 1983; Nugawela, 2001).

Frequency of tapping has a profound effect on the physiology and yield response of trees. Higher frequency will affect the physiological balance between latex extraction and its regeneration, whereas lower frequency would affect yield response. Generally, low frequency systems result in high yield per tapping. An inverse relationship between frequency of tapping and yield per tap was reported for a given length of tapping cut (Ng et al., 1969).

The low frequency systems of tapping with stimulation could be widely adopted by the industry, since they can markedly reduce labour requirement and substantially reduce the cost of tapping through enhanced tapper productivity.

### **Stimulation of latex flow**

Stimulation of latex flow is principally an exogenous process to increase the yield above that, which is normally obtained by tapping a rubber tree. Stimulation introduces flexibility into tapping as labour use in this labour intensive activity may be reduced. This is possible by reducing the labour to compensate for yield increases to get similar yields with less frequent tapping. Greater relative responses to yield stimulants are obtained from trees with high plugging indices (Southorn and Gomez, 1970).

Highest yielding trees would bring the greatest return from stimulation (Gomez, 1983). Stimulants are known to delay plugging of latex vessels and prolong latex flow. It was found that most yield stimulants release ethylene gas which causes large increases in yield. Recently gaseous methods of yield stimulation like HLE (Guha et al., 1992), RRIMFLOW, REACTORRIM (RRIM, 1993) are being looked into. Drying and wounding of bark are serious limitations for commercial adoption of such recent stimulation methods.

Ethrel is an effective yield stimulant for rubber and when used judiciously helps increase latex yields substantially. Its active ingredient is 2 –

chloroethylphosphonic acid. The experience in Sri Lanka has been that, although very high yield increases are obtained with Ethrel in the first year of stimulation, the yield tends to decline in subsequent years with continued stimulation over long periods (Anon, 1999). Indiscriminate use of Ethrel over long periods will produce ill effects such as tapping panel dryness and would also result in uneconomic yield responses. However, if stimulation is used under controlled conditions, economic yield increases can be sustained.

### **Mode of action of stimulants**

All effective yield stimulants increase the period of latex flow after tapping and the volume of latex collected. Generally, they all act by inhibiting the plugging of latex vessel and by extending latex flow time (Abraham et al., 1968; Gomez, 1983).

The action of stimulants also increases the turgor pressure in latex vessels. Hence high yield through stimulation is by increased rates of latex flow by increases in turgor pressure and prolonged flow of latex by delaying plugging. The application of yield stimulants primarily results in increased yields, with two or three fold increases during the first few tappings following stimulation (Sethuraj, 1992). The increase in yield is largely as a result of increased flow time, with flow extended for several hours more than that of an un-stimulated tree (Gunasekera et al., 2005). The increase in flow time induced by stimulation is a consequence of two effects of the stimulant, namely the ability to delay plugging and also the extension of drainage area in the tapping panel (Southorn, 1969; Pakianathan, 1971).

Girth increment is negatively affected by stimulation (Abraham et al., 1975). However, extent of girth depression is largely influenced by age of trees and intensity of tapping in stimulated trees.

The incidence of dryness in stimulated trees is generally higher than that of un-stimulated trees. The extent of dryness during the initial years of stimulation is low but shows an increasing trend on continuous use of stimulation (Sivakumaran et al., 1981).

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## CHAPTER THREE

### EFFECTS OF OPENING GIRTH ON YIELD AND SOME LATEX PHYSIOLOGICAL PARAMETERS GOVERNING YIELD OF HEVEA

The physiology of *Hevea brasiliensis* is unique. Biosynthesis of latex, the economically important product of the plant, is confined to the latex vessels which exclusively occur in the phloem tissue. Biosynthesis of latex takes place within the latex vessels of the plant using sucrose, i.e. end product of photosynthesis, as the substrate (Tupy, 1985). The volume of latex biosynthesized by a plant depends on the number, diameter and anatomical characters of the latex vessel system and some related physiological and biochemical factors. Latex is obtained from the tree by cutting the latex vessels through systematic wounding using a specialized tapping knife. The capacity of latex vessels to synthesize and regenerate latex drained during each tapping is critical with regard to latex yield and is accomplished within the interval between two successive tappings (Nair, 2000).

The physiological aspects that govern the balance between growth and yield are another thrust area of research in rubber. The productivity of a rubber tree is largely determined by genetic and edaphic factors. These genetic differences are expressed through differences in the structure and volume of latex vessels (Gomez, 1983).

Latex flow involves a series of physiological changes occurring in the drainage area of the cut. Since latex production is closely correlated with the rate of partitioning of assimilates, water balance and nutritional status of the tree, from a broad point of view, the physiological changes associated with latex flow affects the entire tree (Wenxian, 1985).

The latex yield is primarily controlled by factors that influence latex production and latex flow. Genetic, environmental and physiological factors are known to influence these two components that determine latex yield (Jacob et al., 1989).

The yield determining factors of a rubber tree are identified as, i.e. initial flow rate, plugging index, dry rubber content and length of tapping cut (Sethuraj, 1981). The length of the tapping cut and the tree girth at commencement of tapping are highly variable among and within clones (Paardekooper and Samosorn, 1969; Sethuraj and George, 1980).

Previous findings regarding the variability and correlation of these factors with yield reveals that plugging index and total yield are highly correlated among clones. Further, the yield differences between trees of the same clone are mainly due to differences in initial flow rate. Plugging index is related to many other clonal characters. It is negatively correlated with yield and incidence of dryness and positively correlated with girth, dry rubber content of latex and the magnitude of response to yield stimulation (Waidyanatha and Pathiratne, 1971).

Among the factors determining the yield of *Hevea* are inherent latex biosynthesis capacity of the bark and the girth of the trunk, the latter influencing the length of the tapping cut and the number of laticifers exploited by the tapping cut. Therefore, an important character of any high yielding clone will be the capacity for a sustained, high rate of girthing during the early years of tapping in order to produce a large trunk and thus ensure a high potential yield during the entire economic life span of the tree (Gooding, 1952). Even if yield per unit length of tapping cut is high, a poor rate of girthing will greatly reduce the potential productivity of a tree. Hence, a high net assimilation rate for growth and a high partitioning rate of assimilate into latex for yield; as opposed to vegetative growth are both physiological requirements of a high yielding tree (Templeton, 1968). During the initial years of tapping, a good balance between annual girth and yield has to be maintained (Templeton, 1969), so that the primary biomass production is least affected (Raghavendra, 1991). This will sustain the physiological functioning of the tree. The girth at opening is of significance in this context and a lower girth is an indication of slower growth and maturity (Obouayeba et al., 2000).

It is commonly believed that commencement of tapping when *Hevea* trees are too young significantly retards the subsequent growth of the tree. Moreover, it is known to lead to a low yield during the entire tapping cycle of a tree as the girth of the tree is positively correlated with yield (Vijayakumar et al., 2000). During the juvenile phase of a rubber tree, i.e. up to 4-5 years, food produced by the plant is used primarily for biomass production. Commencement of tapping during this phase may

lead to physiological and mechanical problems due to partitioning of assimilates towards latex production (Sonquhan et al., 1990).

### **Possibility of exploiting *Hevea brasiliensis* for latex at a younger age**

The yield of *Hevea* is directly related to the girth of the tree (Narayanan and Ho, 1973; Narayanan et al., 1974). Consequently yield is higher when the girth at opening is greater. This is primarily because of the longer tapping cut as observed by Gomez (1983). Gohet et al. (1991) reported that productivity of high yielding clones can be further enhanced by judicious stimulation under d/3 frequency of tapping.

According to Ng et al. (1969), frequency of tapping has a profound effect on the physiology and yield response of rubber trees. A higher frequency of tapping would affect the physiological balance between latex extraction and its regeneration; where as a lower frequency would not affect the yield response.

The yield per tree per tapping (g/t/t) is mainly determined by the yield components such as initial flow rate, plugging index, dry rubber yield and length of tapping cut (Sethuraj, 1981).

Milford et al. (1969) had reported that the plugging index was relatively constant within a clone. An analysis of variance of the data of the present study also showed that the trees of a given clone varied more in initial flow rate than in plugging index. A clone with a low plugging index is expected to give a higher latex yield (Peiris, 1983) and PI can also be reduced by the application of yield stimulants (Boatman, 1966).

It is clear that stimulants delay the plugging of latex vessels and prolong the latex flow resulting in a higher dry rubber yield. Therefore, yield increases through stimulation were mainly due to increases in latex volume and reduction in PI. Milford et al. (1969) and Ho et al. (1973) showed that a clone with a high PI on 1/2S d/2 tapping will respond better to stimulation than one with a low PI. It has been reported that the relative importance of initial flow rate as a factor determining the yield is less than that of PI (Sethuraj et al., 1974; Yeang and Paranjothy, 1982).

Besides clonal characteristics, age of the tree also influenced the DRC in their latticifers (Lee and Ismail, 1982). The DRC was relatively low in stimulated trees than in non stimulated trees as reported by Paadekooper (1989).

In order to interpret the variation in yield, it is necessary to understand the inter-relationships that exist between yield and yield components. Especially in G<sub>40</sub> trees during the first year, the most important factor influencing the yield was latex volume with the other factors being of secondary importance (Gunasekera et al., 2007).

### **Correlation between opening girth and yield parameters**

Overall correlation analysis clearly showed that the initial flow rate was positively correlated with the total yield. Similarly the plugging index and DRC were negatively correlated with yield (Table 3.9).

In agreement with the previous findings regarding the variability of these factors, the correlation between IFR and total yield was particularly high within clones while the correlation between PI and yield was higher between clones. Yield

differences between trees of the same clone were mainly caused by differences in IFR, while differences between clones were mainly associated with differences in flow time. There is a highly significant positive correlation between PI and DRC irrespective of the tapping systems and opening girths (Gunasekera et al, 2007). In agreement with these findings, Milford et al. (1969) also found that PI was highly correlated with DRC. This suggests that a higher DRC, therefore a higher latex viscosity, causes an earlier plugging of the latex vessels. Milford et al. (1969), offer a different explanation, which says that other than latex characteristics, a bottom-fraction mechanism could determine the degree of plugging which in turn would influence the latex DRC. With low index clones, drainage would be more exhaustive and a lower DRC equilibrium would be attained in the tree. Results of the present study support this hypothesis.

However, in the second year, PI versus IFR had a significant positive correlation. During the first year, in  $G_{40}$  (trees opened at the girth of 40cm) and  $G_{45}$  (trees opened at the girth of 45cm ) trees, IFR was mainly determined by the number of latex vessels and size of the latex vessels and not by the DRC. This could have been responsible for the absence of a significant correlation between DRC and IFR. But, in the second year, with age the number of latex vessels and size of the vessels increase. Hence, restriction for IFR may be reduced resulting in a significant positive correlation between DRC and IFR. Similarly  $G_{50}$  trees (higher girth trees) have more latex vessel rings and a greater size of the latex vessels.

Furthermore, during the study period, initial flow rate showed a significant positive correlation with latex volume irrespective of opening girths. Therefore, latex volume may be determined by the IFR. Yield versus IFR also had a significant positive correlation for all opening girths. This reveals that, when the IFR increases, the latex volume also increases and finally it increases the yield.

This study clearly showed that the DRC, PI and IFR vary according to year of tapping, tapping system and opening girth. At the immature phase (lower girth trees) physiological functions may not occur properly. Therefore, lower girth trees ( during the first year of tapping) were probably not mature enough to show normal latex flow relationships (Gunasekera et al., 2005).

## CHAPTER FOUR

### EFFECT OF OPENING GIRTH ON YIELD OF RUBBER

Trunk girth is an important growth parameter that is studied in experiments with rubber due to its significant correlation with the latex yield (Narayanan and Chai Yee, 1970). Girth has been used extensively as a parameter in growth and yield estimation of tree crops, its relationship to yield providing a means of assessing the future yield potentials. In rubber cultivations, girth and the rate of girth increment have been identified as important parameters of growth, especially during the juvenile period. The long immature phase of the rubber tree is a primary concern to the rubber grower and is considered as one of the major constraints, when compared with other cash crops (Sakhibun et al., 1986).

Girth is the only criterion used currently to decide on the opening of trees for tapping. Since girth is a simple measure of tree growth and its correlation with the above ground biomass of the tree is highly significant, it is used in growth analysis of young *Hevea* trees as well (Chaudhuri et al., 1995).

There is an antagonism between the biomass production through vegetative growth of *Hevea* and exploitation of the tree for latex by tapping (Wycherley, 1976; Sethuraj, 1981). Thus, there is a possibility of higher initial yield, leading to lower vegetative growth and hence to poor future yield potentials and reduced long-term

productivity levels (Templeton, 1969). The *Hevea* tree has been known to accumulate rubber within the tree up to a limit beyond which partitioning of assimilates would be in favour of vegetative growth rather than towards biosynthesis of rubber as indicated by the better growth of untapped trees. Exploitation is known to retard drastically, the girthing of the tree and biomass production (Dijkman, 1951; Templeton, 1969). It is known that exploitation of the tree by tapping affects its vigour. The annual biomass increment in a tapped tree is substantially less than that of an untapped tree. On the other hand, tapping removes the latex from the tree and in doing so enhances the breakdown of carbohydrates to generate more rubber at the expense of growth as evidenced by the lower girthing rate following tapping (Dijkman, 1951; Wycherley, 1976). Therefore, to obtain sustained high yields over a number of years, it is necessary to maintain a satisfactory rate of growth in trees under tapping.

Simmonds (1982) has suggested that the energy required for rubber production might be much more than that contained in rubber itself. The biomass production decreased while the harvest index (ratio of dry rubber yield to the dry matter of tree) increased with increasing intensity of tapping. The concept of harvest index therefore might be a very useful character not only for comparison of clones, but also to measure sensitivity of a given clone to exploitation and other environmental factors (Gomez et al., 1989).

Apart from the tapping system, the rate of girthing is influenced by yield stimulation as well. The tree girth is one of the factors determining yield, both directly

through length of the tapping cut and indirectly through the size of the tree and its competitive position in the stand (Wycherley, 1974).

Girth is highly correlated with bark thickness and to a lesser extent with the number of latex vessel rings (Huat, 1981). A tree with a thicker bark will generally have more latex vessel rings and hence thickness of bark greatly influences the yield (Gomez, 1979). Sethuraj (1980) and Gomez (1982) established positive correlations of girth with bark thickness, number of latex vessel rings and yield. It is possible that a drop in yield and growth to take place due to age.

In order to strike a balance between the conflicting phenomena of growth and productivity, an optimum girth at opening for each clone should be established (Obouayeba et al., 2002). The girth at opening is directly related to yield potential with trees opened at lower girth showing lower yield potential. If trees are opened too young or too late the yield obtained will not be economical. Therefore, attempts are now being made to define an age and a minimum girth for the commencement of tapping of modern *Hevea brasiliensis* clones. More recently, a girth of 45 -50 cm at 150 cm above the union for budded plants were used in different rubber growing countries as criteria for selecting trees for commencement of tapping (Paardekooper, 1989; Obouaveba et al., 2000; Vijayakumar et al., 2000). Nevertheless, some are of the view that opening budded plants early, i.e. 45 cm at 150 cm from union reduces the immature period and also improves the economic returns to the growers (Ng et al., 1972).

Genetic improvements made for both yield and growth vigour has paved the way for trees to reach tappable girth in 4-5 years. However, it is feared that commencing of tapping when trees are ca. 4 years of age could lead to high incidence of Tapping Panel Dryness (TPD), wind damage and poor long term yields (Obouayeba et al., 2000).

Girth has been used extensively as a parameter in growth and yield estimation of tree crops (Narayanan and Ho, 1970). Reduction of the immaturity period and maintaining a good growth rate after tapping are desirable objectives for physiological research in rubber (Sethuraj, 1985). In this study, growth in terms of girthing after commencement of tapping was monitored in relation to girth at opening and exploitation systems.

Reports by La Rue (1920) and Frey-Wyssling (1930) indicated that in a normally growing rubber tree, there exists an equilibrium between nutrients, growth and rubber formation in the latex. This equilibrium is affected by extraction of the rubber latex when the trees are tapped. The imbalance is indicated first by an alteration of the composition of the latex extracted, secondly by changes in the latex of the whole tree and thirdly by a growth retardation of the tree.

Studies of Gunasekera et. al (2005) reveals that the girth at opening was directly related to growth after commencement of tapping with the trees opened at lower girth showing lower growth rates.

### **Girth at opening and Clonal differences on Yield**

Clonal differences are also evident with regard to the depression of girth due to commencement of tapping. Further, it is reported that the clones with high plugging index tend to have a better post- tapping girth increment. High yielding trees must have the capacity for a higher rate of girthing so as to produce a large trunk thus ensuring high potential yield. It has been established that, tapping and yield stimulation result in an increase in respiratory activity of the bark (Sethuraj et al., 1974). Besides, the direct effects of wounding and extraction of latex tapping may also lead to higher metabolic activities. The higher respiration rates and increased metabolic activity were also probably responsible for the reduction of girth increment in the tapped treatments of the present study. According to previous findings, an increase in circumference (girth) causes an increase in the number of latex vessel cylinders in the bark. Within a clone, the number of latex vessels generally depends on the thickness of the bark. Clonal differences in yield are also attributed to different lengths of cut (Frey-Wyssling, 1933). Accordingly, results obtained in this study showed that the yield is higher when the girth at opening is greater due to longer tapping cut. A similar observation was made by Southern and Gomez (1970), on comparing cuts of different lengths. It was found that with decreasing length of cut, the plugging index was higher, probably because the drainage area was smaller and leading to lower yield. According to previous findings, for a given system of tapping, girth of a tree determines the length of the cut and high yielding trees have larger drainage areas which in turn will result in a lower response to increase in length of tapping cut. Furthermore, it has been observed that variation in yield due to different lengths of tapping cut also varies with season.

## CHAPTER FIVE

### VARIATION IN YIELD AND YIELD DETERMINING PARAMETERS WITH THE YEAR OF TAPPING (AGE)

*Hevea brasiliensis* is a deciduous tree exhibiting rhythmic seasonal growth characteristics which are reflected in the morphology, structure and function of the plant. Seasonal activity of the tree cambium is governed to a great extent by climatic factors (Cutter, 1978; Kramer and Kozlowski, 1979). The rubber tree defoliates in December to February and refoliates after 2 – 3 weeks. Growth (girdling) is higher during the monsoon (June to September) season. The high latex yielding period is October to December (Sethuraj et al., 1989; Chandrashekar et al., 1998). Seasonal activity of the plant is reflected in the cambium and bark anatomical features. Activity of the cambium may be reflected in the girth of the plant (Thomas et al., 2002).

In *Hevea*, a large proportion of growth occurs during the monsoon and the growth rate declines substantially during the dry period (Chandrashekar et al., 2002). According to Rao et al. (1996) and Rao and Rajput (2001) the variation in starch accumulation in the tree trunk depends on the seasonal activity of cambium and primary growth. Disappearance of starch from the trunk during refoliation has been noted in *Hevea* (Sivakumaran and Pakianathan, 1983).

Yield of rubber per unit land area per year is determined by the average yield per tree per tapping (influenced by seasonal variation and system of tapping), the

number of trees per unit land area and the number of tappings per year. The annual increment in yield has to be ascribed basically to changes in the four major components of yield, i.e. initial flow rate, plugging index, dry rubber content and length of the tapping cut. Yield increment can only be partly influenced by girth increment. According to Sethuraj et al.(1974), annual increase in yield is clearly related to increased assimilate partitioning (harvest index). This can be related only to changes in either initial flow rate or plugging index with successive years of tapping.

Further, it is evident that annual yield or yield increment from a unit area of land is also influenced by factors related to the clone, age of plant (girth), agronomic practices, planting density, exploitation system and climatic conditions. The extent of realization of the yield potential of a clone is regulated by these extraneous factors. The annual average yield per tap will also depend on the frequency of tapping (Abraham and Hashim, 1983).

Being a perennial crop, the yield potential of a rubber tree exhibits seasonal variation as well as year to year variation. Seasonal variation of latex yield has been studied for several commercial clones in Malaysia (Lee and Tan, 1979). Accordingly, four seasonal quarters of the yield cycle have been identified. In a given clone tapped on a particular system, yield drops below average during February to July. At the beginning of the yield declining period, rubber trees shed their leaves. Hence, February, March and April are termed as 'wintering' months with a steady drop in yield. The next period, the 'post wintering' starts from May and extends to the end of July with an increase in yield. August, September and October are termed as 'high

yielding' months, followed by the 'peak yielding' period extending from November to end of January. A different yield cycle was identified in India by Licy et al. (1992), where peak yielding period was taken as September to December and the yield during the period of February to May as the summer yield. However, little information is available on seasonal variation in rubber yield under Sri Lankan conditions (Gunaseera et al., 2005).

It is well known that there is a seasonal variation in plugging index. Saraswathy Amma and Sethuraj (1975) have shown that the extent of seasonal variation in plugging index varies from clone to clone. In wet districts of Sri Lanka, Waidyanatha and Pathiratne (1971) found that plugging is highest after wintering (defoliation) and it declined gradually until the onset of the next wintering. Month to month variation in plugging indices revealed seasonal effects. Paardakooper and Samosorn (1969) found that there was a gradual decline in plugging index from May to December and in December it was only half that in May.

### **Seasonal variation on yield and yield determining parameters**

#### **Within-year variation in yield (g/t/t)**

Since *Hevea* is a tropical deciduous tree, latex yield varies over the year. Rubber yield is influenced by the effect of different environmental parameters on the components of yield. A distinct clonal variation is also observed in this regard (Sethuraj, 1992). According to Premakumari et al. (1996), latex yield is directly related to the total number of latex vessel rows. With age, the number of latex vessel cylinders in the bark increases.

It is evident that the latex yield in *Hevea* is sensitive to seasonal variations. According to Jacob et al. (1989), turgor pressure is regarded as the main driving force behind latex flow. It is sensitive to environmental factors, especially the soil moisture status. Ambient temperature and relative humidity are the important climatic factors involved in maintaining the water potential gradient for water flow in the soil- plant-atmosphere continuum. Therefore, within-year variations of these factors are expected to affect the turgor pressure and ultimately the latex yield.

During the wintering months, there is little photosynthesis due to low rainfall, high temperature and also due to immature leaves may probably caused the low yield. After wintering, favorable environmental conditions together with more mature leaves results in higher yields. Premakumari (1992) observed that a fall in rubber biosynthesis in *Hevea* during defoliation is probably related to the reduction in available photosynthates. Further latex formation is extremely low during the period of refoiliation (Dijkman, 1951; Chua, 1970; Yeang and Paranjothy, 1982) probably due to low starch availability.

#### **Within-year variation in Plugging Index (PI)**

Simulation delays plug formation and thereby allowed increased removal of latex. Moreover, the delaying of plug formation following stimulation would increase the drainage area for latex, which could also contribute to the yield increase due to stimulation.

Seasonal variation in yield has been ascribed to variation in both initial flow rate and plugging index (Milford et al., 1969; Paardekooper and Somosorn, 1969; Saraswathyamma and Seturaj, 1975). It is reported that the widest fluctuations are in plugging index which can be considered the most sensitive yield component affected by environmental factors.

Month to month variation of plugging indices reveals seasonal effects. This feature may be considered as a clonal characteristic as different clones show different patterns of variation in yield during the year and that has been reflected in the corresponding variation in plugging index (Milford et al., 1969; Paardekooper and Somosorn, 1969; Saraswathyamma and Seturaj, 1975). Low yield in dry months was associated with high plugging as reported earlier.

#### **Within-year variation in Dry Rubber Content (DRC)**

The yield output of the rubber tree varies the years and also within a year. This may be due to the fact that the yield depends upon the values of initial flow rate, plugging index and dry rubber content which varies with age and during different times of the year. According to Sethuraj (1992), the environmental situations leading to lower flow rate and higher plugging will reduce the yield.

## CHAPTER SIX

### **PHOTOSYNTHETIC CAPACITY OF HEVEA WITH REFERENCE TO EXPLOITATION**

Photosynthesis is the major physiological process leading to dry matter production of plants. Crop dry matter accumulation is the integration over time of gross photosynthesis less respiratory losses. About 90% of the dry weight of higher plants is derived from the CO<sub>2</sub> assimilated by photosynthesis (Zelitch, 1982).

The CO<sub>2</sub> assimilation rates per unit leaf area, with respect to age, typically increases after leaf emergence reaching maximum at about the time of full expansion and then declines with the onset of senescence (Catsky and Ticha, 1980; and Jarvis and Sandford, 1986).

The rubber tree canopy synthesizes carbohydrates through photosynthesis and the genetic make up of the tree determines the partitioning of carbohydrates to the growth of tree, its metabolic activities and latex production. Latex is a product of the metabolism of the rubber plant. The rate of latex flow after tapping is closely correlated with the physiological status of the leaves. The number of leaves or assimilating area influences the rate and amount of dry matter production. The rate of latex production in the latex vessels of *Hevea* has been related to the supply of sucrose from the adjacent sieve tubes (Gomez, 1983).

This suggests that a close link exists between the CO<sub>2</sub> assimilation capacity and the economically important component of the rubber tree (Nugawela, 1989). Exploitation is known to retard drastically girdling of the tree and its biomass production (Dijkman, 1951; Templeton, 1969). This effect shows that there is significant assimilate partitioning towards latex production by the plant. The annual biomass increment in a tapped tree is substantially less than that of an untapped tree. Continuous extraction of latex by tapping also results in continuous production of latex by the plant and hence this retards the growth of tree (Templeton, 1969). Clonal variations are also reported in this regard. The physiological reasons for biomass loss of a tapped tree, which is not accounted for in the rubber yield, have not been elucidated. Enhanced respiratory activity triggered by tapping could be one of the causes. When a tree is tapped, a part of latex thus synthesized is extracted. It is believed that the loss of latex by tapping triggers its re-synthesis (George et al., 1984).

### **Canopy photosynthesis**

Canopy photosynthesis is governed not only by the photosynthetic process itself, but also by the canopy architecture. Thus canopy photosynthesis is a closely related determinant of productivity as it takes into account the genotypic variation in both light conversion and interception efficiencies.

Canopy characters that improve light interception and photosynthetic efficiency are discussed by Beadle et al., (1985). Photon flux density at different levels in a canopy is often the major factor determining the rate of CO<sub>2</sub> assimilation of individual leaves (Nobel and Long, 1985).

The photosynthetic characters of leaves at different canopy positions are acclimatized to their own micro-environment. The major differences in photosynthetic activity in sun and shade adapted leaves within a canopy are correlated with differences in the concentration of the electron transport chain, photosystem activity and photosynthetic enzyme activity (Beadle et al., 1985). Therefore, it appears that canopy photosynthesis is naturally optimized by partitioning of photosynthetic capacity among the leaves with respect to natural light exposure. Thus gas exchange characters of a leaf from a particular canopy position cannot be considered necessarily to represent the photosynthetic characters of the entire canopy. Hence, estimating canopy photosynthesis has become an important aspect of plant productivity research (Monsi et al., 1973; Beadle et al., 1985).

However for tree crops, a model that describes light attenuation within the canopy and the use of light response curves for leaves at different canopy positions to determine the CO<sub>2</sub> assimilation potential may be the only practicable alternative to estimating canopy photosynthesis. Studies on canopy photosynthesis and yield have shown a clear positive correlation between them (Zelitch, 1982).

Canopy photosynthesis differs with variation in the rate of leaf dark respiration, leaf conductance to CO<sub>2</sub> transfer and light utilization efficiency (Hozumi, et al., 1972) with increasing depth in the canopy.

Thus, understanding the physiological and biological processes involved in canopy photosynthesis could help increase crop yield (Monsi et al., 1973).

### **Light response of photosynthesis**

Photosynthesis is mainly governed by the radiation supplies within the wave band range of 400 to 700 nm, termed Photosynthetically Active Radiation (PAR). The amount of light quanta absorbed by a unit leaf surface area is a primary determinant of its rate of photosynthesis.

The response of photosynthesis to radiation can be characterized by the three parameters,

- I. Light-saturated rate of  $\text{CO}_2$  uptake, i.e.  $A_{\max}$
- II. Light-limited rates of  $\text{CO}_2$  uptake, termed the maximum quantum yield, i.e.  $Q$
- III. Transition from the initial linear region to the upper asymptotic region, characterized by the convexity of the light response curve.

$A_{\max}$  reflects the maximum capacity for  $\text{CO}_2$  assimilation, when radiation is not limiting and is determined by the upper asymptotic section of the light response curve. Quantum yield reflects the maximum efficiency of utilization of captured photons in the photosynthetic reduction of  $\text{CO}_2$ , while the convexity is important for the  $\text{CO}_2$  assimilation at intermediate levels of radiation.

At leaf level, the light response of photosynthesis is curvilinear, whilst at the crop level canopy photosynthesis operates at an almost constant photosynthetic efficiency for intercepted radiation (Monteith, 1994). In the natural environment, radiation loads change continuously and leaves at different levels within the plant canopy receive different proportions of incoming radiation. Convexity depends on the

light absorption characteristics of leaves and photosynthetic properties of the chloroplast.

Most gas exchange studies have been concerned with light-saturated rates of CO<sub>2</sub> assimilation, perhaps because in most C<sub>3</sub> crops CO<sub>2</sub> assimilation rate is saturated by light levels well below full sunlight. In the field situation and particularly in canopies with a large leaf area index (LAI), many leaves may experience light-limiting conditions, since even in full sunlight some leaves (especially those in the middle and bottom canopy layers) will be shaded by others. The significance of this may be seen in measurements of CO<sub>2</sub> assimilation by whole stands. Unlike single leaves, stands of plants show a much longer phase in which CO<sub>2</sub> assimilation responds linearly to increases in PAR. There is now much evidence that CO<sub>2</sub> assimilation by mature crop canopies is determined more by quantum yield than by the light saturated assimilation rate (Long, 1985).

#### **Relationship between photosynthetic light response parameters and yield of rubber**

Light saturated rate of photosynthesis ( $A_{\max}$ ), varies with the position of leaves in the canopy, which could be attributed to adaptations to changes in incident irradiance (Acock et al., 1978). Fraction of intercepted radiation depends on two major parameters, the leaf area index (LAI) and the canopy light extinction coefficient ( $k$ ) (Nobel and Long, 1985).

Light saturation point (LSP) determines how efficiently a crop canopy utilizes its intercepted radiation. Hence, the magnitude of  $A_{\max}$  and LSP plays a very important role in determining crop productivity. There is significant variation in  $A_{\max}$  between genotypes within almost all species. As photosynthesis is the major source of crop biomass, it can be hypothesized that selection for higher  $A_{\max}$  would lead to greater canopy photosynthesis resulting in higher yielding genotypes (Evans, 1993).

Knowledge of the potential yield of a crop and practical limitations to its realization in the field are essential prerequisites before any decision can be made on the crop's economic viability (Cooper, 1970). The amount of dry matter produced by a plant is mainly determined by the amount light intercepted, the conversion efficiency of intercepted light and the rate of loss of dry matter produced (Kramer, 1986; Beadle et al., 1985 and Nelson, 1988). These could be estimated by measuring the physiological yield determinants, i.e. total leaf area,  $\text{CO}_2$  assimilation rate and dark respiration rate respectively. The total dry matter produced and the harvest index, i.e. the amount of dry matter partitioned towards the economically important part, governs the economic yield of a crop. In many crops, the majority of the leaves are under limiting light (Ort and Baker, 1988) and leaves get adapted to the environmental conditions under which they develop (Syversten, 1984).

In a mature *Hevea* plantation, most of the leaves are found under limiting light levels (Nugawela et al., 1995). The physiological yield determinants may be different in areas receiving full and limiting light levels in the canopy. Thus, the capacity for dry

matter production by leaves in the light limiting areas of the canopy will have a significant influence on the economic yield of the crop.

The observation made by Nataraja and Jacob (1999) suggested that rubber clones with the highest net assimilation rate and quantum yield of net CO<sub>2</sub> uptake under low irradiance together with a low light compensation point (LCP) for CO<sub>2</sub> uptake, might tolerate shade better than other clones.

In terms of increasing productivity, a lower LCP is definitely helpful, because a lower LCP will enable the plant to maintain a positive net photosynthetic rate even at very low light intensities. A lower LCP would help crop canopies to maintain a positive carbon balance and thereby continue to accumulate dry matter even under very low absorbed radiation (De Costa, 2000).

### **Predicting the daily gross photosynthetic integral**

#### **Estimation of canopy photosynthesis**

The daily gross photosynthetic rates at different canopy layers, i.e. top, middle and bottom, were estimated using the Charles-Edwards (1982) equation,

$$\Delta F + \Delta R = \frac{\phi s A_{\max} h [1 - \exp(-kL)]}{\phi k s + h A_{\max}}$$

where,

$$\Delta F = \text{daily net photosynthetic integral}$$

|                  |   |                                                                                                        |
|------------------|---|--------------------------------------------------------------------------------------------------------|
| $\Delta R$       | = | daily respiratory integral                                                                             |
| $\phi$           | = | photochemical efficiency - $\mu \text{ mol CO}_2 (\mu \text{ mol PAR}^{-1})$                           |
| $s$              | = | daily light integral - $\mu \text{ mol PAR m}^{-2} \text{ d}^{-1}$                                     |
| $A_{\text{max}}$ | = | light saturated $\text{CO}_2$ assimilation rate - $\mu \text{ mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ |
| $h$              | = | day length - $\text{s d}^{-1}$                                                                         |
| $k$              | = | canopy extinction coefficient                                                                          |
| $L$              | = | leaf area index                                                                                        |

The day length ( $h$ ) and the daily light integral ( $s$ ) were taken as 10 hours, i.e.  $10 \text{ h} \times 60 \times 60 \text{ s d}^{-1} = 36000 \text{ s d}^{-1}$  and  $20 \text{ MJ m}^{-2} \text{ d}^{-1}$ , i.e.  $40 \times 10^6 \mu \text{ mol PAR m}^{-2} \text{ d}^{-1}$  (Nugawela, 1989).

### **Genotypic differences in light response parameters**

#### **Light-saturated maximum photosynthesis ( $A_{\text{max}}$ )**

There were significant genotypic differences in parameters of the light response curves of in different canopy strata (Fig. 6.1). The light saturated assimilation rate ( $A_{\text{max}}$ ) may be considered as a measure of the photosynthetic capacity of the leaf (Long and Hallgren, 1985). The results obtained from this study showed a clear reduction of  $A_{\text{max}}$  from leaves in the upper strata through middle strata to the bottom of the canopy in both clones (Tables 6.1 and 6.2). This indicates that photosynthetic capacity decreased with increasing canopy depth. In each canopy stratum, leaves adapt to the level of light generally prevalent at that stratum. It is well known that leaves developed in high light have more photosynthetic apparatus per unit leaf area (Kwesigo et al., 1986; Wolf and Blaser, 1971) and *vice versa*.

The magnitude of  $A_{\max}$  and light saturation point (LSP) play a very important role in determining crop productivity (De Costa, 2000). *Hevea* is a  $C_3$  plant and therefore light saturation may occur even at 40% of the incident light. However, when leaves develop under low light levels, they get adapted to use the available light efficiently. Such adaptations have been reported by Syvertsen (1984).

According to Dey and Vijayakumar (2002), low irradiance is important for photosynthesis in *Hevea*, since most of the leaves in the mature canopy are exposed to low light. In field-grown conditions, crop canopies hardly become light saturated (Monteith, 1981; Hay and Walker, 1989). Hence, low LCP will enable the plant to maintain a positive net photosynthetic rate even at very low light intensities and increase the productivity (De Costa, 2000).

It is well known that the dark respiratory rates give an estimation of dry matter loss from the plant. Hence, it is an important factor determining the productivity of plants (Chazdon and Fetcher, 1984). It is reported that lower dark respiratory rates associated with high yields are due to a decrease in maintenance respiration (Gifford, et al., 1984).

The canopy photosynthetic rates measured under optimal environmental conditions varied with clone and tapping (Gunasekera et. al., 2007). Mature plants of perennial crops such as tea, rubber and coconut are continuously harvested and a high sink demand is prevalent throughout. The present cultivars of these crops have been selected for higher harvest indices. Thus, in these crops differences in canopy photosynthesis would be expected to influence the yield capacity (Nugawela, 1989). It is well known that the light interception efficiency of a canopy is governed by the

total leaf area and its distribution within the canopy. Canopy photosynthesis is governed not only by the photosynthetic process itself, but also by the canopy structure. Thus it is a closely related determinant of productivity as it takes into account the genotypic variation in both conversion efficiency and interception efficiency. Zelitch (1982), has shown a very close correlation between canopy photosynthetic rate and yield for several crops.

According to Sethuraj (1992), in an untapped tree, biosynthesis of rubber is almost nil in the laticifers of the trunk and there is no translocation of latex. Tapping induces an abnormal physiology by removal of latex. Laticiferous system in the drainage area is then triggered for the re-synthesis of lost latex through photosynthetic stimulation.

## CHAPTER SEVEN

### VARIATION OF LEAF GAS EXCHANGE PARAMETERS WITHIN THE CANOPY OF HEVEA

Light has long been recognized as an essential factor in photosynthesis, which provides the biochemical energy and carbon necessary for growth. The light gathering system consists mainly of an aerial array of leaves, with the light trapping effectiveness depending mainly on plant and environmental factors (Norman and Arkebauer, 1991).

The variation of leaf photosynthetic characteristics with depth in the canopy is an important factor to consider in the prediction of canopy photosynthesis. The sum of the collective effect of all leaves must be obtained to predict the canopy light use.

*Hevea brasiliensis* can be considered as an ideal crop for testing the relation of photosynthetic characteristics to yield, since a close link exists between the economic yield, i.e. latex and sucrose supply (Nugawela, 1989).

Previous studies have shown that gas exchange rates of leaves do not significantly vary within a leaf whorl of a rubber tree (Rodrigo, 1997). Furthermore, ability for rubber leaves to photosynthesize in low light is important, since the majority of leaves in a mature stand of rubber are under such conditions.

## **Response of gas exchange parameters to light**

### **1) Stomatal conductance ( $g_s$ )**

Differences in photosynthetic rates between leaves could be due to differences in stomatal conductance to  $\text{CO}_2$ , the photosynthetic apparatus or both. Improved efficiency or an increase in the amount of the photosynthetic apparatus in a leaf should be linked with a proportionate increase in stomatal conductance to realize the maximum gain of  $\text{CO}_2$  assimilation rate from such change (Nugawela, 1989).

Stomata are located at a strategic point in the  $\text{CO}_2$  and water vapour exchange pathway between the leaf canopy and the surrounding atmosphere. Stomata have the ability to respond to variations in both the external microclimate and the internal leaf cellular environment. Therefore, variation in stomatal conductance, i.e. the degree of stomatal opening, influences both photosynthesis, i.e. transfer of  $\text{CO}_2$  from air to leaf and transpiration, i.e. transfer of  $\text{H}_2\text{O}$  from leaf to air (De Costa, 2000).

Stomata tend to open with increasing light intensity ( $I$ ), thus increasing  $g_s$ . The relationship between  $g_s$  and  $I$  is asymptotic. The exact light intensity at which  $g_s$  reaches a maximum varies from crop species to species (Morrison and Jarvis, 1983).

One of the reasons for stomata to open with increasing light intensity is the increasing rate of photosynthesis which reduces the intercellular  $\text{CO}_2$  concentration. Therefore, stomata have to increase their aperture, i.e. increased  $g_s$ , in order to maintain an adequate flow of  $\text{CO}_2$  for photosynthesis to occur. However, it has been found that stomata have a direct light response which is independent of photosynthesis as well (De Costa, 2000).

## **2) Intercellular CO<sub>2</sub> concentration (C<sub>i</sub>)**

Intercellular CO<sub>2</sub> concentration is the CO<sub>2</sub> concentration within the sub stomatal chamber and the intercellular air spaces in the leaf mesophyll. Hence, C<sub>i</sub> which indicates the availability of CO<sub>2</sub> inside the leaf mesophyll is an important determinant of the rate of photosynthesis (De Costa, 2000).

Stomatal conductance and photosynthesis vary in a way which would maintain a nearly constant C<sub>i</sub> under changing environmental conditions. In most plant species, as light intensity increases, CO<sub>2</sub> assimilation and g<sub>s</sub> increases and C<sub>i</sub> decreases (Raschke, 1975). It has been shown that C<sub>i</sub> has to vary from genotype to genotype within a species for a genotypic variation in carbon isotope discrimination and instantaneous transpiration efficiency to occur (Farquhar et al., 1982).

## **3) Leaf temperature (T<sub>leaf</sub>)**

Two of the most important factors controlling photosynthetic carbon gain in plants are light and temperature (Forseth and Norman, 1993). The decrease in CO<sub>2</sub> assimilation rate due to high temperature appears to be due to a direct effect of it on photosynthetic apparatus rather than to an indirect effect of large leaf to air water vapour concentration difference and stomatal conductance (Roessler and Monso, 1985). Experiments conducted by Schulze et al. (1974), showed that stomata opened with an increase in leaf temperature under constant evaporation conditions and also promoted stomatal closure. The decrease in g<sub>s</sub> at high leaf temperature may partly be due to

partially irreversible thermal damage to guard cells or reduced capacity for photosynthesis in mesophyll cells.

#### **4) Transpiration rate (E)**

All organisms interact with their physical environment through energy exchange processes. For plants, these energy exchange processes are central to determining leaf temperatures, rates of photosynthetic carbon gain and rates of water loss. Virtually all carbon fixed in photosynthesis and the water lost in transpiration must pass through the stomata. Thus, regulation of stomatal opening by the plant determines the balance between carbon gain and water loss (Monteith, 1965). Increased transpiratory water loss induced by high light, could decrease the leaf water potential. However, no relationship has been found between the short term variations in leaf water potential and CO<sub>2</sub> assimilation rate (Kuppers et al., 1986).

#### **5) Water use efficiency (WUE)**

The use of water by plants is strongly influenced by the evaporative demand of the atmosphere. Even under similar environmental conditions, water use efficiency, i.e. the number of moles of water lost per mole of CO<sub>2</sub> fixed is found to vary between cultivars. This is attributed to the cultivar differences in capacity for CO<sub>2</sub> assimilation and regulation of water loss by the leaves (Kozlowski, 1975). Further, plant dry matter production is dependent on the efficiency of water use by the crop. The WUE

is most appropriately expressed as the water use ratio which is defined as the amount of dry matter produced per unit of water transpired.

## **6) Leaf-air vapour pressure deficit (lvpd)**

Leaf-air vapour pressure difference or vapour pressure deficit (lvpd) is defined as the difference between the water vapour pressure of the ambient air and the saturation vapour pressure at the ambient temperature (De Costa, 2000). It has been shown that lvpd has a direct effect on stomata and that increasing lvpd decreases  $g_s$  (Schulze et al., 1972; Schulze, 1986). This direct effect is believed to be mediated through the gains and losses of water in the epidermal cells. Magnitude of the decrease of  $g_s$  with increasing lvpd varies with the genotype, ambient temperature, water availability and ambient CO<sub>2</sub> concentration (De Costa, 2000). Fanjul and Jones (1982) have shown that the decrease of  $g_s$  in response to increasing vpd is faster than the increase of  $g_s$  with decreasing vpd.

## **Gas exchange measurements**

### **1) CO<sub>2</sub> assimilation rate (A)**

Photosynthetic and transpiration rates can be measured by the LI – 6400 system based on differences in the mole fraction of CO<sub>2</sub> and H<sub>2</sub>O of the outlet (analysis cell) and inlet (reference cell) air streams flowing through the leaf cuvette. The net CO<sub>2</sub> assimilation rate, A ( $\mu\text{mol m}^{-2} \text{s}^{-1}$ ) is given by the formula given below (Von Caemmerer and Farquhar, 1981).

$$A = \{ F ( C_r - C_s ) / 100 S \} - C_s E$$

Where, F, C<sub>r</sub>, C<sub>s</sub>, S and E are respectively molar flow rate of air entering the leaf chamber (μ mol s<sup>-1</sup>), mole fraction of CO<sub>2</sub> in the inlet of analysis cell (μ mol CO<sub>2</sub> mol<sup>-1</sup> air), mole fraction of CO<sub>2</sub> in the outlet of analysis cell leaf area (cm<sup>2</sup>) and transpiration (mol H<sub>2</sub>O m<sup>-2</sup> s<sup>-1</sup>).

## 2) Transpiration rate (E)

The equation that the LI – 6400 uses for computing transpiration rate (E) is,

$$E = \frac{F (w_s - w_r)}{100 S (1000 - w_s)}$$

where,

F = flow rate (μmol s<sup>-1</sup>)

w<sub>s</sub> & w<sub>r</sub> = sample and reference water mole fractions  
(mmol H<sub>2</sub>O mol<sup>-1</sup> air)

S = leaf area (cm<sup>2</sup>)

### 3) Stomatal conductance ( $g_s$ )

The equation that the LI – 6400 uses to compute stomatal conductance to water vapour ( $g_{sw}$ ) is,

$$g_{sw} = \frac{1}{1/g_{tw} - k_f/g_{bw}}$$

where,

$$\begin{aligned} g_{bw} &= \text{boundary layer conductance to water vapour (mol H}_2\text{O m}^{-2} \text{ s}^{-1}) \\ &\quad \text{from one side of the leaf} \\ g_{tw} &= \text{total conductance to water vapour (mol H}_2\text{O m}^{-2} \text{ s}^{-1}) \\ k_f &= \text{stomatal ratio} \end{aligned}$$

The stomatal conductance to water vapour (mol H<sub>2</sub>O m<sup>-2</sup> s<sup>-1</sup>) is obtained from the total conductance by removing the contribution from the boundary layer.

### 4) Intercellular CO<sub>2</sub> concentration ( $C_i$ )

The equation that the LI – 6400 uses for computing intercellular CO<sub>2</sub> concentration ( $C_i$ ), (μmol CO<sub>2</sub> mol<sup>-1</sup> air) is,

$$C_i = \frac{(g_{tc} - E/2) C_s - A}{g_{tc} + E/2}$$

where,

$$g_{tc} = \text{total conductance to CO}_2$$

## 5) Water use efficiency (WUE)

The CO<sub>2</sub> and transpiration rates at saturating light levels were used in determining water use efficiency (WUE) as:

$$\text{WUE} = \frac{\text{Photosynthetic rate (A)}}{\text{Transpiration rate (E)}}$$

Genotypic differences in CO<sub>2</sub> assimilation rates in *Hevea* are governed by both stomatal and mesophyll limitations and the higher CO<sub>2</sub> assimilation rates are also associated with relatively higher stomatal conductance (Von Caemmerer and Farquhar, 1984).

The temperature optimum for A in higher plants varies among species and is closely related to the ambient temperature of the growth environment (Ludlow and Wilson, 1971 and Long et al., 1975).

Temperature determines the rates of component biochemical steps of the photosynthetic process through its effects on the kinetics of the reactant molecules and enzymes. In both tropical and temperate environments, within genotypically and environmentally determined limits, higher temperature increases the specific activity of photosynthetic machinery and hence increases the A<sub>max</sub> (De Costa, 2000).

Samsuddin and Impens (1979) compared CO<sub>2</sub> assimilation rates of four *Hevea brasiliensis* clones and concluded that although significant differences in yield potential exist, the CO<sub>2</sub> assimilation rates were comparable. They speculated that

clonal differences in the cumulative carbon production of individual leaves, partitioning of assimilates towards the latex production and canopy architecture were the determinants of yield differences. Subsequent studies have shown significant positive correlations between yields and CO<sub>2</sub> assimilation rates in clones with a higher partitioning of assimilates towards latex production (Samsuddin, 1979).

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## **CHAPTER EIGHT**

### **POSSIBILITY OF COMMENCEMENT OF TAPPING**

#### **EARLIER THAN RECOMMENDED**

One of the serious disadvantages of perennial tree crops appears to be the long immature period with no return to the investment. In rubber, the period between planting and opening for tapping generally extends from five to seven years (Ng et al., 1972). The long immature period of the rubber tree is a disadvantage since it leads to accumulation of capital costs without any returns. Thus, any reduction in the immature period of rubber would bring an early income to the growers. One approach to reduce the uneconomic period is to open the trees for tapping at a smaller girth (Sakhibun et al., 1986).

The girth at which tapping commences is a key element affecting the output from a rubber plantation. Choosing the best girth for commencement of tapping involves a trade-off between growth and commencement of income receipts. According to previous studies, maximum revenue (in present value terms) occurs when tapping commences at a girth of 35 cm, but maximum latex yield occurs when tapping commences at 45 cm (Grist and Menz, 1995).

Recently, recommendations have been made in Malaysia for an earlier opening, i.e. 45 cm instead of 50 cm based on economic considerations, such as advancing the economic returns by a period of about six months. Moreover, even if

initial yields are low, it improves the profitability of estates as cumulative yields over a long period, are higher for earlier opened trees (Ng et al., 1972).

Barlow and Ng (1966) showed that shortening the period of immaturity by six months through the use of advanced planting material increased the estimated present profit per hectare by 10-25% depending on the discount rate used. Shortening the immature period by earlier opening will not have the same effect as opening at a latter growth stage because yields of trees opened at 45 cm are less than for those opened at 50 cm. Nevertheless, under conditions of high prices, earlier opening appears financially attractive (Ng et al., 1972).

### **Economic aspects of tapping**

Tapping is the highest cost item in the cost of production (COP) of natural rubber. It accounts for about 35 to 40% of the total COP and 70% of the workers' time is spent on tapping. In the scenario of low rubber prices and high wages, the yield per tapper is of greater importance than the yield per unit land area. Hence, under such conditions it is economically important to obtain the highest possible yield with as fewer tappings as possible (Nayagam et al., 1993).

Therefore, tapping systems which give high returns without long-term deleterious effects on the trees are of vital importance to the rubber growers. A reduction in tapping cost could be achieved either by increasing the total production of rubber output per unit land area or by increasing the intake of crop per tapper. Higher yields per harvester will contribute to a significant reduction in cost of

production. Improved clones of higher intrinsic yields raise the yield per unit land area as well as per harvester (Wimalaratne, 1973).

It is apparent that in the plantation sector ca. 28.5% of the potential crop is lost each year due to ca. 28% unskilled tappers and 21.5% vacant blocks. This situation leads to low land and tapper productivity whilst escalating cost of production (Nugawela et al., 2000). These tapper-related problems together with situations of poor trading of rubber, erodes the profitability in both plantations and smallholder sectors, threatening the survival of the natural rubber (NR) industry.

Hence, tackling the problem of tapper shortage and maximization of crop extraction to realize better returns per unit area, would require development of exploitation systems that are radically different from existing conventional systems (Abraham et al., 1971).

As shortening of the immature period is believed to be economically more beneficial, studies of Gunasekera et al. (2003) aimed at analyzing the possibility of opening trees at earlier growth stages, i.e. 40 cm ( $G_{40}$ ) and 45 cm ( $G_{45}$ ) than the recommended, i.e. 50 cm ( $G_{50}$ ) with minimum tapping cost, tapper requirement and injury to the plant, in order to bring better economic benefits to the grower.

The harvested yield of *Hevea* trees can be increased to its genetic potentials by appropriate manipulation of agronomic, tapping and stimulation practices. However, very intensive tapping could lead to physiological stress in the tapping panel resulting in development of tapping panel dryness (Do Kim et al., 1996). In such situations, low frequency tapping (LFT) has drawn more and more interest due to many reasons.

Labour savings, improvement of land:man ratio, efficient use of bark and lengthening the economic life of the plantation and hence a smaller depreciation are some of the positive effects of low frequency tapping (LFT).

Barlow (1978) estimated that stimulation without a change in the tapping system, with four rounds of stimulation per year would require a minimum of 200 kg / ha extra yield to secure a worthwhile return. Yee (1983) analyzed yield data from a large number of Malaysian estates, and found that the average difference in yield between stimulated and un-stimulated fields to be 32 % and mean operating profits to be considerably higher in the stimulated fields. Lian and Cheam (1974) showed that maximizing early yields with ethephon stimulation and shortening the exploitation life span would increase the internal rate of return and the benefit / cost ratio of an estate. Therefore, in order to make the ailing rubber industry more viable and profitable, methods of increasing tapper productivity and ways of reducing cost of production and efficient utilization of available labour should be examined (Yogarathanam et al., 2001). According to Obouayeba et al. (2002), early opening results in revenue being earned earlier and it will also bring additional returns to investment.

### **Possibility of exploiting some new *Hevea* clones at a younger age**

The long immature period between planting to opening for tapping is considered as one of the major constraints in rubber industry when compared with other economic crops. Therefore, early opening would result in revenue being earned earlier and bring forth additional returns. But this policy is only justified if it will not adversely affect the subsequent growth and yield of the early-opened trees.

According to previous studies, the normal growth of *Hevea* follows a sigmoid curve. As in all crops this sigmoid curve could be modified by agricultural practices. By and large, it is true that the tree grows rapidly up to a certain period followed by a gradual leveling off. The introduction of tapping causes assimilate partitioning towards latex and a slowing down in growth. However, when considering the long economic life span of the rubber tree, the initial slowing down of growth due to earlier opening may be recovered with time. Therefore, in the context of the whole economic life span, early opening may not cause a significant adverse impact on girthing (Gunasekera et al., 2005).

On the other hand in delayed-opening experiments, the large girth size results in higher yield per tree. However, this happens only for a specified tapping year in the early stages of tapping. In terms of yield per hectare, when planting year is used as the basis of comparison, there is an inverse relationship between annual yield and the size (or delay) at opening for the greater part of the tapping period. This phenomenon may be explained by the fact that the earlier opened trees, which at any tapping year are comparatively younger in age and the girth difference between two stands of trees, planted at the same time but opened at different girths, will be expected to narrow with increasing age (Ng et al., 1972).

In such circumstances, the present study examines the possibility of exploiting some new *Hevea* clones at a younger age without compromising on future yields to enhance the economic benefits to the grower.

### **Influence of girth at opening on growth and yield**

Gunasekera et al. (2005) studied the growth in terms of girthing after commencement of tapping was monitored and results were presented in relation to girth at opening and exploitation systems in different clones.

According to Ng et al. (1972), the actual period of immaturity depends mainly on the growth rate of trees. The growth loss due to tapping varies with clone, age and tapping intensity (Templeton, 1969). In this study as the age and tapping intensity were similar, the variation in girth depression was probably due to clonal differences. Attanayake (2001) indicated that early opening for tapping and achievement of good early yields are only possible with clones having vigorous growth even after tapping. Even though, tapping markedly depresses the girthing of trees, it does not affect the rate at which latex vessels are formed, so that the number of rings increases approximately linearly with age (Gunnery, 1935).

### **Effect of different exploitation systems on yield of early opened trees**

*Hevea* does not accumulate more than a certain amount of rubber in the latex vessels, and draining latex by tapping stimulates the production of more latex to replace it. Thus, a tree can be trained by regular tapping to a continuous process of rubber regeneration leading to high cumulative yield (Wycherley, 1976).

Lian and Cheam (1974) showed that maximizing early yield with ethephon stimulation and shortening the exploitation life would increase the internal rate of return and benefit/cost ratio of an estate. Furthermore, decrease in labour requirements per hectare together with a drop in bark consumption make low

frequency tapping with stimulation economically more profitable than the conventional high frequency tapping, especially if labour is scarce and expensive.

### **Physiological yield determinants responsible for differences in yield due to opening girth or tapping system**

Latex flow of *Hevea* involves a series of physiological processes associated with the entire tree. Since functioning roles of various physiological parameters are complex and some of their interactions are not well understood, the interpretation of their effect as a single factor on yield is not easy. According to Sethuraj (1981), the rubber yield per tree per tapping (g/t/t) is mainly determined by the yield components such as initial flow rate, plugging index, dry rubber content and length of the tapping cut.

Through studies of Gunasekera et al (2005) clearly showed that there are significant clonal differences in the above parameters when tapping commenced at different opening girths. Like many other crops, yield of *Hevea* is also a complex trait. All environmental and management effects on yield must operate through the various components associated with it. Hence, all variations in yield could be an integrated effect of the variation occurring in the yield components.

According to Waidyanatha and Pathiratne (1971), though the PI is a clonal characteristic closely but inversely related to the yield, clones differing considerably in their PI but comparable in yield are not uncommon. Then a clone with the higher PI should obviously be preferred because this may alleviate to some degree the incidence of brown bast and late dripping characteristic of the high yielder without sacrificing the high yield character.

## **Gas exchange and photosynthetic capacity of *Hevea* with reference to exploitation**

Presently new *Hevea* clones are recommended for commercial planting only after monitoring the field performance of the clones for at least 20 years. During this period growth vigour before and during tapping, yield by micro-tapping during immature phase and later by test tapping are looked into. Thus, studies on more fundamental characteristics like net photosynthetic rates could be useful to understand the physiology of the tree and latex production.

According to Templeton (1969), important physiological requirements of a rubber tree with high productivity are high net assimilation rate for growth and high rates of partitioning of assimilates in to rubber. Therefore, any high yielding tree must have the capacity for a high rate of girdling so as to produce a large trunk and thus ensure a high potential yield. According to Latiffe and Travis (1984), clones with a high sink to source ratio exhibited higher rates of photosynthesis than clones with lower sink to source ratio. Furthermore, studies of the light response of canopy gas exchange parameters such as stomatal conductance, water use efficiency, transpiration rate, leaf temperature, intercellular CO<sub>2</sub> concentration and leaf- air vapour pressure deficit, showed a relatively high response in clone with higher canopy photosynthetic rates. Though studies of Samsuddin (1979) indicated that the significant positive correlation between yields and CO<sub>2</sub> assimilation rates in clones with a higher partitioning of assimilates towards latex production. Previous results showed that the maintenance of photosynthetic rate in low light is very important for trees with large canopies like *Hevea*.

### **Physiological basis of latex yield variation in different clones –**

There are significant differences between clones in their photosynthetic characteristics and these differences are correlated with clonal differences in latex yield. Variations in latex yield either due to different girths at opening or tapping systems were controlled by the yield-determining latex parameters such the initial flow rate, plugging index and dry rubber content. There are significant clonal variations in these parameters and these variations have to be taken in to account in devising strategies for yield improvement in different clones. Studies of Gunasekera et al (2005) demonstrated the possibility of exploiting some new *Hevea* clones at a younger age, such knowledge when confirmed and extended could be beneficial not only in the exploitation of *Hevea* but also possibly in its breeding for crop improvement.

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