STUDIES ON THE PHYSIOLOGICAL FACTORS INFLUENCING YIELD
IN
Hevea brasiliensis Muell. Arg.

A Thesis

PRESENTED TO THE FACULTY OF AGRICULTURE
OF THE BANARAS HINDU UNIVERSITY FOR THE DEGREE
OF

DOCTOR OF PHILOSOPHY

By

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Enrolment No. 57309

To

The Registrar,
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Through

The Head,
Department of Plant Physiology,
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Sir,

We are forwarding herewith the Ph. D. Thesis of Shri. M.R. Sethuraj, M.Sc.(Ag.), entitled "Studies on the physiological factors influencing yield in *Hevea brasiliensis* Muell. Arg." for being placed before the next meeting of the Faculty of Agriculture.

Shri. Sethuraj was enrolled for the Ph. D. Degree of this University in January 1973. Since then he has been engaged in this piece of research work.

Shri. Sethuraj has satisfied all the conditions for the supplication of his Thesis.

Yours faithfully,

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PREFACE

Hevea brasiliensis Muell-Arg is the most important source of natural rubber. Future prospects of natural rubber would largely depend on its cost competitiveness. Yield potential of the tree would be the major factor determining the cost of production of rubber and as such, the largest contribution to the efficiency and economic viability of the Hevea tree can be expected from evolution of new high yielding cultivars. *Hevea* clones with yield potential of 3000 kg/ha. per annum have already been evolved. The theoretical maximum potential yield of *Hevea* however is estimated to be in the region of 9000 kg per hectare to 10,000 kg/ha. per annum (Templeton, 1969 b; Swaminathan, 1976).

In India, the average yield per hectare is still below 800 kg. The low average yield is mainly due to the fact that only around 25% of the total area under rubber (2,24,428 hectares) is planted with high yielding budded materials (Indian Rubber Statistics, 1976). The rate of increase in productivity of rubber in India during the last three decades however had been impressive. Taking the triennium ending 1961-62 as base (=100) the rate of increase in productivity per hectare for rubber in 1975-76 was 216.1 compared with 133.9 for plantation crops as a whole and 127.4 for all commodities (Indian Rubber

Statistics, 1976). The average yield per hectare rose from 320 kg/ha. during 1948-49 to 772 kg/ha. during 1975-76. This phenominal increase in productivity was achieved by the introduction of selected clonal seedlings and higher yielding clones.

Despite this creditable achievements, the yield potential of the highest yielding clones is still far below the estimated theoretical maximum. It has been stressed that future yield improvements have to be based on better understanding of the physiological basis of yield potential in rubber tree (Subramaniam, 1974). A physiological analysis of the yield components would be rewarding for a meaningful planning in plant breeding. Judging from coefficients of determination, Kronstad and Foote (1964) suggested that direct selection for yield might be less effective than selection through the yield components. While Boatman (1966), Sethuraj (1968) and Milford <u>et al</u> (1969) have emphasised the influence of the flow restricting process on yield, Templeton (1969) considered partitioning ratio as an important clonal characteristic. The partitioning ratio, ie. the ratio of rubber yield to the total biological yield need not necessarily represent the potential rubber biosynthetic capacity of a clone, as this is a factor which can easily be altered by exploitation methods. The yield from a rubber tree is the result of the abnormal physiology induced by tapping. For the same reason, a comprehensive study of the physiological aspects of rubber production is imperative.

The susceptibility of Hevea tree to climatic variations is reflected in seasonal fluctuations in yield. Elucidation of the influence of environmental factors on yield as well as yield components is necessary to develop methods to circumvent the climatic constraints on production.

Hevea is a summer deciduous plant and the annul leaf fall (wintering) occurs during the early part of the year. The period of lowest yield is associated with the phase of refoliation and flowering. Assuming physiological strain to the tree, many plantations have a practice of giving tapping rest during this period. It has not been elucidated how far the depression in yield is related to this phase as this relationship is complicated by the fact that this period is synchromised by the onset of drought conditions which may have a direct effect on yield. A study on the physiology of yield depression might conceivably give some insight on the proportionate roles the leaf fall and soil drought play in reducing yield during this period.

The present investigations encompass studies on the effect of environmental and internal factors on yield, influence of exploitation methods and the physiological changes during the period of summer defoliation.

In Section I, our present knowledge on the physiological aspects of rubber production is reviewed. This review encompasses all aspects of the physiology of rubber production, as a comprehensive integration of the present knowledge was considered useful to understand the implications of the results obtained from the present study.

Section II presents the results of the studies on the effect of environmental factors on yield. In order to get a comprehensive picture of the direct and indirect effect of different factors, the correlations were partitioned into direct and indirect effects by path coefficient analysis. Relationship between variations in yield and variations in latex flow characteristics was also examined.

The findings of interest include the predominant role of soil temperature and relative humidity on yield. The interrelationship of different environmental factors as well as the direct effect of these factors on yield were brought out by path coefficient analysis. It was revealed that there is clonal variation in the response to soil moisture stress and that the rate of yield increase after the annual tapping rest during wintering is dependant more on the rainfall pattern than on the stage of leaf maturity. It also became evident that the effect of environmental factors on yield is mediated through modulations in the latex flow pattern. It would appear that clonal susceptibility to drought is mediated through differential plugging behaviour. By determining plugging index at varying soil moisture status, it would be possible to select clones for drought proned areas.

Studies on the influence of internal factors influencing yield are presented in Section III. The influence of four major internal factors, namely initial flow rate, plugging index, dry rubber content in latex and biochemical composition of latex, on yield was investigated. The factors which influence initial flow rate, plugging index and dry rubber content were also subjected to investigation. The influence of individual factors on yield as well as the relationship between different internal factors were evaluated by correlation analysis wherever possible. Such a statistical analysis has strengthened the validity of the results. Earlier attempts to study the influence of certain of these internal factors on yield were limited in scope and in the present study a more comprehensive approach has been made. The results have emphasised that the latex flow and the factors influencing it are more important determinants of yield compared to the factors influencing the rubber synthesis. The necessity for distinguishing between cause and consequence of high yield is illustrated in the results obtained on the relationship between RNA content and yield. The finding that clonal variations in yield could to some extent be explained by the variations in the mineral composition of latex fractions has important implications and might stimulate further investigations. The relationship found between drainage area and latex vessel plugging indicate that exploitation methods designed to enlarge drainage area might result in higher yields. This knowledge can profitably be made use of in exploitation techniques to be evolved.

Section IV deals with the effect of exploitation methods on yield. The design of the tapping experiments was such as to study the individual effects of length of the cuts, number of cuts and frequency of tapping. Most of the tapping experiments in the past had not included the objective of understanding the individual effects of these factors. Even in a comprehensive study by Paardekooper (1975) effect of double cuts was not considered. The present studies indicated that tapping efficiency per unit of tapping cut length or tapping intensity decreased by increasing the length of the cut and intensity respectively. It was demonstrated that among systems of the same intensity, double cut systems gave higher yields. There was differential clonal response to lengthening of the tapping cut indicating that development of drainage area for a particular length of cut might differ according to clonal characteristics. The results obtained point out the need to analyse the physiological differences among clones with regard to the tapping systems so that suitable systems for individual clones can be identified on a physiological basis. Seasonal interaction with systems of tapping were also evident in the present study. Another result of interest has been the finding that the harmful effects of higher intensities of tapping can be alleviated by sharing the intensity between two cuts.

In the studies on stimulation, emphasis was given to factors which influence the effectiveness of stimulants. A finding of practical interest was that the declining trend in response to prolonged application of stimulant was notably less when lower concentrations were used. Nevertheless, lower concentrations of Ethrel were as effective as higher concentrations. The results of Ethrel stimulation in clone Gl 1 indicate that atleast certain clones may be adversely affected, as indicated by the higher incidence of brown bast. The results of the present study also revealed seasonal variation in the effectiveness of Ethrel stimulation, the extent of variation being different between clones. It has also been established that methods of applications of Ethrel aimed at enhancing the drainage area resulted in better response. The outstanding effect of multiple band application of Ethrel on yield is suggestive of the possibility of practical adoption of this method of stimulation.

In Section V, the physiological changes during the period of summer defoliation as related to yield depression are described. Clonal variation in the degree of yield depression during the period of summer defoliation was observed. The fall in yield could be explained in terms of an increase in the plugging index. The modulations in plugging index as influenced by summer defoliation was different in different clones and this was the reason for the clonal variations in the degree of yield depression. The results of the present study confirmed that the yield depression during summer defoliation was due to alterations in the lutoid stability. No relation between reduction in yield and biochemical changes in latex could be established. Moreover, the results did not indicate any necessity for tapping rest during this period. Strong evidence was obtained from the present studies that the drop in yield during summer defoliation is more of a result of the drought conditions prevailing during the period rather than of defoliation and refoliation. The studies also indicated that physiological methods aimed at reducing the plugging index or enhancing the water status of the tree would effectively counteract the falling trend in yield during this period.

The major information obtained from an analysis of the results in the five sections are the importance of latex flow, drainage area and water relations of the tree as factors governing yield. Any effort to increase yield should necessarily be based on these factors.

The entire work was conducted during the years 1973-'77 in the Rubber Research Institute of India, Kottayam, Central Experiment Station, Chethackal and in selected estates in Kerala and Tamil Nadu. The author undertakes full responsibility for the experimental part of the work reported herein.

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CONTENTS

SECTION I

PHYSIOLOGY OF RUBBER PRODUCTION: A REVIEW

SECTION II

EFFECT OF ENVIRONMENTAL FACTORS ON YIELD

Results ... ...

Discussion ... ...

SECTION III

STUDIES ON THE INTERNAL FACTORS INFLUENCING LATEX FLOW AND YIELD

Results ... ...

(b) Factors influencing initial flow rate:

Page

(d) Factors influencing plugging index

(f) Factors influencing dry rubber content of latex ... ...

Relationship between biochemical composition of latex and yield ... ...

Discussion ... ...

Effect of latex flow pattern on yield: ...

SECTION IV

STUDIES ON EXPLOITATION METHODS AS FACTORS INFLUENCING YIELD

SECTION V

STUDIES ON YIELD DEPRESSION DURING THE PERIOD OF SUMMER DEFOLIATION.

Discussion

SECTION I

PHYSIOLOGICAL ASPECTS OF RUBBER PRODUCTION: A REVIEW

1. INTRODUCTION

In this review an effort is made to integrate our present knowledge on all physiological aspects of rubber production. Although the main theme of the work is on the factors affecting productivity, attention was given to catalogue the recent advances in more basic fields of latex physiology and latex biochemistry also, besides documenting the available information on the internal and external factors influencing productivity. Although excellent reviews on certain specialised aspects are available, the necessity for a comprehensive treatment of all aspects of physiology of productivity has long been felt. This attempt to integrate such information is justifiable for more than one reason. A sound knowledge of all aspects of the physiological basis of productivity is essential to understand the implications of the results obtained in different experiments. This has also fulfilled atleast to some extent the long felt need to integrate the bits of information that have been accumulating since a similar attempt was made by Dijkman (1951). In the present review emphasis was given to more recent work and literature available till June 1976. Due to the non-availability of many early publications in different foreign languages, this review may not be an all inclusive integration. But care was taken to ensure that such inevitable omission of any particular contribution has not resulted in omission of any important information which would add to our knowledge.

2. STRUCTURE AND COMPOSITION OF LATEX

(1) Structure of Latex vessels

The latex vessels constitute a specialised tissue system composed of tubular cells or cell complexes which contain latex. In *Hevea brasiliensis* the latex vessels almost exclusively occur in the phloem region. The basic knowledge on the latex vessel system of *Hevea brasiliensis* was obtained from the studies of Arisz (1918), Bobilioff (1918, 1923) and subsequently from those of Van Aggelen Bot (1948), de Hann and Van Aggelen Bot (1948) and Schweiser (1949). The latex vessels of *Hevea brasiliensis* have an articulated anastomosing pattern. The vessels of the mature bark are formed by the cambium in a certain sequence and are arranged in concentric circles or rings along the axis of the trunk and branches alternating with parenchyma cells and phloem elements. Radial connections between latex vessel rings occur only very rarely (Gomes, 1975 a). Dijkman (1951) has reviewed the early work on the structural details of the latex vessel system of <u>Hevea brasiliensis</u>.

Further progress in elucidating the structure of latex vessels was slow till the introduction of electron microscopy. Andrews and Dickenson (1961) reported for the first time the ultra-structure of latex vessels, which revealed its structural complexity. It was observed that latex is enclosed within a thin membrane - possibly equivalent to plasma membrane - adpressed to the latex vessel wall. A thin layer of cytoplasm is often present within this membrane. The differential shape, structure and electron density of different particles of latex, like rubber lutoids etc, were clearly distinguishable in the electron micrographs of the vessels. Considerable progress has been made in our knowledge of the ultra structure of latex vessels in recent years through electron microscopic studies on green branches (Archer <u>et al</u>, 1963 a; Dickenson, 1964, 1969) leaf petioles (Southorn, 1966) and mature latex vessels (Dickenson 1965; Gomes, 1974) and the presence of mitochondria, golgi bodies, nucleus, nucleolus, rubber particles, lutoids, Frey-wyssling particles and microfibrils have been detected in latex. Recently Gomes (1975 b) extended these studies in an attempt to correlate the ultra structure of young and mature [illegible] vessels and to relate the ultra structure to the [illegible] of the various organelles in the latex vessel. He has shown that there are differences in the frequency of occurrence of various cellular organelles and their ultra structure in the embryonic, young, mature and senescent vessels.

(2) <u>Structure of latex</u>

Hevea latex is a hydrosol in which the dispersed particles are strongly protected by a complex film made of protein and phospholipid. Verhaar (1959) has reveiwed the colloidal properties of latex. The principal water insoluble component, rubber particles, occurs as discrete particles. *Hevea* latex contains more than one disperse phase. Frey-Wyssling (1929) identified a type of yellow particles microscopically and named 'Frey-Wyssling' particles. The yellow colour of these particles is due to the presence of carotenoids. A further complexity was revealed by Homans and Van gils (1948) when they observed still another particle - irregular shaped transparent islands with an irregular structure - in latex and named these particles 'lutoids', mistakingly abscribing the yellow colour of the bottom fraction to these particles. An alternate name, 'viscoid' was suggested by Verhaar (1952).

The discovery of lutoids gave rise to speculation as to their origin and function. Schweizer (1949) suggested that it originated from sieve tubes. Ruinen and [illegible] (1950) refuted this contention and demonstrated the [illegible] of lutoids in latex vessels. Ruinen (1951) has also provided evidence for the occurrence of such particles in other latices as well.

The size and shape of the rubber particles received much study in the past and contradictory evidences were provided by different workers. Hauser (1930) usihg conventional light microscopy, described rubber particles as ovoid and pear shaped, while Lucas (1938) reported it to be spherical. The limitations in the available techniques stood in the way of a clearer understanding of the structural details of rubber particles till Andrews and Dickenson (1961) employing improved preparative techniques in electron microscopy, could describe the rubber and non-rubber particles in latex. Their studies confirmed that rubber particles are invariably spherical at least in young latices and considered the particles which appear pear shaped as artifacts. They however did not rule out the possibility of the presence of pear-shaped rubber particles in older latices. The rubber particles may be as large as 5-6 microns in diameter or less than 100 A$^{\circ}$. They are strongly protected in suspension by a film of adsorbed protein and phospholipid and visual evidence of such a film may be seen in electron-micrographs of sectional rubber particles (Archer et al, 1963 a).

Separation of latex particles by ultra centrifugation has paved the way for the rapid progress in our knowledge of the complexity of latex. Cook and Sekhar (1953) showed that latex could be separated in the ultra centrifuge into distinct zones. Moir (1959) with improved techniques, staining and temperature control, could separate latex into eleven resolvable zones. Southorn (1961) made a photomicrographic study of these various fractions of latex and observed large and small rubber particles, Frey-wyssling and certain other yellow particles, semi-transparent and solid grey coloured particles and lutoids in the preparations made from various fractions. Probably recognising the fact that the ultra structural features of expelled latex might be incomplete and prone to artifacts, most of the later workers (Dickenson 1964, 1969; Gomez 1974, 1975 b) preferred to use intact latex vessels for electron microscopic studies on latex structure. The observations reported in the most recent studies are summarised below.

In embryonic latex vessels, apart from the prominent nucleus containing a single large nucleolus, normal cellular organelles such as mitochondria, proplastids, golgi bodies, endoplasmic reticulam, lutoids and ribosomes are present. The rubber particles measure 50 to 3000 A^{o} and the number of lutoids is comparatively few. In the young latex vessels of secondary phloem in tender tissues, the most prominent organelles are the osmiophilic rubber particles, which measure approximately 100 to 5000 A^{o}. The diameter of lutoids varies from 1 to 3 μ and are bounded by a unit membrane and contain characteristic protein microfibres. Frey-wyssling complexes and golgi bodies can also be observed occasionally. Extensive studies have already been made on the fibrillar components of young lutoids by Audley (1965) and Audley and Cockbain (1966). These microfibrils have been shown to consist of an acidic protein. Their helical structure has been demonstrated (Gomez, 1975 b). The Frey-wyssling complexes of such young latices contain osmiophilic interior particles and have a well developed double membrane. In mature vessels under tapping, the rubber particles almost fill up the whole vessel although the presence of mitochondria, parietal endoplasmic reticulum, lutoids and Frey-wyssling complexes are common. On centrifugation of this latex and electron microscopical studies of different fractions, the top zone contains large rubber particles ranging in size from 500 to 30000 A^{o}. In the zone just below, rubber particles of smaller size are seen. The lutoids which are relatively electron transparent occasionally contain large numbers of microhelices. Frey-wyssling complexes in tapped latex show typical mature characteristics with large osmiophilic lipid droplets and rope-tubular configurations in a martix. Ribosomes are also occasionally seen in tapped latex but these occur in the bottom fractions of the centrifuged latex.

Composition of latex

From the foregoing discussions, it could be evident that latex is a specialised form of cytoplasm. What flows out on tapping is the fluid fraction of this cytoplasm. The composition of latex collected on tapping is not a true representation of that of the latex inside the latex vessels. Depending upon the physiological variations in flow, the composition of latex collected and that of the latex inside the vessels may vary. Many investigators have not recognised this limitation, while interpreting data obtained from studies on collected latex.

Archer *et al* (1963 a, 1969) have reviewed the work on the composition of latex. Besides rubber and water, the major components of latex include proteins, lipids and carbohydrates and inorganic salts. The presence of small quantities of numerous other components represents the complexity expected in any cytoplasmic material.

1. Carbohydrates:- Quebrachitol (methyl inositol) is the most concentrated single component in the serum phase, amounting to about 1% of the latex. Evidence for the presence of inositol, sucrose, glucose and fructose has been provided by Van Dillen (1922), Auzac and Pujarniscle (1959) and Lowe (1960). Smith (1954) detected the presence of galactose associated with phospholipids. The concentration of sucrose, glucose and fructose in latex is influenced by various factors such as planting material, tapping system and stimulation (Auzac and Pujarniscle, 1961; Chun *et al*, 1969 and Bealing, 1969).

ii. Proteins:- The total protein content of latex is approximately 1% of which, about 20% is adsorbed on the rubber particles and a similar proportion is associated with bottom fraction. The rest of the proteinstogether with the phospholipids provide the colloidal stability to the latex. As early as 1927, three protein fractions were identified in latex (Bishop, 1927). These results were confirmed by Kemp and Staritiff (1940). Subsequently, more protein fractions have been identified using electrophoretic techniques. Roe and Ewart (1942) distinguished serum proteins in the serum of fresh latex. The soluble proteins of bottom fractions have been detected with the aid of paper electrophoresis by Archer (1960) and Moir and Tata (1960). The latter authors obtained different protein patterns for the serum and bottom fraction extracts. Similar results were obtained by Archer and Sekhar (1955). These proteins differed widely in their isoelectric points, and varied from pH 3 to over 9. Karunakaran et al (1961) using starch gel electrophoresis could identify atleast fifteen proteins. They have also demonstrated the presence of at least 8 proteins in the bottom fraction of fresh latex.

The proteins adsorbed on the rubber particles have [illegible] been studied in detail due to experimental difficult[illegible] It has, however, been found that the isoelectric [illegible] of rubber particles in fresh latex varies from about

4 to 4.6 and it has been ascribed to the presence of more than one protein on the rubber particles and it is also thought that the relative proportion of the adsorbed proteins is a clonal characteristic (Bowler, 1953).

The different proteins that have been studied in detail are globulin which is present in the highest concentration in the serum (Archer and Cockbain, 1955; Hahn <u>et al</u>, 1971); Hevin, a crystalline protein present in the bottom fraction (Archer, 1960); Fibrillar proteins obtained from the microfibrils contained in the lutoid particles (Archer <u>et al</u>, 1963 a; Dickenson, 1955; Audley, 1965); and basic proteins (Audley, 1965). Among these proteins, Hevin (Tata, 1975) and Fibrillar proteins (Audley, 1966) have been subjected to further study. A basic protein, Hevamine with strong flocculating effect on suspensions of rubber also has recently been reported (Tata and Yip, 1968; Archer, 1976).

iii. Amino acids:- Presence of amino acids in latex was reported as early as 1925 (Belgrave, 1925). Later work by Whitby <u>et al</u> (1926), McGavack and Rumbold (1934), Altman (1951), Drake (1951), Ng (1961) have contributed to our knowledge about the amino acid composition of latex. While these early work gave only approximate estimations of the quantity of individual amino acids, Chai <u>et al</u> (1969) and [illegible]owska <u>et al</u> (1974) have reported quantitative estimates. [illegible]owska <u>et al</u> (1974) using an advanced technique [illegible]fied 23 known and 7 unknown amino acids in C and B [illegible] of latex.

Careful studies by Yong and Singh (1975) could not confirm the earlier observations (Chai *et al*, 1969; Brozozowska *et al*, 1974) of seasonal and clonal variations in amino acid content of latex.

iv. Miscellaneous nitrogen compounds:- Archer *et al* (1969 a) have reviewed the work of isolation and identification of nucleic acids, nucleotides and other nitrogen bases contained in the latex. They have confirmed the previous report of Mc Mullen (1960 a, 1960 b, 1962) and added the presence of many nucleotides in the list.

v. Other organic substances:- Phospholipids form an important component of bottom fraction particles (Smith, 1954), especially of lutoid membrane (Jacob, 1975) as well as the protective envelope of rubber particles (Van Rossem, 1932; Blackly, 1966; Ho *et al*, 1975; Sentheshanmuganathan *et al*, 1975), Presence of α-tocotrienol (Dunphy *et al*, 1965; Whittle *et al*, 1966; Chou and Draper, 1970). Steroids (Altman, 1946; Heilborn *et al*, 1941; Archer *et al* 1963 a, 1969 a), Carotene (Frey-Wyssling, 1929), Betaines (Altman, 1941; Karunakaran *et al*, 1960; Tan and Audley, 1968), Phenols and other antioxidants (Nadarajah *et al*, 1971) and thiols (Mc Mullen, 1960 a) have also been reported.

vi. Inorganic constituents of latex:- Archer *et al* (1963 a) have furnished data on the normal concentration of mineral constituents in latex.

The relative proportions of different ions, which show both genetical and environmental variations, could influence the colloidal stability of latex. A high Mg/PO_4 ratio is often associated with latices of low stability (Beaufils, 1954). Pushparajah *et al* (1975) have found that a higher potassium content in the latex resulted in enhanced latex flow. On the other hand, infusing of solutions containing calcium or magnesium into the bark was observed to have destabilising effect on latex (Pushparajah, 1966).

vii. Enzymes in latex:- Latex contains all the enzymes normally seen in cytoplasm, true to the complexity of cytoplasm. Peroxidases (Hann-Homans, 1950) and Polyphenol oxidase (Hsia, 1958) in latex have long been subjected to study. D'Auzac and Jacob (1969) and Bealing (1969), have established the presence of all the enzymes required for the metabolism of sucrose to pyruvate. Arreguin and Rock (1967) have provided evidence for the presence of enzymes of hexose monophosphate 'shunt' in latex. Work on the isolation and characterisation of enzymes responsible for the conversion of acetyl Co-A to rubber have been catalogued by Archer and Audley (1967) and Lynen (1967, 1969). Audley (1964) has reviewed the enzymic activity of lutoid particles. Archer *et al* (1963 a) gave the first report of phosphatase activity of lutoid serum, studies on which were further extended by

Ribaillier et al (1971), Jacob and Sontang (1974) and Jacob (1975). Activity of ATP-ase also has been detected by D'Auzac (1975) and Jacob (1975). In addition to this, lysozyme has also been shown to exist in latex by Meyer (1948), Archer *et al* (1969 a) and Tata *et al* (1976).

Recently, Sheldrake and Moir (1970) and Sheldrake (1970) have detected the presence of cellulase in latex and ascribed it a function of dissolution of end walls of laticiferous systems during the early stage of differentiation.

The foregoing account on enzymes is given only to illustrate the complexity of latex and need not necessarily be complete. Further discoveries on activities of hitherto unreported enzymes can reasonably be expected.

3. PATHWAY OF RUBBER BIOSYNTHESIS

The first indication regarding the route of biosynthesis of rubber was obtained from the structure and analysis of rubber (Bouchardat, 1875). He proposed that rubber was composed of isoprene units linked together to form a polymer. This contention was confirmed later by the experiments of Harris (1913) and Staudinger (1932). Rubber differs from the majority of isoprenoid compounds in two respects. It has a high molecular weight which varies from 1,00,000 to several million (schulz and Mula, 1961) and the geometrical configuration of double bonds is exclusively [illegible] Bunn, 1942; Golub *et al*, 1962). The first indication that the precursor of rubber might be acetate was obtained by Bonner and Arreguin (1949) in the Mexican rubber plant, Guayule (Parthenium argentatum). Later it has further been confirmed that acetate forms the basic precursor of rubber biosynthesis in all rubber plants.(Bonner, 1949; Arreguin et al, 1951; Park and Bonner, 1958; Bandurski and Teas, 1957). Kekwick et al (1959) and Harris and Kekwick (1961) used fresh latex of Hevea as the enzymatic system for study of biosynthesis of rubber. Using labelled precursors, they found that latex could incorporate acetate and mevalonate to rubber.

(1) In vitro studies on early stages of the pathway

Early workers studying in vitro conversion of labelled substrates to rubber in latex soon found that many factors affect the rate of incorporation. Kekwick (1964) found that the ability of latex to incorporate acetate into rubber falls rapidly with storage. Incorporation of mevalonate and pyruvate was, however, unimpaired by storage. The conclusion drawn up from these results was that the labile stage must be the initial formation of acetyl Co-A from acetate by acetyl Co-A synthetase. Pyruvate incorporation was only about 20% of that of acetate at the same concentration of the substrate. Later workers (Bealing, 1975) also could not detect any appreciable rate of conversion of pyruvate into rubber. [illegible] explanation could be that the acetyl Co-A formed in the mitochondria from pyruvate diffuses into the cytoplasm only very slowly. It could also be possible that the collected latex with low mitochondrial population is unable to utilize pyruvate in vitro (Moir, 1969). Bealing (1975) also found that addition of ATP at higher concentrations depressed acetate incorporation while mevalonate incorporation was enhanced, indicating an ATP sensitive step between acetyl Co-A and mevalonate. The conversion of acetyl Co-A to mevalonate through the generally accepted pathway of synthesis does not involve the participation of ATP and hence the above observation is intriguing. Earlier work on a similar effect of ATP on the incorporation of acetate into cholesterol was reviewed by Kekwick (1964). There is no report however that a similar situation exists in the case of latex. Despite the low rate of in vitro incorporation obtained with acetyl Co-A, Kekwick (1964) maintains that this compound could form the principal starting material for the formation of mevalonate. It has also been demonstrated that incorporation of acetate almost certainly proceeded through mevalonate since unlabelled mevalonate inhibits acetate incorporation and labelled mevalonate is readily incorporated to rubber. The acetyl Co-A pool in latex should conceivably be generated from sucrose and D'Auzac and Jacob (1969) and Bealing (1969) have established that Hevea latex contains all the enzymes required for the metabolism of sucrose to pyruvate. Enzymes required for the conversion of acetate and mevalonate to rubber have also been reported in latex (Lynen, 1969). Pathway from HMG Co-A to rubber has been well established by several independant investigators (reviewed by Archer and Audley, 1967; Lynen, 1967, 1969). The conversion of pyruvate to HMG Co-A in latex has not been established beyond doubt and the remarkably low rate of conversion of pyruvate to rubber only confirms the necessity for further investigations in this line. The conversion of pyruvate to acetyl Co-A in latex has never been proven and this is considered to be the 'unknown step number-I' in latex metabolism by D'Auzac and Jacob (1969). The low ability of collected latex to convert sucrose or pyruvate into rubber does not, however, exclude the possibility that the sucrose is the normal precursor under in vivo conditions, as the biochemical and structural composition of collected latex is understandably different from the latex inside latex vessels.

(2) Possible alternate pathways for the formation of HMG Co-A

Bealing (1969, 1975) has suggested alternate pathways for the formation of rubber and raised the possibility that glycolysis does not supply the material for rubber biosynthesis, although glycolysis does exist in latex. He has calculated the rate of conversion of sucrose in latex in vitro which was far too insufficient to account for the rate of rubber regeneration, in a tree under tapping. Struck by the remarkable correlation between the ability of certain families of plants to produce rubber and their abilities to produce quebrachitol or L-inositol, Bealing (1969) has suggested that quebrachitol and inositol may well involve in an alternate pathway, related to the biosynthesis of rubber. It has also been shown that quebrachitol and inositol are metabolised in latex after collection. Recently, using C^{14} quebrachitol, Bealing (1975) has given evidence that it can be readily metabolised both _in vivo_ and in tapped latex and that the rate of break down was relatively rapid. The identity of the break down products, however, has not so far been established and the suggestion that quebrachitol might be involved in an alternate route to rubber still remains a speculation. Drawing a parallel from the incorporation of leucine into carotenoids in _Phycomyces blakesleeanus_ (Yokoyama _et al_, 1957), Kekwick (1964) made a suggestion of an alternate pathway for the formation of HMG Co-A and mevalonate, although under the conditions of their experiment, they could not obtain any incorporation of labelled leucine into rubber by latex.

(3) _Formation of mevalonate from HMG Co-A_

Discovery of mevalonic acid by Wright, Folkers and Associates (Wagner and Folkers, 1961) was a decisive point in the formulation of general pathways leading to isoprenoids compounds. Labelled mevalonic acid was incorporated into rubber in _Hevea_ latex (Park and Bonner, 1958; Kekwick et al. 1959). Mevalonic acid is derived from HMG Co-A in a NADPH linked reduction which also occurs in *Hevea* latex (Archer and Audley, 1967) and the activity of the enzyme HMG Co-A reductase in latex has been measured by Lynen (1969). This enzyme activity is surprisingly low and Lynen (1969) has suggested that the constitute level of this enzyme may be a limiting factor in rubber biosynthesis.

(4) Conversion of mevalonic acid to IPP

Conversion of mevalonate to isopentenyl pyrophosphate requires two preparatory phosphorylations leading to 5-phospho and 5-pyrophospho mevalonic acid (Archer and Audley, 1967). The enzymes required for these conversions, mevalonate kinase and phosphomevalonate kinase respectively, have been detected in latex and their activity assayed by Lynen (1969).

All the necessary enzymes required for the conversion of HMG Co-A to isopentenyl pyrophosphate have been detected in the serum fraction of latex (Lynen, 1959).

(5) Polymerisation of IPP to rubber

The mechanism of polymerisation of isopentenyl pyrophosphate has been elucidated, largely, from the work of Lynen *et al* (1959) on terpene biosynthesis. Two processes are involved in this; the isomerization of isopentynyl pyrophosphate to dimethyl allyl pyrophosphate (DMAPP) by a shift of the double bond and the condensation of DMAPP with IPP to give a C_{10} pyrophosphate. This has the allelic structure also and is able to repeat the condensation with a further molecule of IPP. This propagation step is repeated many hundreds of times in the formation of natural rubber to give a high molecular weight. The stereospecificity of polymerase enzyme in latex ensures a cis-configuration about each double bond. Henning *et al* (1961) provided evidence that freshly tapped latex from *Hevea brasiliensis* catalysed the incorporation of C^{14} labelled IPP into rubber. Archer *et al* (1963 b) showed that the conversion of IPP into rubber in latex takes place on the surface of existing rubber particles, which are essential for the *in vitro* formation of poly-isoprene. This would mean that the incorporation of IPP is predominantly a chain extension process on already existing rubber chains, which carry allyl pyrophosphate end groups (Archer and Audley, 1967). Lynen (1969) agrees with the contention that the *in vitro* synthesis of rubber is largely a chain extension process. But he asserts that chain initiation could also be observed. He has found that the incorporation of IPP into rubber is strictly dependant on the addition of DMAPP, once all soluble enzymes including IPP-isomerase had been completely removed from the rubber particles. After this treatment, polymerase was still present on rubber particles and in the presence of DMAPP, it could incorporate labelled IPP into rubber. Based on his results with latex system, Lynen (1969) holds the view that both chain initiation and chain elongation can occur in latex and attributes the failure of Archer and Audley (1967) to detect any chain initiation, to contaminating enzymes. The IPP-isomerase activity (required for the formation of DMAPP) has not been detected in latex, but this could be due to the fact that the requirement for DMAPP would be extremely small, since each molecule of rubber contains several thousand isoprene units of which only one would be derived from DMAPP (Archer, 1964).

(6) Site of rubber biosynthesis

Mc Mullen (1960 a) has proposed a seemingly attractive theory for the biogenesis of natural polymers involving a nucleotide template. No experimental evidence has so far been obtained to confirm this hypothesis. Lynen (1969) considered the site of polymerase activity at the interphase between serum and rubber particles. In this proposed system, the hydrophilic substrates, DMAPP and IPP, are converted into a lipophylic end product. It has been assumed that the growing hydrocarbon chain of rubber diffuses into the interior of the rubber droplet and that the hydrophilic pyrophosphate end group remains in the serum phase, where it will interact with IPP, bound to the active site of polymerase enzyme. The possible pathway of rubber biosynthesis, diagramatically represented by Moir (1969) is given in Fig. 1.1.

(7) Inhibition of rubber biosynthesis by enzymes in lutoid serum

The non-rubber particles of latex including lutoids which can be separated as bottom fraction by centrifugation

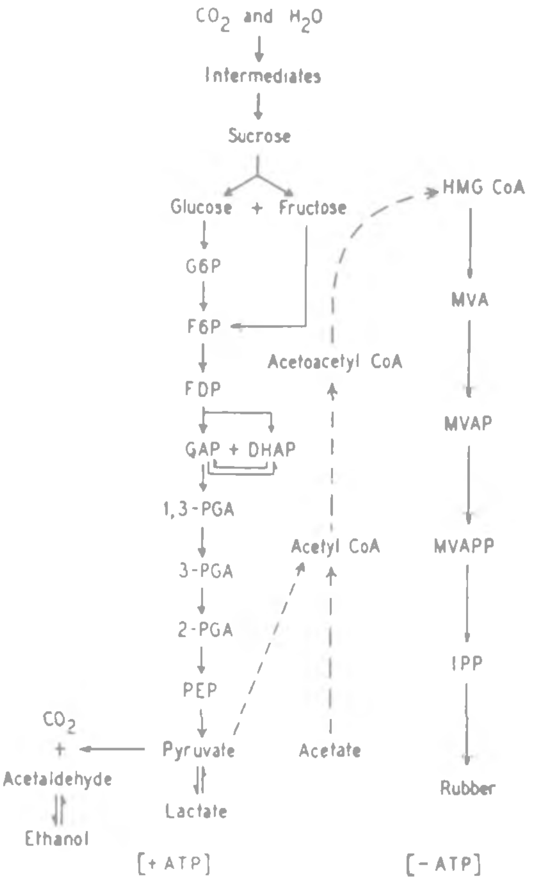

Fig. 1.1. Pathway of rubber biosynthesis. After Moir, G.F.J. (1969). J.Rubb.Res. Inst.Malaya 21(4):407.

G6P	glucose-6-phosphate
F6P	fructose-6-phosphate
FDP	fructose-1.6-diphosphate
GAP	glyceraldehyde-3-phosphate
DHAP	dihydroxyacetone phosphate
1,3-PGA	1,3-diphosphoglyceric acid
3-PGA	3-phosphoglyceric acid
2-PGA	2-phosphoglyceric acid
PEP	phospho-enol pyruvate
ATP	adenosine triphosphate
Acetyl-CoA	acetyl coenzyme A
Acetoacetyl-CoA	acetoacetyl coenzyme A
HMG-CoA	β-hydroxy-β-methyl-glutaryl coenzyme A
MVA	mevalonic acid
MVAP	mevalonic acid 5-phosphate
MVAPP	mevalonic acid 5-pyrophosphate
IPP	isopentenyl pyrophosphate

do not appear to be necessary for the formation of rubber from mevalonate (Archer, 1964). On the other hand, early work on rubber biosynthesis (Bandursky and Teas, 1957) pointed out to the possibility that lutoid contents might exert slight inhibitory effect on the synthesis of rubber from acetate. The inhibitory effect of the lutoid serum on isoprene anabolism has already been demonstrated *in vitro* by Archer (1964) and Ribaillier *et al* (1971). The decrease in the rate of incorporation was attributed to the presence of hydrolytic enzymes possessing phosphatase, pyrophosphatase and ATP-ase activity (Archer, 1964) which have been shown to be released, when bottom fraction particles are disrupted. Addition of ATP was shown to counteract the inhibitory effect of bottom fraction contents by Archer (1964). Jacob (1975) made detailed studies on lutoid acid phosphatase and found that co-factors such as ATP, Co-A and NADP and substrates such as phosphoenolpyruvate can be very easily destroyed by this enzyme. Audley (1964) suggests the possibility that the lutoid phosphatase, released from lutoids, might be responsible for the chain termination process in rubber synthesis by removal of pyrophosphate ion from the end of the growing rubber chain. Leakage of phosphatase into serum *in vivo* might be conditioned by peculiar physiological states or ageing of laticiferous cells. Jacob (1975), however, believes that a number of *in vivo* factors might prevent the efficient action of phosphatase liberated from lutoid. The pH of cytoplasmic serum itself is far from optimum for the acid phosphatase. In addition, the presence of inorganic phosphates in the latex serum might exert an inhibitory action on these enzymes. The magnesium present in latex serum is also considered to provide a protective role for ATP by the formation of ATP-Mg chelate (Jacob, 1975). The significance of such enzymes, segregated in lutoid particles of latex, in regulating biosynthesis of rubber <u>in vivo</u> is still a speculation.

4. PHYSIOLOGY OF LATEX FLOW

The presence of earlier reviews on latex flow by Sethuraj (1968), Southorn (1969) and Boatman (1970) has made the present compilation an easier task and the aim of the present review is confined to trace the conceptual developments in latex flow physiology, with emphasis on recent work not reviewed so far.

(1) Early work and theories of latex flow

There is evidence that in an untapped tree, there is little or no movement of latex in the vessels (Schweizer, 1949). Latex flow is actually an abnormal physiological phenomenon induced by tapping. Many studies have been carried out to elucidate the mechanism of latex flow, of which the pioneering work of Arisz (1918, 1928), Vischer (1920), Bobilioff (1921), Zimmermann (1927) and Frey-wyssling (1932) deserve special

mention. Frey-Wyssling (1932) attempted a mathematical exposition of the physics of latex flow. When the amount of latex per unit of time after tapping was plotted against the volume of latex produced, he obtained a curve in which the first part of the flow followed an exponential law, ascribed to an elastic contraction of latex vessels or a hydraulic gradient. The second part of the curve was considered to represent a capillary flow following the parabolic law of Poiseuille. Riches and Gooding (1952) attempted a different mathematical approach which however retained the general concepts of latex flow developed by Frey-Wyssling (1932). The observations of Pyke (1941) on contraction of trunk following tapping and that of Ferrand (1941) on changes in the *in situ* dilution of latex on tapping were further confirmed by Gooding (1952 b). The mechanism of latex flow as conceived by these early workers can be summarised as follows:
Latex vessels are filled with viscous latex under hydrostatic pressure. When the vessel is cut the pressure at the location of the cut is released and viscous latex exudes. This expulsion of latex could result in the displacement of latex along the length of the latex vessels owing to the strong forces of cohesion existing in the liquid phase. This leads to a fall of pressure in the latex vessels and consequently water from surrounding tissues would enter into the latex vessels due to gradients in water activity. This dilution of latex termed 'dilution

reaction', would make the latex less viscous resulting in an enhanced flow rate. It was assumed that when the flow rate decreases, the adjoining cells might even remove water from the latex itself, thus increasing the latex concentration to the point of coagulation, so that the flow would stop completely.

Except for the mechanism of cessation of flow, the ideas entertained by these pioneer workers on the process of latex flow are still valid.

(2) Modern concepts in the Physiology of latex flow

The discovery by Boatman (1966) of the existence of an in-built flow restricting mechanism was a break-through in the conceptional development in latex flow physiology. He observed that when a tree is tapped at frequent intervals on the same day a 'stepped' flow curve was obtained. A marked recovery of flow rate was observed at each tapping, indicating the removal of an impediment to flow, located very near the latex vessel ends. Further work by Southorn (1969) indicated the presence of an inherent clotting mechanism within the latex vessels which is responsible for the cessation of latex flow. As has already been described, latex is a dual colloid system in which the potential destabilising substances are segregated inside the lutoid particles. The rupture of lutoid membrane, and the consequent release of the destabilising system trigger the process of flocculation of latex particles which results in the cessation of latex flow.(Southorn and Edwin, 1968; Southorn and Yip, 1968 b). The extent of latex vessel plugging can be assessed by plotting flow patterns in a graph with rate of flow in the ordinate and time after flow in the abscisa.

Milford et al (1969) proposed an index - the plugging index - for measuring the extent of plugging and this index is now widely adopted. However, as the volume yield on tapping is the function of both the rate of flow and extent of latex vessel plugging, plugging index alone would not indicate the yielding capacity of a tree.

(3) Mechanism of latex vessel plugging

As variation in the rate of plugging could be intimately related to the intrinsic differences between latices with regard to the flocculating mechanism, most of the investigators have concentrated their attention on the biochemical and biophysical aspects of the formation of plugs. But one factor which would counteract the retardation of flow by such barriers could conceivably be the rate of flow, as the force of a rapid flow can sweep out, to certain extent, the plugs that are being formed in the vessels. Factors which influence the rate of flow are thus important in the plugging process. But much attention has not been given to this aspect by most workers. The work on latex vessel plugging can be grouped under two heads, (a) The biochemistry and biophysics of plug formation, (b) Factors affecting latex vessel plugging or plugging index. (Included under FACTORS AFFECTING YIELD).

i. The biochemistry and biophysics of plug formation:- It has been well established that latex contains an in-built clotting system, normally segregated away from the contact of the rubber particles in specialised particles. This stability equilibrium is disturbed during latex flow and flocculation takes place inside latex vessels which eventually seal the vessel. Evidence for the formation of such sources of obstruction of flow has been provided by Boatman (1966) by repeated tappings and by Southorn (1968) by demonstrating the presence of internal plugs and coagulum cap in the longitudinal sections of latex vessel near tapping cut. Electron microscopy also revealed the particle distortion along the flow stream. The plugging material comprised of rubber and damaged lutoid particles. Role of lutoids in this flocculating action had long been suspected (Paton, 1953; Mc Mullen, 1951). The observation that the microflocs encountered in the field latex was always associated with damaged lutoids (Southorn, 1961) gave emphasis to such a view. Direct evidence that the serum from the bottom fraction (B-Serum) has an extremely fast and complete flocculating action on aqueous suspensions of rubber particles was provided by Southorn and Edwin (1968), Ribaillier (1970), Pujarniscle and Ribaillier (1970). The situation was observed to be different in the case of whole latex, due to the presence of C-Serum; B-Serum and C-Serum react with each other and the rapidity of flocculation process depends on the balance of activities between the two Sera (Southorn and Edwin, 1968). It was also shown that lutoid disrupted by ultrasonic irradiation, always leads to formation of microflocs in latex.

ii. Mode of action of B-Serum:- The action of B-Serum was first thought to be due to enzymes. The presence of phosphatases and other hydrolytic enzymes in B-Serum had been reported by Pujarniscle (1965, 1966), Pujarniscle and Ribaillier (1966) and Archer et al (1969 a). It has been suggested that B-Serum would lyse the protective envelope of rubber particles and that lutoids might be homologous to the lysosomes of animal cells (Pujarniscle, 1968). The divalent cations, Mg^{++} and Ca^{++} present in B-Serum in comparatively higher concentrations than in C-Serum as well as the B-Serum proteins of high isoelectric point have been implicated in the clotting action of B-Serum, and an electrostatic mechanism has been proposed (Southorn and Yip, 1968 b). It has also been shown that cationic surfactants have effects on latex stability similar to that exerted by B-Serum. Methods have also been developed to estimate the electrostatic activity of the B-Serum quantitatively by its titration against anionic surfactants. The dominant role of proteins in B-Serum is however clear from the finding that the B-Serum activity is retained even after the removal of cations by dialysis. Tata and Yip (1968) could attribute the activity to a particular protein zone in starch gel electrophoresis pattern.

iii. Possible causes of lutoid damage during latex flow:- Southorn (1969) characterised different stages of disintegration of lutoids and assumed that factors such as thermal, electrical, osmotic, mechanical and chemical might be involved in the process. Of these, thermal factor is unlikely of any consequence. Electrical wound potential following tapping has been demonstrated (Lim et al, 1969) and further studies on this aspect would be desirable. As the osmotic sensitivity of lutoids has been recognised, the role of osmotic changes during latex flow on the disruption of lutoids merits further attention. Pakianathan et al (1966) attributed a greater degree of damage to lutoids in early flow fractions to osmotic shock following dilution of latex after tapping. It may however be mentioned that the lowest osmotic concentrations reported in different flow fractions of latex were not such as would be expected to damage lutoids to the extent observed. The greater degree and number of damaged lutoids in early fractions would be expected if one assumes that the force of initial fast flow would sweep out the damaged particles (Chua, 1965).

Southorn (1969) emphasised that shear stresses to lutoids during flow along latex vessels could also be important. By simulating pressure gradients in glass capillary tubes with internal diameter approximately those of latex vessels, breakage of lutoids, assumably due to shear, has been demonstrated by Southorn and Yip (1968 a). It is pertinent to remember here that the latices freed from lutoids by centrifugation fail to form plugs in the capillaries even with great pressure gradient (Yip and Southorn, 1968). Though there are limitations in such simulated experiments with glass capillaries, these studies have indicated that shear could well be one of the factors causing disruption of lutoids during flow.

Involvement of any biochemical factor in the disruption of lutoids is still to be proved. In this connection, studies on lutoid hydrolases (Pujarniscle _et al_, 1970) would be rewarding.

These studies have so far not shed much light on the reasons for clonal variation in plugging intensity. An understanding of the factors which signal the excitation of polarised membranes of lutoid during latex flow would elucidate many of these obscure problems.

5. FACTORS AFFECTING YIELD

(1) Environmental factors

It is well known that there is considerable seasonal variation in the yield of rubber. The highest yield is generally during the wet months, while the lowest yield is during the dry season (Polhamus, 1962). This apparently simple relationship is complicated with the fact that the periods of high and low productivity are synchronised with the vegetative growth phases of leaf maturity and wintering, respectively. While the general observations of the influence of season, especially, of dry period, on yield are documented by Edgar (1958), Polhamus (1962) and Bouychou (1962), specific studies to correlate yield with climatic factors are surprisingly sparse. Ninane (1967 a) has, however, conducted extensive studies on the effect of climatic factors on the transpiration rate and water balance of the tree, assuming intimate relationship between yield and water balance. He held that the output from a tapping could be predicted, taking into account the wind-speed and saturation deficit of the air, both of which affect the transpiration of the tree, during the two days before tapping. Paardekooper and Samosorn (1969) contended, that the usually observed increase in yield during the second half of the year after wintering is entirely the result of a longer duration of flow. No marked seasonal variation in the initial flow rate, to account for the yield variation, was observed by these workers. Most of the direct effects of the climatic factors such as wind velocity, temperature and saturation deficit of the air on yield should be mediated through alterations in the transpiration rate and the consequent water balance of the tree, as envisaged by Ninane (1967 b). The turgor pressure of the latex vessels would, thus, be directly influenced by these factors. The influence of turgor pressure would be predominantly on the initial flow rate rather than on the plugging index. But a direct effect of soil moisture content on plugging index was demonstrated by Sethuraj and George (1976), by irrigation experiments. The depression in yield when the trees are tapped on later hours of the day is, presumably, influenced by changes in transpiration rate and turgor pressure. As the seasonal variation in yield is largely accounted by the variation in plugging index, the path through which each climatic factor exerts its influence on yield, requires further investigations. Nevertheless, it can be expected that water balance of the tree, which is susceptible to climatic influences is a deciding factor in yield variations. It may be mentioned that a higher initial rate of flow per se can result in a lower plugging index (Sethuraj et al, 1974 b) presumably because the rubber flocs that are formed inside the latex vessels are sweeped out with the surge of high flow rate (Chua, 1965).

Another factor, which complicates our understanding of the relationship between climatic factors and yield is the influence of defoliation, refoliation and leaf maturity on yield. It is difficult to partition the individual influences of climate and growth phase, experimentally. Evidence for the yield depressing effect of drought, irrespective of the growth phase, is provided by Maas and Bokma

(1950) in their data, comparing the yield patterns in two different regions of Indonesia, where the period of drought occur in different months of the year.

(2) Physiological factors

i. Latex physiology. The yield from a *Hevea* tree on tapping is determined by the volume of latex and its dry rubber content.

(a) Latex flow. The two characteristics of latex flow which determine the volume of latex upon tapping are the rate of flow and the intensity of plugging in the latex vessels.

Initial rate of flow:- Initial rate of flow gives an indication of the velocity of flow, uninfluenced by the process of latex vessel plugging which starts operating within a few minutes after tapping, resulting in reduced flow rate. Sethuraj *et al* (1974 b) have indicated that the initial rate of flow might be a clonal character and that high yielding nature of certain clones could be ascribed to a higher initial rate of flow rather than to a low plugging. Paardekooper and Samosorn (1969) also have reported correlation between initial flow rate and yield. This character has received very little attention in studies on the factors affecting yield and only scant information is available on the various anatomical and physiological factors which might influence the initial flow rate. Sethuraj *et al* (1974 b) obtained significant correlation between initial flow rate and number of latex vessel rows. This is expected, as more number of latex vessel rings, when cut, would expel a higher volume of latex. There are numerous reports on the relationship between latex vessel rings and yield (Sanderson and Sutcliffe, 1929; Frey-wyssling, 1930; Wycherley, 1969). As the number of latex vessel rings has no influence on plugging index (Tan and Subramoniam, 1975), the effect of this character on yield should have mediated through its effect on initial flow rate. It can further be expected that the influence of girth on yield also is mediated through its effect on the initial flow rate; plugging index is not affected by the girth of the tree (Tan and Subramoniam, 1975). A significant correlation between length of the tapping cut and initial flow rate has already been reported by Paardekooper and Samosorn (1969).

Another factor which might directly influence the initial flow rate is the turgor pressure of latex vessels at the time of tapping. Unfortunately, no study correlating turgor pressure with initial flow rate is available.

Plugging index:- The relationship between flow restricting process and yield has been well established (Boatman, 1966; Sethuraj, 1968; Milford *et al*, 1969; Paardekooper and Samosorn, 1969).

Clonal variation in latex flow pattern was reported by Sethuraj (1968). Milford *et al* (1969) found plugging index to be a clonal character. Paardekooper and Samosorn (1969) and Saraswathy Amma and Sethuraj (1975) made extensive studies involving large number of clones and distinct clonal variation in this character was demonstrated. The physiological basis of this clonal variation is not well understood. It has however been suggested that initial rate of flow might be a clonal character and that initial flow rate would influence plugging index (Sethuraj _et al._ 1974 b). Paardekooper (1966) has reported a positive correlation between initial flow rate and plugging index. But in a later work (Paardekooper and Samosorn, 1969), no correlation between there characters was obtained. Further investigations on the biochemical and biophysical factors related to plugging process in different clones are necessary to elucidate the basis of clonal variations in plugging index

Although seasonal variation in yield is generally known, studies relating this to latex flow pattern are limited. Sethuraj (1968) reported that yield depression during the period of summer defoliation can be ascribed to a short duration of flow. The contention of Milford _et al_ (1969) that the day-to-day variation in plugging index was only slight was contradicted by Paardekooper and Samosorn (1969) who reported seasonal variation in plugging index. The magnitude of seasonal effects on plugging index appears to be more pronounced in agroclimatic regions with prolonged drough periods (Saraswathy Amma and Sethuraj, 1975). Milford _et al_ (1969) could not find any significant variation in plugging index between different plots. In a recent study (Sethuraj and George, 1976), it was demonstrated that soil moisture content is an important factor influencing plugging index.

The 'drainage area' may also influence the plugging index. The observed influence of the length of the tapping cut on plugging index (Southorn and Gomez, 1970) could perhaps be explained by assuming an extension of drainage area. Sethuraj *et al* (1974 c) obtained evidence that plugging index could be altered by facilitating an extension of drainage area. There is general lack of appreciation about the role of drainage area in the latex vessel plugging, although it was recognised that the drainage area increases after stimulation (De Jonge, 1955; Lustinec *et al*, 1967). It was considered only as a consequence rather then the cause of yield increase after stimulation. Sethuraj *et al* (1974 c) proposed that the influence of yield stimulants might be mediated through an extension of drainage area. Later they provided further experimental evidence for this hypothesis (Sethuraj *et al*, 1975).

Recently Pakianathan *et al* (1975) mapping the displacement area, utilising a manometric technique, demonstrated that Ethrel stimulation would extend the potential displacement area. Therefore it can be assumed that the low plugging index associated with stimulation may well be the result of an extended drainage area.

Wilford *et al* (1969) have examined if the age and panel of a tree would influence plugging index. No correlation between plugging index and these factors was obtained.

The relationship between high Mg content or high Mg/PO_4 ratio with frequent premature coagulation and coagulation at the tapping cut has been recognised (Beaufils, 1954). Pushparajah (1966) could induce plugging by infusing solutions containing Ca and Mg ions into the bark. The destabilising effect of cations in lutoid stability is also known (Southorn, 1969; Yip and Gomez, 1975 b). Pushparajah et al (1975) reported a shortening of the duration of latex flow by the application of rock phosphate and calcium content in the rock phosphate was considered to be the causative factor. Although the possibility of nutritional factors playing a role in latex flow has been established, further systematic studies on the role of nutrient interaction in latex vessel plugging are necessary for definitive conclusions.

b. Dry rubber content of latex

Under a given system of exploitation, the dry rubber content (d.r.c.) is an indicator of the biosynthetic capacity of the tree. If a tree is left untapped, the production of rubber virtually stops when the d.r.c. attains a particular level. Removal of latex by tapping triggers the biosynthetic activity. A gradual fall in d.r.c. with excessive withdrawal of latex by intensive tapping is an indication of the inability of latex vessels to regenerate rubber particles at a rate sufficient to replenish the loss. Clonal variations in the dry rubber content perhaps indicate the differences in the biosynthetic potential of the clones. But the clonal difference in d.r.c. level is not as great as to be of much significance in yield variation. In a comparatively recent study, it has been established that yield is not correlated with d.r.c. (Paardekooper and Samosorn, 1969). Moreover, a direct correlation between d.r.c. and plugging index has been obtained (Milford et al. 1969). So the possibility of a higher d.r.c. having an inhibitory effect on yield cannot be ruled out. From these results it can be assumed that factors influencing the d.r.c. of the latex is not very important in determining yield as long as the rate of removal of latex by exploitation techniques is not beyond the capacity of the tree to replenish the loss before the next tapping. But with intensive systems of exploitation, resulting in excessive withdrawal of latex, there would be a gradual fall in the d.r.c.

The data presented by Schmole (1940) is suggestive that nutritional factors or photosynthetic rate might also influence the d.r.c. of latex. He showed that with higher density of planting, the d.r.c. tends to be lower. In seedlings, Fuller (1947) detected a higher d.r.c. when full insolation was provided for shaded leaves. A seasonal variation in d.r.c. also is reported (Ribaillier, 1972).

c. Metabolic activity in the latex vessels.

Efforts have been made by various workers to correlate the biochemical activity in latex with the productivity of the tree. D'Auzac (1964) observed a close relationship between glycolysis and biogenesis of rubber. Amount of high energy labile phosphorus in latex (D'Auzac, 1965) nucleic acid content in latex (Tupy, 1969), invertase activity in latex (Tupy, 1973 a) and sucrose content in latex (Tupy, 1973 b) have been related to the yield potential. Hepper and Audley (1969) could detect seasonal variations in the rate of incorporation of HMG Co-A into rubber in latex in vitro, indicating that such variations in the biosynthetic efficiency may be related to seasonal variations in yield.

All the above findings indicate that latex metabolism is intimately related to productivity. Our present knowledge, however, does not permit us to visualise how an enhanced metabolic activity can result in enhanced latex flow. On the other hand, one could conceive the possibility that the dry rubber content in latex might increase as a result of enhanced metabolic activity. But the findings that d.r.c. is not correlated with the yield (Paardekooper and Samosorn, 1969) discounts the possibility that a higher rate of metabolic activity would influence yield by enhancing the level of d.r.c. in latex. It may have to be mentioned that the aspect of latex flow was not considered in these investigations. Therefore, a re-evaluation of some of these results would be necessary to appreciate their significance.

An examination of the data of D'Auzac (1965), D'Auzac and Pujarniscle (1963) and Tupy (1969), reveals that the high yielding trees, the latices of which recorded a higher metabolic rate <u>in vitro</u>, had actually a higher volume of latex and that the dry rubber contents were generally lower than that of the low yielding trees compared, indicating that the high yield was due to a lower plugging index. Nevertheless, the data do show a higher rate of <u>in vitro</u> conversion of labelled acetate to labelled rubber by the latex of high yielding trees. Likewise, all the high yielding trees used by Tupy (1969) also recorded higher nucleic acid content and a higher rate of P^{32} incorporation into nucleic acids.

Accepting the importance of these studies, two facts have to be emphasised. (1) The high yielding and low yielding trees were of the same clone and (2) these studies were conducted <u>in vitro</u> using collected latex.

It is difficult to understand, why two trees of the same clone should differ so vastly in their biochemical components of latex and in their efficiency of biosynthetic activity. The principles of genetics makes this observation difficult to comprehend. Environmental effect on such basic characters could not be more than negligible. It would have been more convincing, if direct correlation between clonal variation in yield and clonal variation in biosynthetic rate of rubber existed. On the other hand, difference in the latex flow characteristics between two trees of the same clone, planted at a distance, is quite understandable, particularly on the basis of the known modifying effect of moisture status on plugging index.

Another question to be examined is whether the level of enzymatic activity in the collected latex really represents the inherent biosynthetic potential of the tree. It is not proper to make any speculation in this regard, as this is an aspect requiring careful and intensive study. Nevertheless, it is probable that the level of enzymes, and the cytoplasmic particles in the collected latex can be expected to be dependent on the rate and duration of flow. The finding by D'Auzac (1964) that biosynthetic turnover gradually falls with successive fractions of latex, obtained during the same tapping is interesting in this context. It is, however, intriguing that diametrically opposite results have been reported in a later publication from the same laboratory; the latter fractions recorded higher biosynthetic rate than the earlier fractions (Pujarniscle *et al.* 1970).

These contradictory findings only show that the state of biochemical and ~~bio~~ physiological condition of the latex at the time of collection is of prime importance in determining its biosynthetic activity <u>in vitro</u>. So due caution is warranted in the interpretation of the data. The report by Pujarniscle and Ribaillier (1970) that biosynthetic activity and protein nitrogen increase in the latex collected after successive tappings on a newly opened tree is partially confirmed by the findings of RRIM scientists in Malaysia (Rep. Rubber Res. Inst. Malaya, 1971) that untapped trees were virtually incapable of converting mevalonate to rubber and that the ability to do so increased twenty-fold within four days of initial tapping. Thus, it is tempting to suggest that the removal of latex from the tree might induce the capacity to regenerate rubber. This suggestion is supported by the work conducted at the Rubber Research Institute of India, that respiratory rate (O_2 uptake) by the bark collected from the drainage area is significantly higher than that of bark collected farther away from the drainage area. In addition, it was also shown that the O_2 uptake by the bark of intensively tapped trees (400%) were higher than the bark collected from control trees, tapped S/2 d/2 (ie. 100%) (Sethuraj <u>et al</u>. 1974 c). These results indicate that the execessive removal of latex from the tree results in greater metabolic activity, major part of which may presumably be due to rubber regeneration. A higher concentration of rubber in the latex vessels <u>per se</u> may be a controlling factor in the mechanism of rubber biosynthesis (Bonner, 1969).

In other words, excessive removal of latex in a high yielding clone with low plugging may induce greater rubber regeneration activity. On the other hand, a low yielding clone with high plugging index may also tend to be less efficient in biosynthetic activity. The role of lutoid in plugging process is well recognised. It has also been demonstrated that the contents of lutoids can inhibit the rate of rubber biosynthesis in vitro (Archer, 1964; Ribaillier et al, 1971). It looks probable that a higher rate of disruption of lutoids may induce earlier plugging as well as exert some inhibition on the process of rubber biosynthesis.

ii. Whole tree physiology.

In the preceding sessions, the factors which directly influence the yield of a given day on tapping have been considered. The productivity of a tree during its economic life span is governed by many indirect factors which influence the physiology of the whole tree.

a. Growth vigour.

Growth vigour is measured in terms of girth. As has already been described, the total number of latex vessels exploited is determined by the girth of the tree. Perfect correlation between yield and girth have been reported (Narayanan et al, 1974; Ho, 1975; Tan and Subramoniam, 1975). The girth being only one of the factors which influence yield, all vigorous clones need not necessarily be high yielders. Moreover, Ho (1975) has reported that in certain phases of its productive period, as during exploitation on panel 'A', girth has no influence on yield. Nevertheless, a higher girth is a desirable character and a higher proportionate girth increase in relation to the total vegetative growth should be considered as an ideal characteristic. Sethuraj _et al_ (1974 a) have proposed an index, girth index to quantify this character.

b. Girth increment of trees under tapping.

It is well recognised that tapping depresses the rate of girth increment (Rue, 1920; Arisz, 1923; Frey-wyssling, 1932 ; Vollema, 1941; Schweizer, 1949; Templeton, 1969). The rate of depression is greater with increased intensity of tapping. There is marked clonal variations in this regard. There are indications that the order of the decrease varied between low and high yielding clones (Blackman, 1964). Templeton (1969) presented evidence that the yield of dry rubber ~~content~~ per unit length of tapping cut was inversely related to girth increase of trunk. In clones in which the reduction in shoot dry weight increment due to tapping was confined largely to the trunk, the weight of dry rubber produced was approximately commensurate with this reduction. In clones in which tapping also substantially reduced the growth of the canopy, the weight of rubber extracted amounted only to 10 to 25% of the growth loss. These studies show that the depression in girth increment after tapping is related to physiological competition between growth and yield. Sethuraj et al (1974 a) have suggested an index termed girth increment index (GII) to measure the girth increment in relation to unit yield. These authors have reported marked variations in GII between clones.

c. Bark renewal.

It is well known that yield from the renewed bark in relation to that of the virgin bark show clonal variations. Early workers like Schweizer (1929) made detailed studies comparing the productivity in virgin and renewed bark. He found that the first regenerated bark yielded considerably more than the virgin bark at the same height. This difference in the productivity of the virgin bark diminished when the tapping cut reached the bottom of the regenerated bark. An examination of the yield pattern of different clones through successive tapping panels (Plrs. Bull. Rubb. Res. Inst. Malaysia, 1974) indicates that the contention of Schweizer (1929) that renewed bark always yielded more than virgin bark need not be generalised, as the yield pattern shows distinct clonal variations. As the total yield from a tree during its economic life span is an important aspect in a commercial plantation, clones which maintain a high yield in the renewed bark are to be preferred. Little study has however been carried out on the physiological basis of this clonal variations. Further studies on these aspects may be rewarding.

d. Clonal response to seasonal effects.

It is generally recognised that the yield from rubber tree is markedly influenced by seasonal variations and the work on these aspects have already been reviewed. The period of lowest yield is usually associated with annual defoliation which also happens to be a period of drought. The rate of yield depression during this period varies from clone to clone. (Paardekooper, 1965). Susceptibility or tolerance of a clone to drought conditions appears to be a predominant factor in clonal variation of yield depression during summer defoliation period. Sethuraj (1968) has indicated that yield variation due to season are mediated through the latex flow pattern. Saraswathy Amma and Sethuraj (1975) reported that the rate of increase in plugging index and thus the extent of reduction in yield due to variations in soil moisture content is a clonal characteristic. The physiological factors which contribute to this clonal variability are still obscure. The studies aimed to elucidate this are important as tolerance of a clone to drought conditions has a profound impact on its overall productivity, especially so, in areas with a prolonged period of drought.

e. Influence of stock on scion.

A major part of the area under rubber in replantings is planted with budded plants. Though buddings are less variable than seedlings, a source of heterogenity can still be traced to the root stock effect, as the seedling root stocks are heterozygous. It is known that tree to tree variation in yield exists in any budded area and one of the contributory factors for this might be the variations in the stock material (Langlois, 1969 a; Wycherley, 1968). The root stock might influence both the vigour of the scion as well as the latex yield. The extent of root stock influence has not been assessed mainly due to experimental limitations. The physiological reasons of this yield variation also have not been looked into.

f. Incidence of dryness (Brown bast).

Brown bast is generally recognised as a physiological disorder caused by over-exploitation (Rands, 1921; Sharples and Lambourne, 1924; Taylor, 1926; Ng <u>et al</u>. 1969; Bealing and Chua, 1972). The loss in yield due to incidence of brown bast can reach serious proportions and this disorder remains an important factor governing tapping intensities and thus the potential productivity. It is well recognised that susceptibility to the incidence of brown bast vary from clone to clone. The exact reason for the incidence of brown bast is still a debatable point (Bealing and Chua, 1972; Paranjothy <u>et al</u>, 1975). Milford <u>et al</u> (1969) have furnished data on an inverse correlation between brown bast incidence and plugging index of clones.

g. Summer defoliation (Wintering) of Hevea brasiliensis

Hevea brasiliensis is classified as summer deciduous (Addicott and Lyon, 1973). The word 'summer' is used to indicate the dry period rather than a particular part of the calendar year. The abscission of leaf is correlated with moisture stress.

The annual process of leaf fall in rubber tree is popularly called 'wintering' which occurs during the drier months of the year. The dry period happens at quite different times in various parts of the tropics and consequently, the period of wintering varies from place to place. In South India, the annual leaf fall usually occurs during the month of January and February, but the actual time may vary with the locality and the prevailing weather. Moreover, the leaf fall period is not identical to all clones or for all trees and even a single tree may at one time have portions of its canopy in different stages of defoliation (Polhamus, 1962). In South Malaysia, it has been observed that the normal defoliation which occurs during the first two or three months of the year is followed by a late or second defoliation in the dry weather of July-September (Edgar, 1958).

Most of the information published is from observational studies and the work of Wimalaratna and

Pathiratna (1974) deserves special mention, for the systematic approach. They have observed that there is clonal variation in the leaf fall pattern in conformity with the findings of Paardekooper (1965). Clonal variation in leaf fall pattern had also been noted by Dijkman (1951). He reports, that the life span of leaves varies from 10-13 months in different clones. Chua (1970) has worked on the physiolcgy of leaf senescence and abscission, associated with the summer defoliation and has provided evidence that the ageing of leaves is correlated with changes in the contents of growth regulating substances. The growth promoter level, probably of indole acetic acid, decreased with age, but the level of growth inhibitor, probably absicissic acid was found to remain constant. The activity of IAA-Oxidase increased with age.

Yield depression during summer defoliation:- The depression in yield during the period of summer defoliation is well known. Paardekooper (1965) reported on the clonal variation in the extent of yield depression during wintering. A detailed survey by Wimalaratna and Pathiratna (1974) show that the reduction in yield is greatest at the commencement of bud break of the new flush and the time taken to attain the normaloy is variable from clone to clone. Their data, however, indicate that no meaningful relationship between yield variation and leaf fall pattern can be deduced. Sethuraj (1968) has demonstrated that the yield depression during the period of defoliation is mainly mediated through a shortening of the duration of latex flow. The difference in the flow pattern before and during wintering was more pronounced in the clone the yield of which was severely affected during wintering, compared to a clone in which the effect was negligible. The findings (Abraham and Tayler, 1967; Sethuraj and George, 1975), that the response to yield stimulation in terms of percentage over unstimulated control, is highest during the period of summer defoliation, is an indirect evidence that yield reduction during this period is due to an increase in the plugging index as the stimulants act through lowering of plugging index. Saraswathy Amma and Sethuraj (1975) have also furnished data to show that the yield depression during the period of summer defoliation is due to a higher plugging index. The increase in plugging index is more pronounced in clones with a higher depression in yield during summer defoliation, compared to comparatively tolerant clones. The defoliation in rubber tree is correlated with the onset of drought. It is generally assumed that the yield from a rubber tree is sensitive to the water status of the tree. Sethuraj and George (1976) have also shown that plugging index and thus yield would be influenced by soil moisture content. So what might have been considered as the effect of defoliation and refoliation on yield could well be due to, to a great extent, the influence of the drought conditions prevailing during the period of defoliation.

(3) Exploitation methods

i. Tapping.

The time of tapping, length of tapping cut in relation to girth, number of tapping cuts, depth of tapping and frequency of tapping are the factors which influence the effect of tapping.

a. Time of tapping

The earliest experiments conducted to study the relation between hour of tapping and yield were reported by De Jong (1913, 1915, 1916). The results of these small scale experiments were inconsistent. The results of a larger experiment (Van Lennep, 1920) show that yield decreased when trees were tapped after 07.00 hours to a minimum of 84% at 13.00 hours, followed by a small increase towards 16.00 hours. Dijkman (1951) furnished data on the extent of yield drop when trees were tapped at 09.00 hours and 11.00 hours as compared to tapping at 07.00 hours; the yield was reduced to 96 and 85% respectively. Gooding (1952 b) also observed 15-20% reduction in yield in trees tapped at 11.00 hours as against 08.00 hours. This drop in yield was entirely due to a lesser volume, as the d.r.c. at 11.00 hours was slightly higher than at 08.00 hours. Ninane (1967 b) also has furnished data on the influence of time of tapping on yield. There was 14-19% yield decrease in clone PR 107 when the trees were tapped at 14.00 hours as compared to the yield from morning tapping (6.00 hours). The d.r.c. was two points higher in the afternoon compared with that at 06.00 hours. This again indicates that the drop in yield was due to lesser volume of latex. Paardekooper and Sookmark (1969) studied the diurnal variation in yield and its relation to saturation deficit of air. They found that yield was maximum and constant between 20.00 hours and 07.00 hours and during day, the yield decreased gradually to a minimum of 70% of the maximum yield around 13.00 hours. The dry rubber content of latex at mid-day was found to be 4 points higher than that obtained during night. The diurnal variation in yield followed the variation in saturation deficit of air and the correlation was inverse.

Dijkman (1951) suggested that decrease in yield during day might be the result of increased transpiration and a lower turgor pressure of the laticiferous system. While Gooding (1952 a) gave indirect evidence to this, Buttery and Boatman (1964 , 1966) made direct measurements of hydrostatic pressure in the phloem and proved that diurnal fluctuations occur in the turgor pressure, with a minimum in the afternoon. They reasoned that diurnal yield variations can be attributed to the variations in turgor pressure in the latex vessels. Ninane (1967 a) obtained significant correlation between transpiration and absolute saturation deficit of the air. Based on these results, it can be assumed that the rate of transpiration, through its influence on the turgor pressure of the latex vessels, would influence yield. Therefore, if tapping is carried out, when atmospheric conditions facilitate a higher turgor pressure, a higher yield can be expected. The observed increase in the dry rubber content during mid-day as compared to night and early morning could be explained, assuming a lesser extent of dilution reaction after tapping (Gooding, 1952 b). A high initial rate of flow during night and early morning (Paardekooper and Sookmark, 1969) would result in a higher volume of latex and this will offset the effect of a slightly lower d.r.c. content, on yield. These studies indicate the importance of time of tapping on yield.

b. Length of the tapping cut

Length of the tapping cut in relation to the circumference of the tree is an important factor determining yield. Common systems of tapping include full spiral cut (S/1) half spiral cut (S/2) and one-third-spiral cut (S/3). Ham (1940) demonstrated that while the yield increases with increasing the length of the tapping cut, the yield per unit length of tapping cut decreases. Frey-wyssling (1933) observed that there was clonal difference in the rate of yield variation as influenced by varying the length of the cut. Differential response of high and low yielders to shortening the cut was observed by Ham (1940) who assumed that the ratio of yield to different lengths of tapping cut is dependent upon the horizontal length of the drainage area. Larger the drainage area, lesser would be the effect of increasing the tapping cut length on yield. In otherwords, high yielding trees respond less to increasing the length of the tapping cut. In actual large scale field experiments, Porwerda (1940), using clone LCB 1320, showed that shortening the cut from S/3 to S/4 gave only a slight decrease in yield. Further evidence on differential clonal reactions in yield response to the various lengths of tapping cut has been provided by Ng _et al_ (1969). It has also been demonstrated that better drainage of the panel can be obtained by the use of shorter, regularly spaced tapping cuts (Langlois, 1969 b). Recently acquired knowledge on the latex flow offer better explanations for these earlier observations. Milford _et al_ (1969) have found that clones with low plugging index showed no response to full spiral tapping, while clones with high plugging index responded well. Southorn and Gomez (1970) have demonstrated that lengthening of the cut tends to lower the plugging index, resulting in enhanced yield. Therefore a low response to the lengthening of the cut by a clone with low plugging index is understandable.

Lengthening of the cut would result in an extended drainage area. Sethuraj et al (1974 c) and Sethuraj and George (1976) have shown that an extended drainage area per se can lower the plugging index. It can thus be concluded that in clones having larger drainage area and a lower plugging index, lengthening of the cut would have comparatively lesser influence on yield.

Another indirect effect on the length of the cut on yield is mediated through its effect on the rate of girthing. Lengthening of the cut to full spiral has a depressing effect on the girth increment (Wa, 1941; De Jonge, 1965, 1969 b; Tjasadihardja, 1973). Results of the large scale experiments of Ng et al (1969) and Paardekooper and Retana (1971) also show that retardation of girth increment is related closely with the length of the cut. Lengthening of the cut is more deleterious for girth increment than a higher frequency for a given tapping intensity (De Jonge, 1969 b; Ng et al 1969).

c. Number of tapping cuts

Dijkman (1951) has reviewed the earlier work on tapping systems with more than one tapping cut. Results from the experiments of Kuneman and De Jonge (1940), Schmole (1949), Huyzer (1941), Schweizer (1941) and Vollema (1941) offer the following general conclusions: By operating two cuts, the area of latex extraction and regeneration is extended and hence the productivity is enhanced. The two cuts operate independently in a physiological sense as long as their drainage areas do not merge. The dry rubber content and the composition of the latex collected from upper and lower cuts might vary. If the two cuts are too close, the drainage areas may merge each other. The common systems of tapping with two cuts are 2 S/2 d/3 (133% intensity), 2 S/3 d/2 (133% intensity) and 2 S/2 d/2 (200% intensity). Based on the assumption that the two tapping panels are physiologically independent, Dijkman (1951) reasoned that when a clone stands a tapping intensity of S/3 d/2 (67% intensity), then it can be tapped 2 S/3 d/2 (133% intensity), provided a sufficient distance is left between the cuts. De Jonge (1965) after extensive studies concluded that double cut systems might affect the girthing and such systems were considered unsuitable for young trees. Ng *et al* (1965) observed that double cut systems would be profitable after B-panel. The claim of Tobin (1965) that S/2 d/2 (2x2 d/4) tapping system was advantageous over other double cut system of equal intensity was later disputed by De Jonge (1967). Studying the physiological aspects of double cut system, Sethuraj and George (1971) found that opening of the upper cut might lower the plugging index of the lower cut, resulting in enhanced yield and they ascribed this phenomenon to merging of the two drainage areas.

d. Depth of tapping

The number of latex vessel cylinders increase in a centripetal direction. As a result, the number of cylinders, which are opened by the cut, increase as the tapping cut is made deeper into the tree. Because of this, the yield will be more with an increasing depth of the tapping cut (Dijkman, 1951; De Jonge and Warrier, 1965). Unfortunately if the tapping is made too deep, the cambium is liable to be injured. De Jonge (1969 a) has demonstrated that deep tapping results in prolonged duration of latex flow and reduced d.r.c. Even girth increment was found to be affected by the depth of tapping.

Deep tapping can theoretically be expectedto result in a lower plugging index, as the lutoids of the inner younger vessels might be more stable, compared to those in the outer older vessels.

e. Frequency of tapping

Frequency of tapping is a factor which would influence the physiology of the tree as well as the yield from the tree. While a high frequency of tapping would affect the physiological balance between extraction of latex and its replenishment in the latex vessels, too low a frequency would result in reduced yield. The different frequencies of tapping generally practiced are d/1 (daily tapping), d/2 (alternate daily), d/3 (once in three days) and d/4 (once in four days).

Different workers, using different planting materials and different systems of tapping have obtained a spectrum of diverse results that a generalised conclusion is impossible. This review aims at drawing general conclusions of physiological significance in relation to frequency of tapping, rather than to summarise the various results reported. Ng et al (1969), from results of large scale experiments, have confirmed many earlier observations that low frequency systems resulted in high yield per task per tapping. For a given tapping cut length, a general inverse relationship between frequency of tapping and yield per tapper, was observed. In the case of certain clones, at least, the cumulative yields over three years in young trees was better with low frequency systems (Ng et al, 1969). The increased yield obtained for low frequency system in the experiments of Ng et al (1969) could be attributed to an increased level of late dripping recorded by them. How exactly a longer rest period between tappings, as in the case of d/3 system as compared to d/2 system, results in a lower plugging index is obscure.

Ng et al (1965) has also observed that reducing the frequency of tapping at a constant length of the cut did not result in any appreciable difference in girth increment. Further experiments by Ng et al (1969) also have confirmed this contention. They have found that for a given length of the cut, reducing the frequency of tapping did not result in any significant increase in the rate of girthing. However, all periodic systems (with a period of tapping rest) gave better girth increment than the corresponding continuous system. Such findings have been reported by earlier workers also (Shearlow [illegible], 1961; Rooth, 1961). De Jonge (1969 b) observed that for a given length of tapping cut rate of girthing is related to the yield and not necessarily to tapping frequency.

Incidence of dry trees was however related more to the frequency of tapping than to the length of the cut for a given tapping intensity (Sands, 1921; Sharples and Lambourne, 1924; Schweizer, 1949; Ng *et al*, 1969; Bealing and Chua, 1972; Paranjothy *et al*, 1975). De Jonge (1969 b) however observed that within tapping intensities (decided both by the length of cut and tapping frequency), there were no differences in the incidence of dry trees. In certain clones however, the length of the cut was closely related to incidence of dryness. The view expressed by Schweizer (1949), that a short cut has a smaller area of flow and that by increasing the frequency of tapping, the balance between extraction of latex from unit area and the rate of regeneration will be upset, seems to be physiologically sound.

f. Bark consumption in tapping

Early experiments by Maas (1925, 1926) and Schmole (1938) have established that above certain minimum bark consumption, increasing the thickness of bark shavings has no effect on yield. Low frequency tapping however results in more drying of cut surface, making a thicker bark shaving per tap necessary for good yield. A bark consumption of 20-22 cm per annum is often recommended (De Jonge, 1969 b).

ii. Use of yield stimulation chemicals

The growth regulators 2,4-D and 2,4,5-T and lately the new compound Ethrel, have been used extensively as yield stimulant for Hevea. The effectiveness of these stimulants are influenced by various factors. As the work on yield stimulation has been reviewed in detail elsewhere in this review, only the factors which influence the effectiveness of stimulants would be considered here. The chemical used, concentration of the chemical, method of application, duration of continuous application, clonal response, nature of bark, age of the tree, tapping system and climate during application are factors which would influence the effectiveness of stimulation.

a. Chemicals used as stimulant

Substituted phenoxy acetic acids, 2,4-D and 2,4,5-T and similar derivatives, have been used for many years for stimulating yield (Chapman, 1951; Baptiste and De Jonge, 1955; Blackman, 1961; Abraham and Tayler, 1967).

Abraham et al (1968 a) screened a series of chemicals and it was found that with the exception of 2,4-dichloro 5-flurophenoxy acetic acid, none of the other compounds tested had significantly better stimulating activity than 2,4-D or 2,4,5-T. By this time it was recognised that the ethylene inducing capacity of these chemicals was responsible for many of their physiological actions (Morgan and Hall, 1962; Maxie and Crane, 1967). The first evidence for the effectiveness of 'ethylene-generator' chemicals like 2-chloroethylphosphonic acid (ethephon) was provided by Abraham et al (1968 b). It has now been generally recognised that Ethrel (containing ethephon) is far more effective as yield stimulant than 2,4-D or 2,4,5-T and is devoid of the undesirable side effects on bark noticed for the latter compounds (Abraham, 1970).

This chemical has now been proved by large scale testing (Abraham et al, 1973; Abraham et al, 1975; George et al, 1974; Gener and du Plessix, 1975; Lukman and van Brandt, 1975; RRCT, 1970/71; Chandrasekhara, 1973). There is however a range of new experimental chemicals under testing, but they are not under commercial use, and are not considered here.

b. Concentration

It has been shown by Baptiste and De Jonge(1955) and later by Blackman (1961) that in the case of 2,4-D or 2,4,5-T, over the tested range of active ingredient concentration from 0.3 to 2.7 % in the formulation, the yield from a 1 % concentration of the stimulant gave the maximum economic response. Abraham *et al* (1973) have reported the effect of different concentrations of ethrel. While some clonal variation with regard to the optimum concentration was noticed, ethrel formulations of 10% a.i. ethephon is generally recommended.

c. Method of application

Two methods of stimulant application, bark application (below the tapping cut, after slight scraping) and panel application (above the tapping cut, in renewed bark) are commonly used in plantations. Certain advantages of panel application claimed by Puddy and Warrier (1961) were nullified by the bark damage observed when 2,4-D or 2,4,5-T is used as the stimulant (De Jonge, 1957; Gomez, 1964). Anliker and Scanlon (1955) however suggest that panel application can be safely carried out by reducing the concentration of the stimulants. Bark application method has been successfully adopted for 2,4-D and 2,4,5-T. The observation of Baptiste and De Jonge (1955) that higher yielding trees responded better to bark application and lower yielding trees better to panel application does not seem to hold good in all cases. Both these methods are commonly adopted for the application of Ethrel also (Abraham *et al*, 1971). P'ng *et al* (1973) reported yet another method: groove application. This is direct application to the cut surface of the tapping cut after pulling out the lace. The method requires only relatively lesser quantity of the stimulant.

d. Duration of continuous application

A declining trend with repeated application of 2,4-D (Abraham and Tayler, 1967) and Ethrel (Abraham *et al*, 1971; Abraham *et al*, 1973; Ho *et al*, 1973; George *et al*, 1976) has been generally recognised. When the price of rubber is low the prolonged use of Ethrel may not even be economical (Pee and Abraham, 1972; George et al, 1976) due to this declining trend in response.

e. Clonal variation in response

It is generally recognised that there is clonal variation in the response to stimulation (Levandowsky, 1961; De Jonge, 1955). Systematic large scale studies on this aspect have been conducted by Abraham (1970), Abraham *et al* (1973), Hochaiyee *et al* (1973) and Mainstonne *et al* (1973). The general conclusion which could be drawn from these studies indicate that clones RRIM 605, 610, 612, 623, PB 86, G1.1 and PR 107 gave better response than RRIM 617, 600, GT.1 and PB 5/51.

The initial good response shown by clone Tjir 1 however is often followed by a marked declining trend in response. Milford *et al* (1969) have found that high plugging clones respond better to stimulation compared to low plugging clones. The clonal variation in response may however be influenced by other agroclimatic factors as well (George *et al*. 1974).

The condition of the bark itself might influence the response to stimulation. One of the causes of clonal variation in response could well be the differences in the structure of bark (De Jonge, 1955). The age of the tree also will determine the bark condition.

f. Climate

The effect of climate on response to yield stimulation has been reported by Abraham and Tayler (1967) and Sethuraj and George (1975). Usually, the response in terms of percentage increase in yield is higher during periods of drought.

g. Interaction with tapping systems

It has been well recognised that with increasing tapping intensity, the response to yield stimulation declines (De Jonge, 1955). The interaction between tapping systems and stimulation has been elucidated by large scale experiments by Abraham (1970), Abraham *et al* (1972), George *et al* (1974) and Abraham *et al* (1975).

6. YIELD STIMULANTS AND THEIR ACTION

(1) Early work

The history of chemical yield stimulants in *Hevea brasiliensis* has already been reviewed by Blackman (1961), Abraham and Tayler (1967), Sethuraj

(1968) and Boatman (1970). Kamerun (1912) was the first to report the stimulatory effect of periodic scraping of the outer bark on yield. Baptiste (1939) thought the scraping would invoke a wound reaction, resulting in growth regulating substances. This contention was confirmed later by Chapman (1951) who reported the results of experiments (initiated in 1937), using mixtures of vegetable and mineral oil, cow-dung, plant nutrients and sulphur in various forms. He concluded that all the effective mixtures contain plant hormones. Baptiste and De Jonge (1955) tested the effect of IBA, NAA, 4-CPA, α-NOXA and β-NOXA in paraffin oil emulsion at 0.1 and 1% concentrations. Chapman (1951) on the other hand, reported very large increases in yield by applying 2,4-D to scraped bark below the tapping cut. Having tested a total of fifty different preparations using 2,4,-D, NAA, etc. he found that 1% 2,4-D was the most effective. Compagnon and Tixier (1950) also showed that an injection of a few grams of 2,4-D could produce a good yield response. Later, Baptiste and De Jonge (1955) confirmed the results of Chapman. In further experiments, they tested 2,4,5-T also and found it to be very effective as yield stimulant. Although extensive trials have been carried out at the RRIM from 1956, out of the 89 compounds screened only 2,4-dicloro-5-flurophenoxy acetic acid showed significantly better stimulating activity than 2,4-D or 2,4,5-T.

Making an entirely different approach, Tixier (1951) reported that copper sulphate injection can also effectively increase yield. Substances like manganese sulphate, Boric acid, Iron and Zinc sulphate were not very effective. Effect of $CuSo_4$ was confirmed by Banchi and Poliniere (1969) also. Wiersum (1953) found that copper sulphate applied as a paste to the bark, could also increase latex yield. Mainstone and Tan (1964) reported a synergistic effect between 2,4-D or 2,4,5-T and copper sulphate. Copper sulphate is not, however, widely used because copper contamination would affect the manufacturing properties of rubber. The results of Taysum (1961) with antibiotics were not consistent. Abraham et al (1968 a) has summarised the early results and maintained that 2,4-D and 2,4,5-T were the best materials for commercial use, among the compounds tested till then.

Developing on the concept that the action of the auxin type growth regulators such as 2,4-D and 2,4,5-T might mediate through the production of ethylene in plant tissues (Morgan and Hall, 1962; Maxie and Crane, 1967). Abraham et al (1968 b) tested a variety of chemicals capable of producing ethylene in plant tissue, as possible yield stimulants in rubber. This approach was more than justified with the discovery of 2-Chloro ethyl phosphonic acid (ETHREL), as a very potent yield stimulant. Once absorbed by the plant tissue, 2-chloro ethyl phosphonic acid, evolves ethylene by disintegration, while 2,4-D or 2,4,5-T promotes the cellular production of ethylene in the tissue over a period. Ethylene and Acetylene gas have also been shown to enhance latex flow (Abraham *et al*, 1968 b). Search for more effective and cheaper chemicals is continuously being done (Pakianathan, 1970, 1972; Dickenson *et al*, 1975).

(2) Mechanism of action of yield stimulants

Blackman (1961), Abraham and Tayler (1967), Sethuraj (1968), Abraham et al (1968 b), Ribaillier and D'Auzac (1970) and Ribaillier (1972) have reviewed the conceptional development in the mechanism of action of yield stimulants. It is logical to assume that the increase in yield after stimulation would be the result of either an increase in the dry rubber content or in the volume of latex or in both. The dry rubber content generally decreased consequent to yield increase after stimulation (De Jonge, 1953; Chapman, 1951; Ho and Paardekooper, 1965). On the other hand, duration of flow was found to be prolonged resulting in late dripping (Chapman, 1951; De Jonge, 1953; Ho and Paardekooper, 1965; Schweizer, 1953). Another effect of stimulation was considered to be the extension of drainage area (Chapman, 1951; Weirsum, 1957; Ho and Paardekooper, 1965; Schweizer, 1953).

i. Effect on d.r.c. and metabolic activity

It can be assumed that with greater loss of latex per tapping, consequent to stimulation, the trees inherent ability to regenerate rubber is insufficient to replace the lost of rubber completely, resulting in a lower d.r.c. The fact that the drop in d.r.c. is more in the clones which respond well (De Jonge, 1955) supports such a contention. The very fact that the dry rubber content decrease after stimulation discounts the possibility that the enhanced yield is due to its effect on rubber biosynthesis. Blackman (1961, 1964) however holds that some indirect effect on the biosynthesis cannot entirely be ruled out. Tupy (1973 a, b) tried to relate the enhanced yield with the increase in sucrose content and an enhanced invertase activity in latex after stimulation. He also provided some data that the pH of the latex increases after stimulation and assumed that the enhanced invertase activity could be ascribed to this altered pH. Tupy (1973 a) has however not attempted to explain how an enhanced biosynthetic rate could result in an enhanced flow as his data indicate that the increase in yield was the result of enhanced volume of latex. Till such a relationship is established, caution is warranted in accepting the contention that the increase in yield after stimulation is a consequence of higher rates of metabolism, or translocation of carbohydrates. The small number of replications in the experiments of Tupy (1973 a) makes it desirable to reinvestigate these effects. It may also be mentioned that Sethuraj et al (1974 c) could not obtain any statistically significant increase in the content of non-reducing sugars after stimulation.

ii. Effect on mineral composition of latex

A few workers have turned their attention on the changes in the mineral content of latex as a result of yield stimulation. Regular but slight increase in the potassium content and a greater increase in the phosphorus content were reported both with 2,4-D and $CuSO_4$ treatments (Beaufils, 1954). A general increase in the Cu content also is reported (Beaufils, 1954; Ho and Paardekooper, 1965). Correlations between increases in Cu content and yield have also been obtained. High negative correlations between response to stimulation and potassium content in latex before stimulation as well as a positive correlation between response and Mg/PO_4 ratios in latex before stimulations are reported (Puddy and Warrier, 1961). Clones with low Cu and high Mg are reported to respond better (Ho and Paardekooper, 1965).

It would thus appear that K, P and Cu contents of latex might increase after the application of yield stimulants and that the clones with low concentrations of these elements in latex give better response to stimulation. High content of Mg as well as high ratio of Mg/PO_4 in latex is reported to be associated with frequent premature coagulation and coagulation at the tapping cut (Beaufils, 1954). If the relationship between duration of flow and tendency of latex to pre-coagulate at the tapping cut is recognised, then it follows, that clones with factors responsible for shorter duration of flow may respond better to yield stimulation.

Our knowledge is still imperfect as to how the mineral balance in latex is changed as a result of stimulation. More imperfect is our knowledge regarding the role of high content of K and Cu in the mechanism of yield stimulation. Further studies on the effects of stimulants on the membrane permeability and the possible role of the mineral elements on the lutoid stability might throw light on the mechanism of stimulation.

iii. Effect on latex flow

Teirsum (1957) suggested that the viscosity of latex after stimulation may be reduced. But later work, using better techniques, could not confirm this hypothesis (Boatman, 1966). Changes in latex viscosity were not correlated with yield increases. But relaxation of the restrictions to flow inside the latex vessels is one of the possible effects. De Jonge (1955) looked for effects on the number and size of the latex vessels and found these were not affected by stimulation. Boatman (1966) also could not find any difference between a treated tree and control in the extent of latex vessel collapse after tapping.

Blackman (1961) speculated that 2,4,5-T might operate by changing the plasticity of the cell walls and thereby increasing the osmotic concentration in the latex vessels. With a steeper pressure gradient thus developed, the initial surge of the latex may be greater. But surprisingly, the actual measurements of the turgor pressure of stimulated trees have recorded lower or equal values, compared to the control trees (Chua, 1965; Buttery and Boatman, 1967). Moreover, no appreciable change in osmotic pressure of the first latex samples during flow was obtained by Boatman (1966). But a slight increase in the osmotic concentration in the later samples of latex during flow was encountered in the stimulated trees. It was postulated that 2,4,5-T might promote either in the inflow of solutes into the latex vessels after tapping or the release of solutes into the latex serum from the lutoids. Our knowledge in this field is so insufficient to make further comments on this matter.

It is interesting that despite greater dilution of latex, the turgor pressure at the time of latex flow is low in the yield stimulated tree. While a more efficient flow restricting process operating at the out end of the latex vessels in the untreated tree contributes to the development of turgor pressure in the latex vessels, an enhanced flow of latex towards the cut in the stimulated trees may not facilitate any increase in the turgor pressure in the latex vessels, despite a greater dilution. Boatman (1966) has recorded a higher initial flow during the period immediately after treatment and a longer duration of flow without any higher initial flow a few days after stimulation and suggested that two distinct mehanisms may be involved. But it is doubtful if the results are sufficient proof in support of that contention.

A major break-through was achieved by the finding of Boatman (1966) that flow restricting process was less efficient in stimulated trees.

Although it can now be accepted that yield stimulating substances exert their influence by lowering the plugging index (Milford <u>et al</u>, 1969), the actual mechanism is not yet clear. Chua (1965) has suggested that the greater dilution in stimulated trees during early flow, by reducing the viscosity, enables a greater rate of flow to sweep the floculating material out of the tree more efficiently. But evidence for a lowering of viscosity is lacking (Boatman, 1966) and considering the prolonged duration of flow, there is little difference in dilution during flow in the treated tree as compared to control. Nevertheless it can be assumed that inhibition of flow restricting process itself may result in an enhanced flow rate.

iv. Role of ethylene

Abraham *et al* (1968 a) after screening various chemicals and their mode of action as stimulants have concluded that all effective compounds act by increasing the duration of flow. Another important finding of Abraham *et al* (1968 b) was that all the effective non-caseous stimulants of latex flow, seem to have one common feature, viz. production of ethylene. While ethylene gas as well as ethylene-releasing chemicals provided ethylene to the tissues directly, synthetic auxins and $CuSO_4$ induce the tissue to produce ethylene. Formation of ethylene by plant tissue, when treated with auxins, copper sulphate or herbicides, or when subjected to injury, has been reported by Pratt and Goeschl (1969). Archer *et al* (1969 b) have furnished evidence that *Hevea* tissue produces ethylene after the application of 2,4,5-T or 2,4-D. The stimulatory effect of Acetylene however can be ascribed to its close structural anology with ethylene.

v. Effect on lutoid stability

Having accepted the contention that the yield stimulatory effect of the known chemicals is mediated through the formation of ethylene, the exact role of ethylene in enhancing latex flow is still obscure. As the relationship of lutoid particles with the process of plugging has been amply demonstrated, it is only natural to suspect that the effect of ethylene might be exerted through some changes in the lutoid stability. Though not fully demonstrated, the indication obtained from the work of Ribaillier (1970) that hormone stimulation might have certain stabilizing effect on lutoids is worthy of special mention. A greater influx of water into the latex vessels during latex flow, has been demonstrated by Pakianathan and Milford (1973), from their data on the osmotic concentrations of latex fractions collected after tapping. It is interesting that the lutoids exhibit a greater stability in spite of such a greater dilution in stimulated trees. Our knowledge of the mechanism by which the membrane stability of lutoid is enhanced is still imperfect. A change in the surface properties of the lutoid as assessed by rheological measurements after stimulation with ethrel and acetylene has been reported by Yip _et al_ (1974). Another interesting observation of these authors was the increase in anionic activity in latex C-Serum after stimulation. As the anionic activity of C-Serum is considered to be a stabilising factor against flocculation (Southorn and Yip, 1968 b), this aspect of investigation merits further intensification.

vi. Effect on drainage area

Plugging index is a function of both the inherent flocculating potential of the latex and the force of the flow which might sweep out the microfloce that are formed, out of the latex vessels. The biophysical factors influencing the rheological properties of latex, might influence the drainage area and the process of plugging. Sethuraj *et al* (1974 c) and Sethuraj and George (1976) have established that the extent of drainage area *per se* can influence plugging index. The assumption of Sethuraj *et al* (1974 c, 1975) that action of stimulants is mediated through an extension of drainage area was further confirmed by Pakianathan *et al* (1975). The only conceivable effect such an extended drainage area on plugging index can exert is on the flow rate. A delayed bottom fraction particle accumulation within the cut end of latex vessels after stimulation was observed by Pakianathan and Milford (1973). While our understanding of how ethylene can induce enhanced latex flow was greatly improved in recent years, there are many unanswered questions which haze our present concepts.

7. BROWN BAST

Brown bast is essentially a disorder of the latex vessels and the symptoms do not spread from virgin bark to regenerated bark or from one regenerated panel to another, indicating continuity of the laticiferous vessels is necessary for its spread (Paranjothy *et al*, 1975). The presence of discoloured patches in and below the tapping cut form the chief characteristic of the disease. The affected portion of bark stops yielding latex. Usually the actual onset of brown bast is preceded by an excessive dilution of latex and consequent late dripping (Dijkman, 1951). Whether this is a general rule for all the above classes of brown bast is doubtful. It has been noted that certain trees go dry with no earlier late dripping. Sethuraj (1968) has pointed out the possibility that the different types of brown bast (Compagnon et al, 1953) might have different causative factors. Schweizer (1936) held the view that the development of this syndrome is related to the nutrient status and it was demonstrated that the tree ring barked above the tapping cut succumbed to dryness readily. This result as well as that obtained from surgically isolated bark (Chua, 1966) cannot be considered as proof for the nutritional involvement as the physiological strain and abnormal metabolism forced upon the tree by such experimental techniques need not be the same as those which predisposes brown bast under normal conditions.

However, the observations of Vollema (1949) and Compagnon _et al_ (1953) that incidence of brown bast is greater during and after wintering deserve further investigation. Fluctuation in the water relations as a consequence of excessive removal of latex has been suggested by Sharples and Lambourne (1924) to be the causative factor. Frey-Wyssling (1932 a) held the contention that an abnormally strong dilution reaction during latex flow would favour the development of brown bast. Sethuraj *et al* (1976) found that in intensively tapped trees initial flow rate and turgor pressure are reduced before the onset of dryness. Beaufils (1954), however, considered mineral metabolism to be the causative factor. Rands (1921) and Rhodes (1930) suggested that the cause of brown bast may be related to the phenomenon of wound reaction and Bealing and Chua (1972), based on their experimental results on the latex composition of brown bast affected trees, expressed the view that wound reaction might lead to a reduction in the permeability of the wall of the latex vessel resulting in a reduced availability of assimilates. These authors have reported a progressive decline in the cation concentration of latices of the trees subjected to intensive tapping to induce brown bast. Conversely, Paranjothy *et al* (1975) obtained a higher concentration of cations in latices of intensively tapped trees and it has been suggested that changes in the cation concentration might play a role in the observed deterioration of lutoids. With the aid of electron microscope, these authors have provided evidence for the flocculation of rubber particles around lutoid particles in such latices and proposed a hypothesis that coagulation of rubber particles inside latex vessels due to decreased lutoid stability might be the causative factor for the onset of brown bast syndrome. They assume that the histological characteristics of brown bast affected bark, such as tyloses and stone cells, follow the development of disorders caused by damaged lutoids while features such as tissue necrosis and hyperplasia of the surrounding cells follow the death of the vessels. As these authors failed to detect any phloem necrosis, they rule out the possibility that phloem necrosis or senescence could be the primary cause of this disorder as suggested by Horne (1925) and Chua (1966).

The spectrum of views on the physiology of brown bast leave behind the vital question how only a few trees in a plantation of monoclonal budded material develop the brown bast symptom. Much more work is warranted to elucidate the different stages of physiological disorders which culminate in the brown bast syndrome.

SECTION II

EFFECT OF ENVIRONMENTAL FACTORS ON YIELD

INTRODUCTION

Influence of environmental fluctuations on yield in *Hevea* is well recognised. Surprisingly, systematic and scientific enquiries to elucidate the relationship of yield with different environmental factors are sparse. An attempt had been made by Ninane (1967 a) to relate the variations in the environmental factors with changes in the transpiration rate at different hours of a day. He contended that variation in yield when a tree is tapped at different times of the day is related to the changes in the water status of the tree.

The role of environmental factors in the seasonal variations in yield however, requires further elucidation. Studies of Sethuraj (1968), Paardekooper and Samosorn (1969) and Sethuraj and George (1975) have shown that seasonal variations in yield are mediated through the changes in the latex flow pattern.

A better insight into the roles of individual environmental factors in seasonal variations in yield would prove useful as the performance of rubber trees in any new area could then be predicted if the meteorologic data are available. An understanding of the physiological basis of yield variations as influenced by climatic and edaphic factors would also be rewarding.

In the present study, experiments were planned to get a clear understanding of the pattern of yield variations in different periods of the year, the physiological basis of such yield variations and the effect of soil moisture on latex flow pattern. The relative importance of rain fall and leaf maturity on the pattern of yield increase after the annual tapping rest was also studied. In order to obtain a clear picture of the direct as well as the indirect effects of environmental factors on yield, the technique of path coefficient analysis was used.

MATERIALS AND METHODS

1. Experimental materials and locations

(a) Hevea brasiliensis clones Tjir 1, Gl 1 and PB 86 were chosen for the study on the pattern of monthly yield variations. The yield (dry rubber) from selected tapping blocks of these popular clones was recorded for three consecutive years from 1973, at

Pullengode Estate, situated at the Malapuram District of Kerala. The trees were tapped under S/2, d/2 * system (half spiral cut andalternate daily tapping) on Panel C (first renewed bark).

(b) Role of initial flow rate and plugging index in the monthly yield variations were studied in four clones (Tjir 1, LCB 1320, BD 10 and PB 86) with five replications, planted at the experiment station of RRII. These trees were also being tapped under S/2 d/2 system, on Panel B (second panel of virgin bark).

(c) In the experiment to study the effect of soil moisture status on plugging index and initial flow rate (the factors which determine the yield of latex) clones Tjir 1 and Gl 1 were studied. These clones were selected, considering their varying response in yield to soil drought. There were six trees under each clone which were being tapped under S/2 d/2 system of tapping on Panel C (first renewed bark). This experiment was conducted at the Rubber Research Institute of India (Kottayam District).

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* The current tapping notations are used; it may however be mentioned that the International Rubber Research and Development Board nominated a Committee to revise the tapping notations and this Committee finalised the draft rules of Revised International Tapping Notations during the IRRDB Symposium at Jakarta, Indonesia, in November, 1976. The new rules will be operative only after the official announcement.

(d) The influence of rainfall on the pattern of yield increase after resumption of tapping after the period of annual tapping rest was studied utilising the data on yield and rainfall at the Rubber Research Institute of India (RRII) experiment station. The selected tapping blocks were clone trial areas, composed of different RRII clones.

(e) The yield data collected from one tapping block comprising of the RRII 1955 clones were utilised for the path coefficient analysis.

2. Recording Procedure

(a) Meteorologic data and soil moisture.

The environmental factors such as maximum and minimum temperature, morning and afternoon soil temperature, morning and afternoon humidity, wind velocity, sunshine and rainfall were recorded in the meteorological station of the RRII experiment station. Soil moisture was recorded by using gypsum blocks. These were installed at a depth of 30 cm three meters away from the experimental trees. The moisture status was recorded by Bouyoucos moisture meter, twice a month for one year on the same days when the plugging index and initial flow rate were recorded.

(b) Yield

In the experiments where one tapping block was taken as one plot, the latex of each experimental block was separately coagulated, pressed to sheets, dried in smoke house for four days and weighed. In the case of single-tree single-plot designs, yield of rubber was recorded by cup-coagulation method. The latex from each tree was coagulated in the collection cup itself, by adding appropriate quantity of 1% formic acid and the cuplumps were collected separately, dried in smoke house for 3 weeks and weighed. As the lumps retain moisture even after prolonged smoke-drying a correction factor of 10% was applied to account for the water content.

In the experiment to study the pattern of monthly yield variations, recordings were done for three consecutive years from 1973. There was however no tapping and hence no yield recordings during November, 1973 and August, 1974, for reasons beyond control. For studying the role of initial flow rate and plugging index in monthly yield variations, yield was recorded twice a month for one year. The initial flow rate and plugging index were also recorded on the same days.

The yield data recorded on all tapping days from April 1974 to January 1975 were utilised for the path coefficient analysis. The period of annual defoliation and refoliation was however avoided considering the possibility that the influence of these factors might vitiate the direct effect of environmental factors on yield.

(c) Estimation of initial flow rate (IFR)

The total volume of latex for the first five minutes after tapping was taken as the initial flow rate. Corrections for the tree-to-tree variation in girth were made by adjusting the value for a standard girth of 50 cm.

(d) Estimation of plugging index (PI)

The plugging index (PI) was calculated according to the formula of Milford et al (1969):

$$PI = \frac{\text{Mean latex yield per minute over first 5 min} \times 100}{\text{Total latex yield}}$$

3. Path coefficient analysis

The technique of path coefficient analysis was used to get a clearer picture of the direct and indirect effects of different environmental factors on yield; the path of indirect effect of individual factors, as also the total direct effect, becomes evident in path coefficient analysis. The correlations between the above factors and yield were worked out. In the case of rainfall, the total rainfall during the fortnight previous to each tapping day was taken for the computations. The correlation coefficients were partitioned into direct and indirect effects by path coefficient analysis by the method of Li (1956).

RESULTS

Pattern of monthly variations in yield

The data on average monthly yield of clone Tjir 1 during the years 1973, 1974 and 1975 are presented in figures 2.1, 2.2 and 2.3 respectively along with the rainfall pattern. The pattern of seasonal variation differed from year to year. While the month of highest yield during both 1973 and 1975 was July, in 1974 the highest yield was recorded in the month of October. As is clear from Figures 2.1, 2.2 and 2.3 the peak period of rain fall during 1973 and 1975 was July, but in the year 1974 it shifted to October. The period from February to April represented the period of lowest yield in all the years studied. While the yield during the months of highest yield accounted for 14.41%, 14.66% and 12.43% of total yield during 1973, 1974 and 1975 respectively the lowest monthly yields during these years were of the order of 4.93, 4.62 and 4.71 percent of the annual yield (Table 2.1).

The Figures 2.4, 2.5 and 2.6 give the pattern of seasonal variation in yield in clone Gl 1 during the years 1973, 1974 and 1975 respectively. As in the case of Tjir 1 the lowest yield for all the three years was during April, but the month of highest yield varied from year to year: August in 1973, October in 1974 and July in 1975 (Table 2.2). The months of highest yield contributed 11.8%, 12.4% and 10.5% of the annual yields during these three years. The yields were only 5.41%, 5.22% and 5.14% of the annual yield during the month of lowest yield during the years 1973, 1974 and 1975 respectively.

Table 2.1

Monthly yield as percentage of annual yield in Clone Tjir 1

Month	Year		
	1973	1974	1975
January	11.11	11.40	9.98
February	5.69	5.87	5.44
March	5.30	5.32	4.87
April	4.98	4.62	4.71
May	6.90	6.77	7.83
June	10.50	9.78	10.36
July	14.41	9.20	12.43
August	12.44	*	8.37
September	10.16	9.92	8.43
October	9.08	14.66	8.27
November	*	11.72	9.15
December	9.47	10.75	9.89

* No tapping during November 1973 and August 1974.

Table 2.2

Monthly yield as percentage of annual yield in Clone Gl 1.

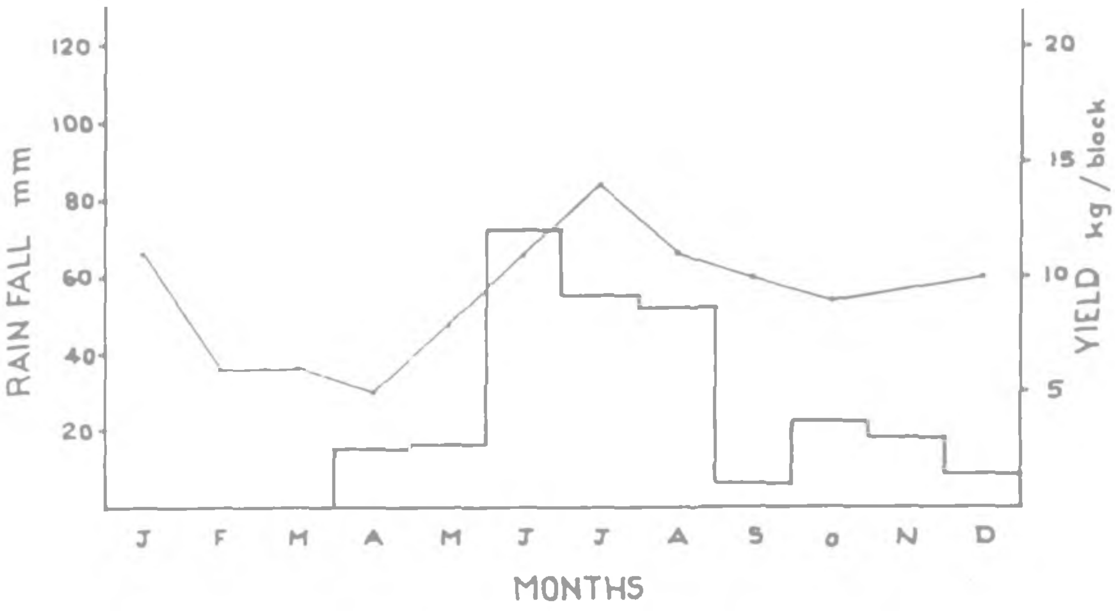
Month	Year		
	1973	1974	1975
January	10.81	9.41	8.53
February	7.33	7.81	7.52
March	6.80	5.96	6.03
April	5.41	5.22	5.14
May	6.60	8.13	7.06
June	11.07	10.01	9.72
July	11.50	9.65	10.43
August	11.76	*	8.03
September	10.06	8.78	8.73
October	9.45	12.40	9.15
November	*	11.44	9.36
December	9.20	11.20	9.76

* No tapping during November, 1973 and August, 1974

Fig. 2.1 : Monthly variations in yield (graph) in clone Tjir 1 and rainfall pattern (histogram) during 1973.

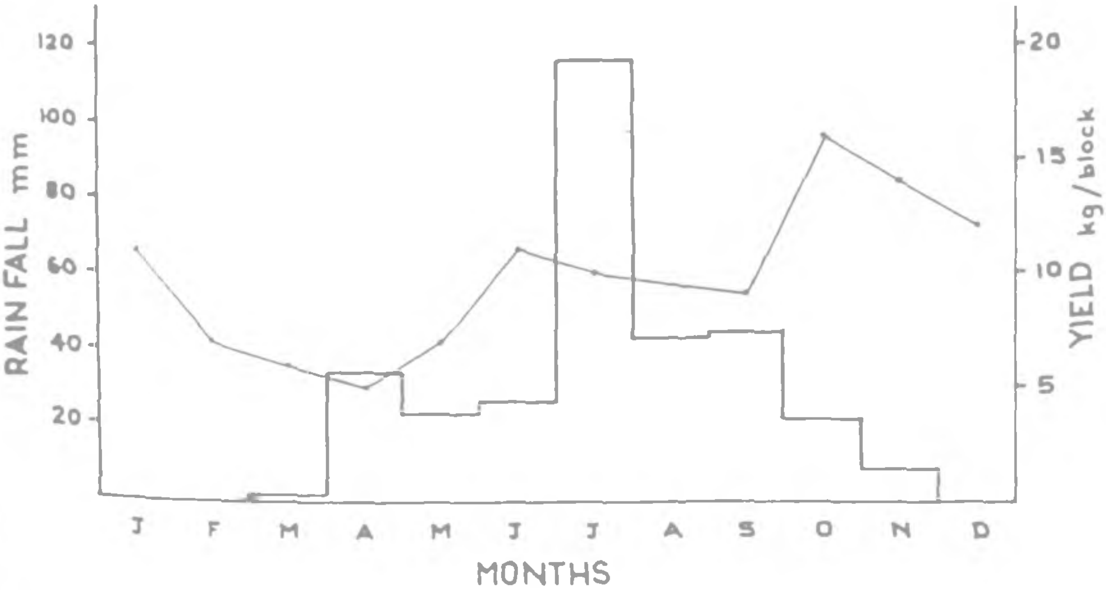
Fig. 2.2. Monthly variations in yield (graph) in clone Tjir 1 and rainfall pattern (histogram) during 1974.

FIG:2.1



RAIN FALL mm
120
100
80
60
40
20
20
15
10
5
YIELD kg/block
J
F
M
A
M
J
J
A
S
O
N
D
MONTHS

FIG:2.2



RAIN FALL mm
120
100
80
60
40
20
20
15
10
5
YIELD kg/block
J
F
M
A
M
J
J
A
S
O
N
D
MONTHS

Fig. 2.3 : Monthly variations in yield (graph) in clone Tjir 1 and rainfall pattern (histogram) during 1975.

Fig. 2.4 : Monthly variations in yield (graph) in clone Gl 1 and rainfall pattern (histogram) during 1975.

FIG: 2.3

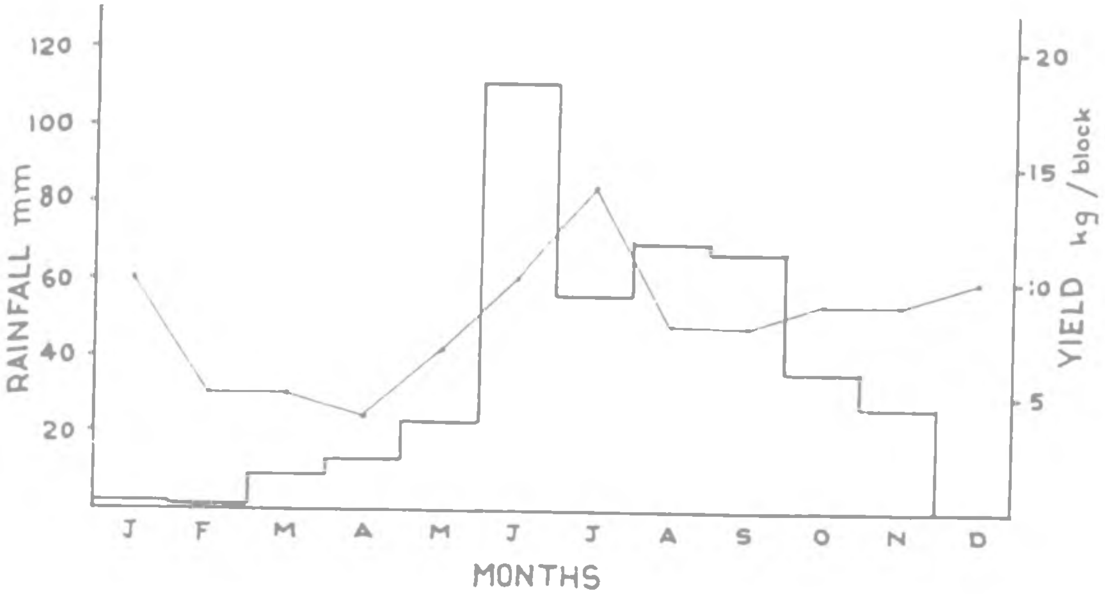

120
100
80
60
40
20
RAINFALL mm
20
15
10
5
YIELD kg / block
J
F
M
A
M
J
J
A
S
O
N
D
MONTHS

FIG: 2.4

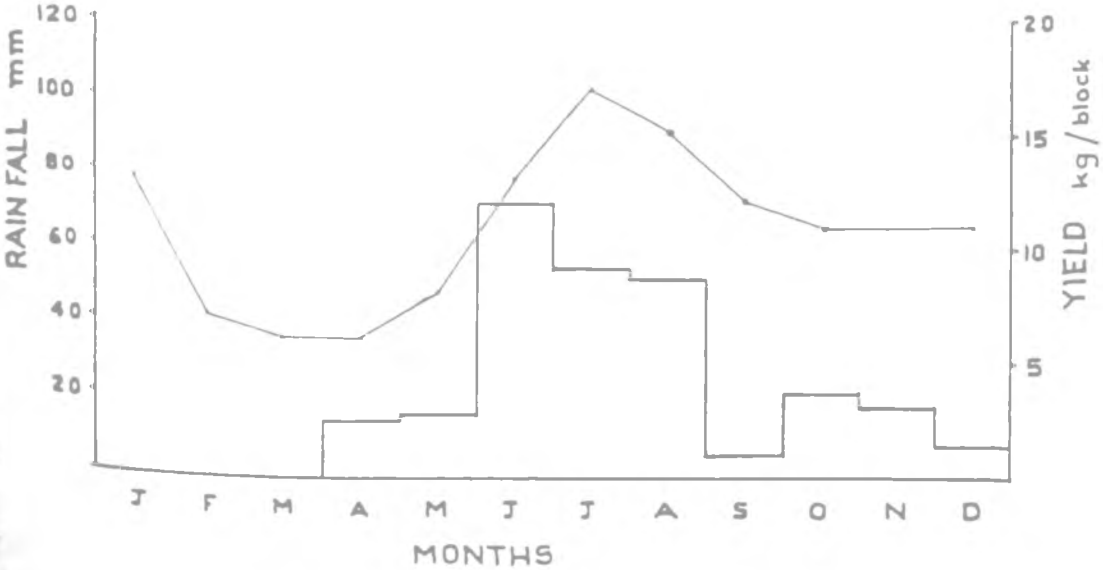
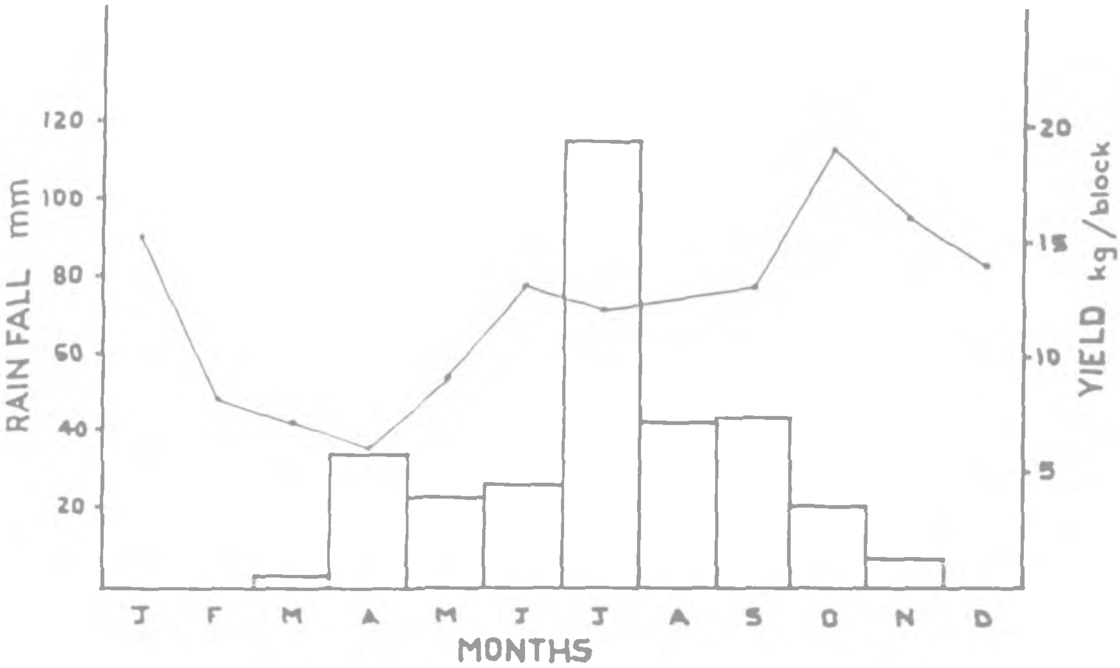

120
100
80
60
40
20
RAIN FALL mm
20
15
10
5
YIELD kg / block
J
F
M
A
M
J
J
A
S
O
N
D
MONTHS

Fig. 2.5 : Monthly variations in yield (graph) in clone Gl 1 and rainfall pattern (histogram) during 1974.

Fig. 2.6 : Monthly variations in yield (graph) in clone Gl 1 and rainfall pattern (histogram) during 1975.

FIG:2.5



RAIN FALL mm
120
100
80
60
40
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YIELD kg/block
20
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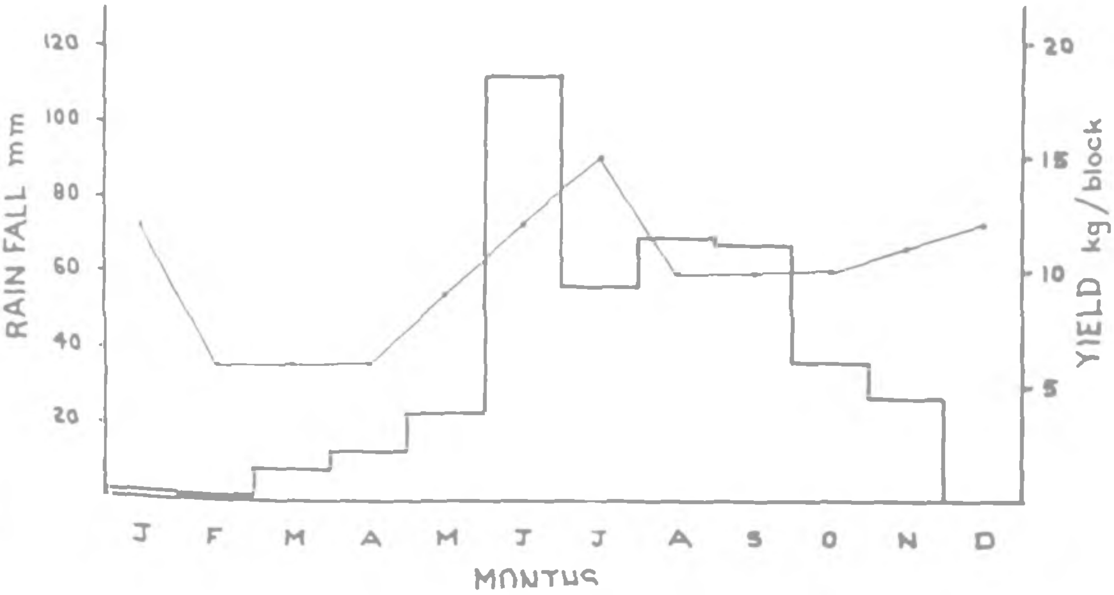
MONTHS

FIG:2.6



RAIN FALL mm
120
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YIELD kg/block
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D
MONTHS

The yield pattern was essentially the same in clone PB 86 also (Figures 2.7, 2.8 and 2.9). The percentage contributions by the month of peak yield to the annual yield during the years 1973, 1974 and 1975 were 13.97, 14.91 and 13.49 respectively. The corresponding figures for the months of lowest yield were 5.15, 4.31 and 4.46 percent of the annual yield (Table 2.3).

Seasonal variations in initial flow rate and plugging index and their relationship with seasonal variations in latex yield

The data on monthly average values for initial flow rate, plugging index and latex yield, expressed as percentage of annual average (=100%) in clones Tjir 1, LCB 1320, BD 10 and PB 86 are presented in Tables 2.4, 2.5, 2.6 and 2.7 respectively. Figures 2.10, 2.11, 2.12 and 2.13 depict the percentage increase or decrease of the above characters in different months compared to the annual average values.

An inverse relationship between the variations in latex yield and plugging index was evident for all the four clones studied. On the other hand a positive relationship between the initial flow rate and variations in latex yield was found to exist. This relationship was however, less specific in that the periods of highest and lowest initial flow rate did not necessarily

Table 2.3

Monthly yield as percentage of annual yield in Clone PB 86.

Month	Year		
	1973	1974	1975
January	10.73	10.14	9.79
February	6.10	6.64	5.12
March	5.59	5.17	5.16
April	5.15	4.31	4.46
May	7.48	6.82	6.70
June	11.06	9.79	10.46
July	13.97	9.63	13.49
August	11.35	*	8.38
September	10.16	8.71	7.99
October	8.83	14.91	8.62
November	*	12.36	9.42
December	9.58	10.91	10.39

* No tapping during November, 1973 and August, 1974.

Table 2.4

Monthly variations* in the initial flow rate, plugging index and latex yield in Clone Tjir 1.

Month	Initial flow rate	Plugging index	Latex yield
March	61.6	196.1	30.6
April	61.9	144.4	36.5
May	69.1	133.3	38.5
June	104.0	120.5	69.4
July	110.5	63.6	131.2
August	127.0	50.2	178.9
September	99.3	51.9	130.2
October	103.9	47.9	163.9
November	126.3	55.2	157.1
December	116.3	53.8	158.0
January	135.5	126.2	165.9
February	83.9	156.5	43.1

* Monthly average as percentage of annual average (annual average = 100%)

Table 2.5

Monthly variations* in initial flow rate, plugging index and latex yield in Clone LCB 1320.

Month	Initial flow rate	Plugging index	Latex yield
March	98.2	138.8	56.3
April	88.4	108.5	75.9
May	89.8	133.3	57.3
June	98.4	111.4	74.8
July	73.5	60.9	140.0
August	96.4	82.3	120.0
September	96.2	86.3	97.2
October	108.9	66.1	151.4
November	108.9	81.8	115.9
December	93.6	83.3	113.2
January	147.8	88.2	126.9
February	100.2	70.8	71.2

* Monthly average as percentage of annual average (annual average =100%)

Table 2.6

Monthly variations* in initial flow rate, plugging index and latex yield in Clone BD 10.

Month	Initial flow rate	Plugging index	Latex yield
March	90.5	103.6	71.3
April	113.1	94.2	106.0
May	103.5	148.1	64.3
June	112.0	86.2	104.6
July	103.4	87.1	114.6
August	112.0	81.2	128.9
September	98.5	78.4	113.3
October	103.7	70.7	129.9
November	117.1	83.6	114.3
December	79.6	85.4	114.9
January	107.6	93.4	94.8
February	66.2	192.9	42.6

* Monthly average as percentage of annual average (annual average = 100%)

Table 2.7

Monthly variations* in the initial flow rate, plugging index and latex yield in Clone PB 86

Month	Initial flow rate	Plugging index	Latex yield
March	83.2	137.4	59.0
April	84.6	118.3	69.7
May	89.0	111.4	73.3
June	103.1	120.1	74.6
July	79.3	111.2	80.9
August	100.0	78.6	109.7
September	89.8	75.5	105.3
October	94.0	60.7	137.0
November	116.8	89.8	112.0
December	107.4	77.8	133.1
January	130.4	76.3	159.4
February	122.3	142.5	85.3

* Monthly average as percentage of annual average (annual average = 100%)

Fig. 2.7 : Monthly variations in yield (graph) in clone PB 86 and rainfall pattern (histogram) during 1973.

Fig. 2.8 : Monthly variations in yield (graph) in clone PB 86 and rainfall pattern (histogram) during 1974.

FIG:2.7 FIG: II 7

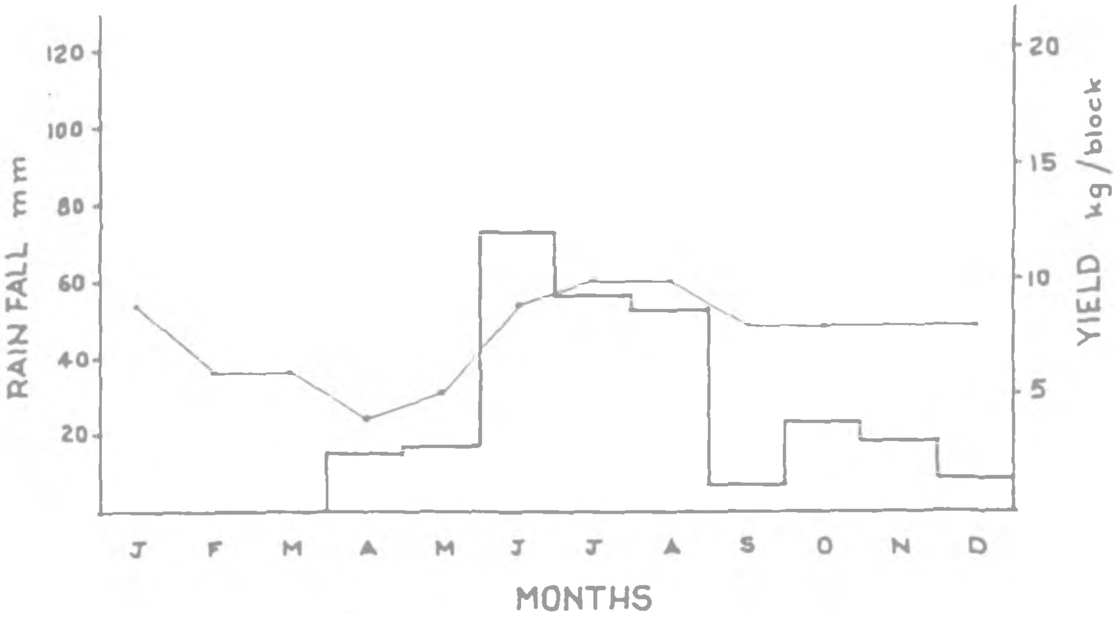


FIG: 2.8

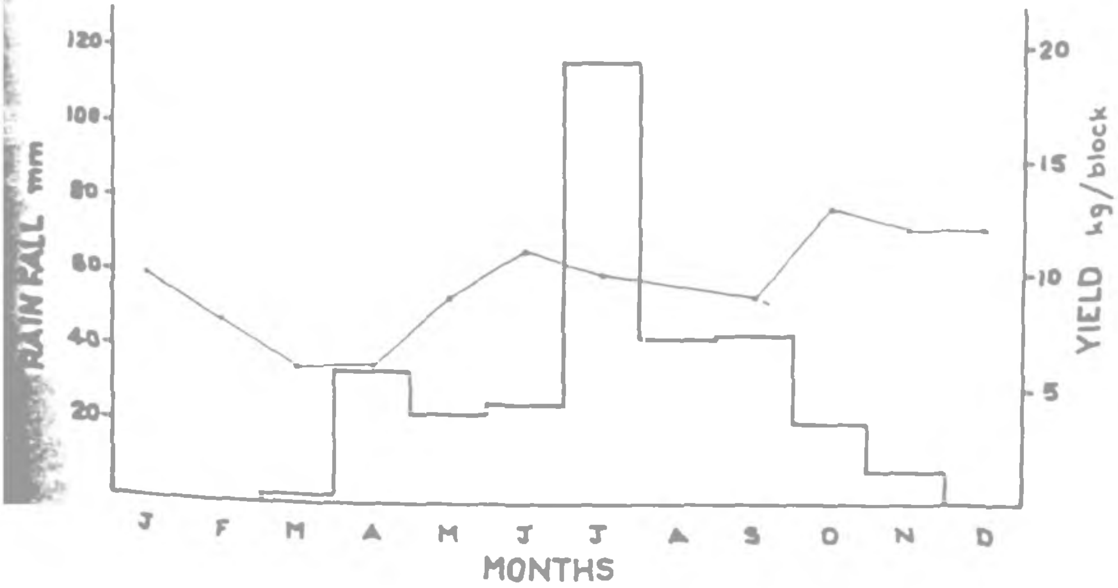


Fig. 2.9 : Monthly variation in yield (graph) in clone PB 86 and rainfall pattern (histogram) during 1975.

FIG: 2.9

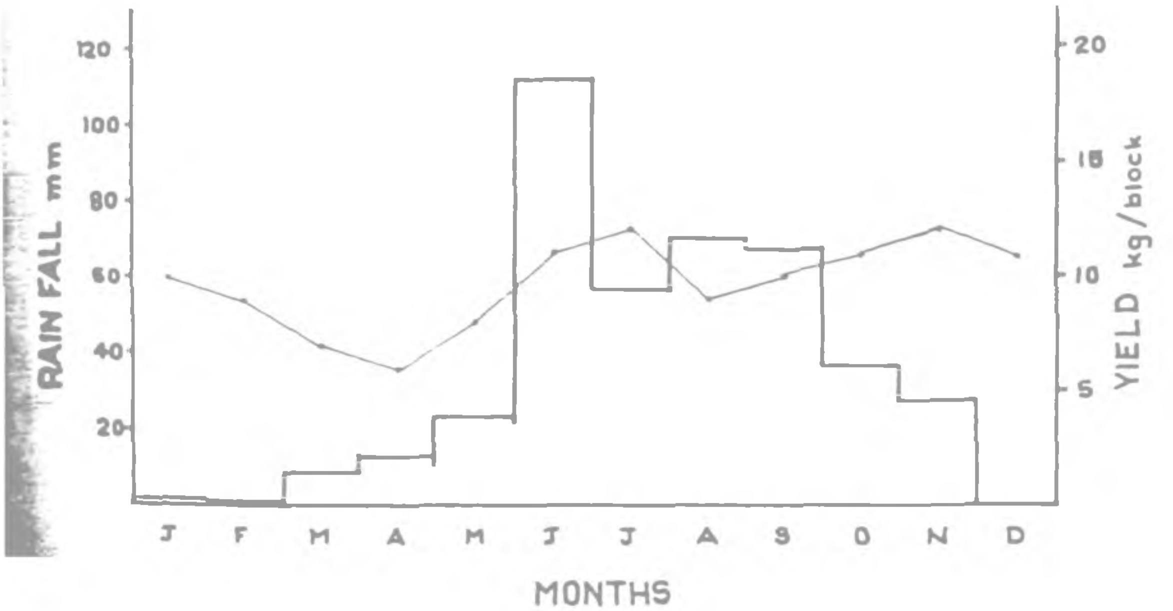

RAIN FALL mm
120
100
80
60
40
20
YIELD kg/block
20
15
10
5
J
F
M
A
M
J
J
A
S
O
N
D
MONTHS

Fig. 2.10 : Variations in initial flow rate, plugging index and latex yield in different months of the year compared to annual average in clone Tjir 1.

FIG: 2.10

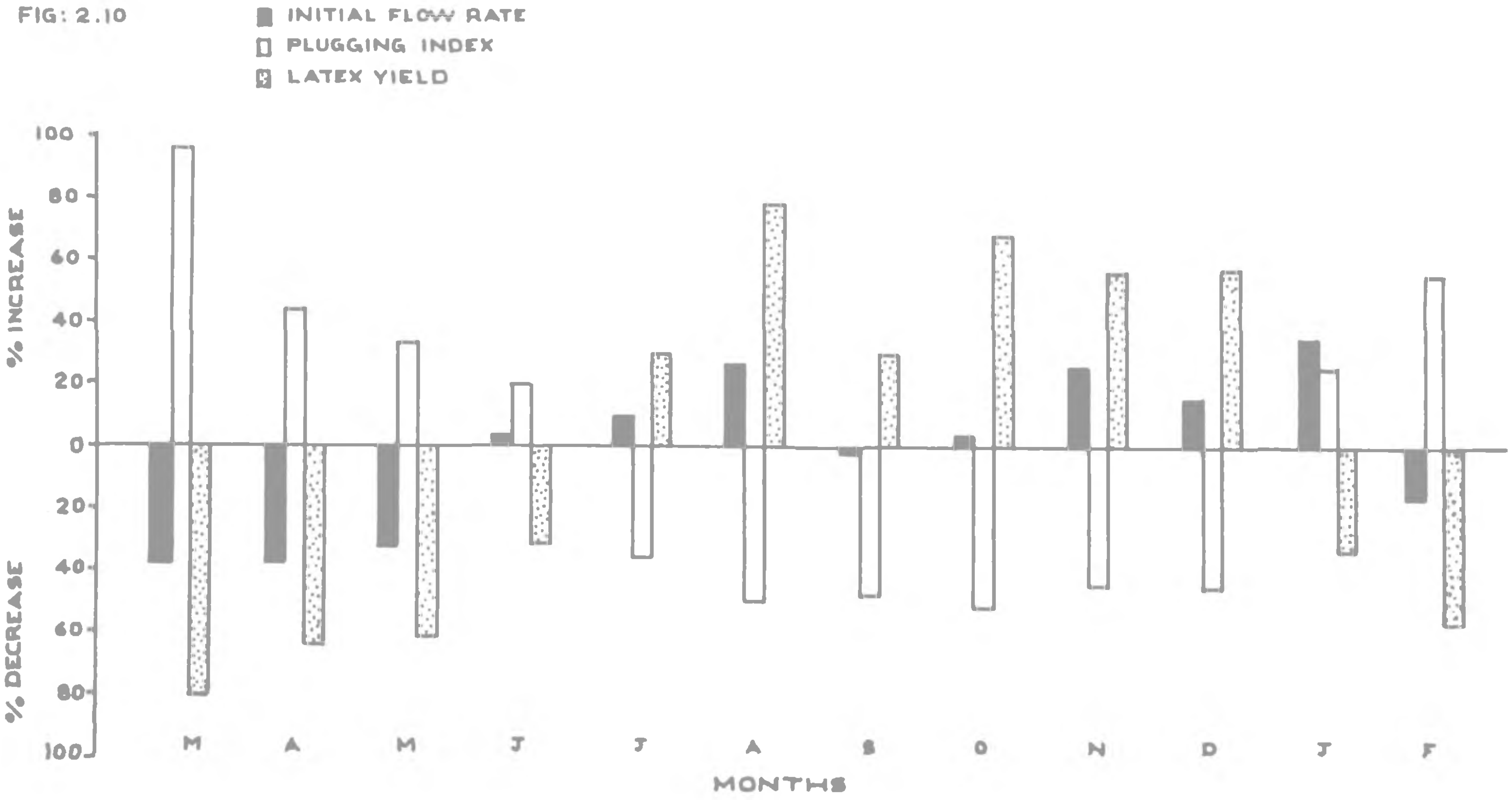

■ INITIAL FLOW RATE
▯ PLUGGING INDEX
▨ LATEX YIELD
% INCREASE
% DECREASE
100
80
60
40
20
0
20
40
60
80
100
M
A
M
J
J
A
S
O
N
D
J
F
MONTHS

Fig. 2.11 : Variations in initial flow rate, plugging index and latex yield in different months of the year compared to annual average in clone LCB 1320.

FIG: 2.11

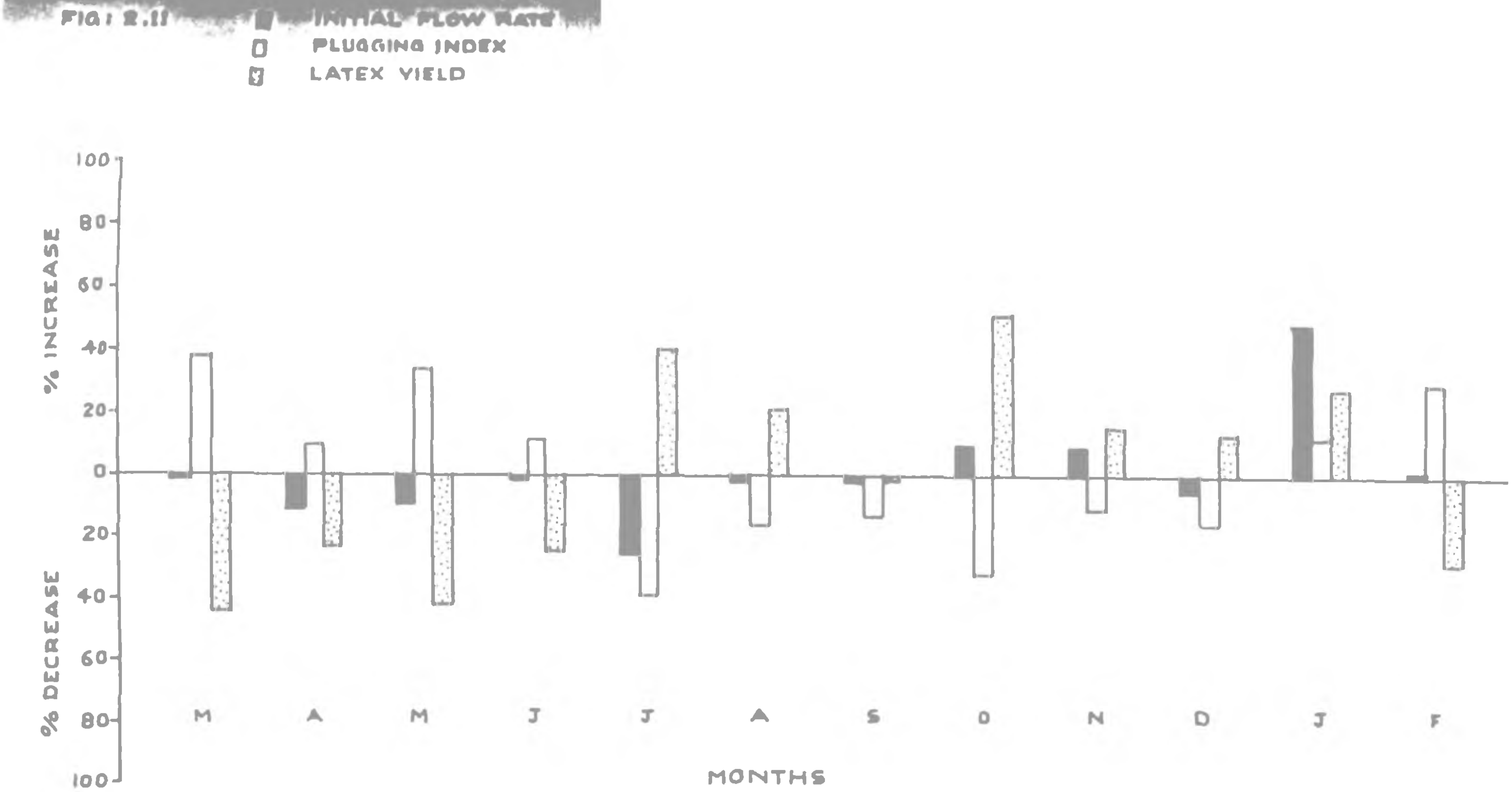

INITIAL FLOW RATE
PLUGGING INDEX
LATEX YIELD
% INCREASE
% DECREASE
100
80
60
40
20
0
20
40
60
80
100
M
A
M
J
J
A
S
O
N
D
J
F
MONTHS

Fig. 2.12 : Variations in initial flow rate, plugging index and latex yield in different months of the year compared to annual average in clone BD 10.

FIG: 2.12

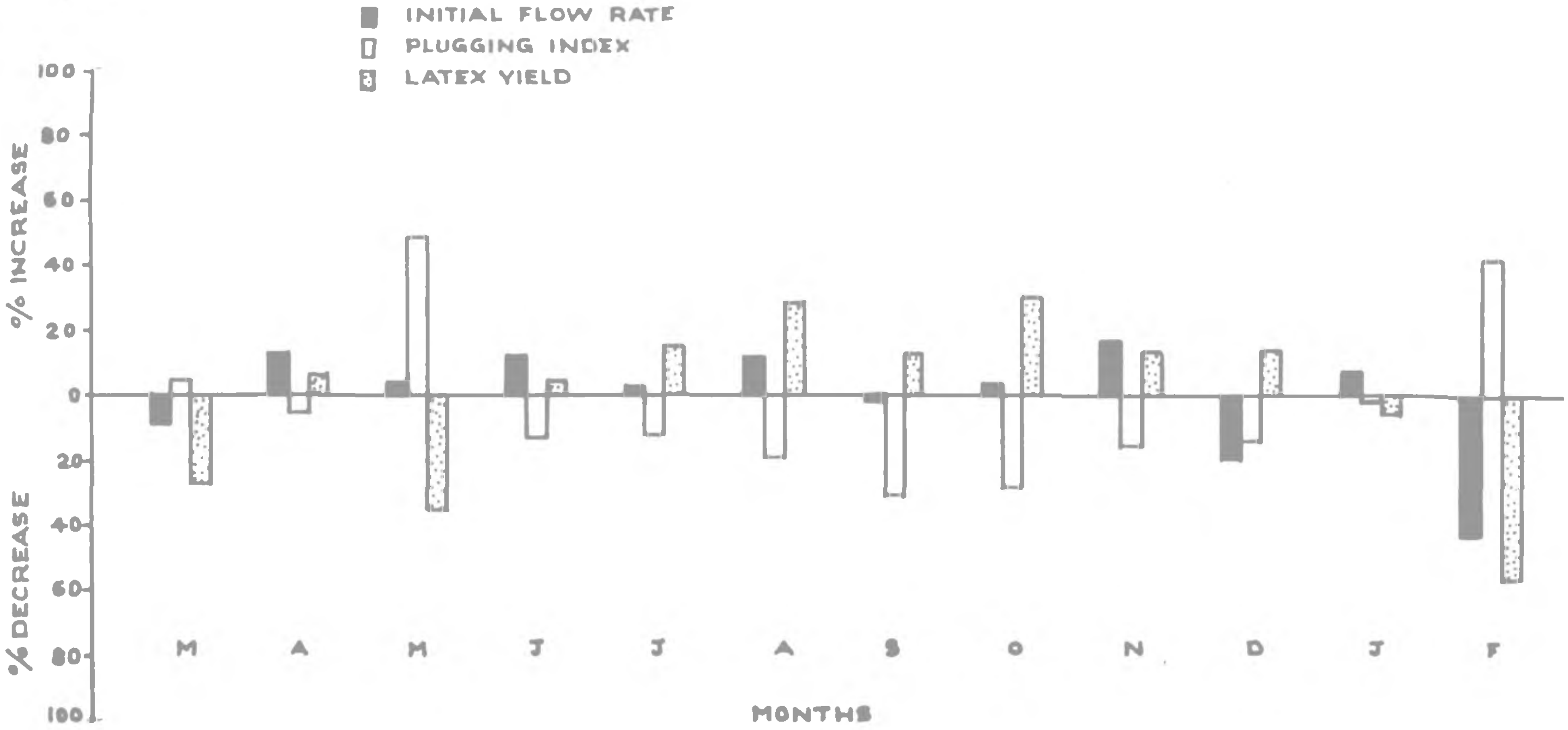
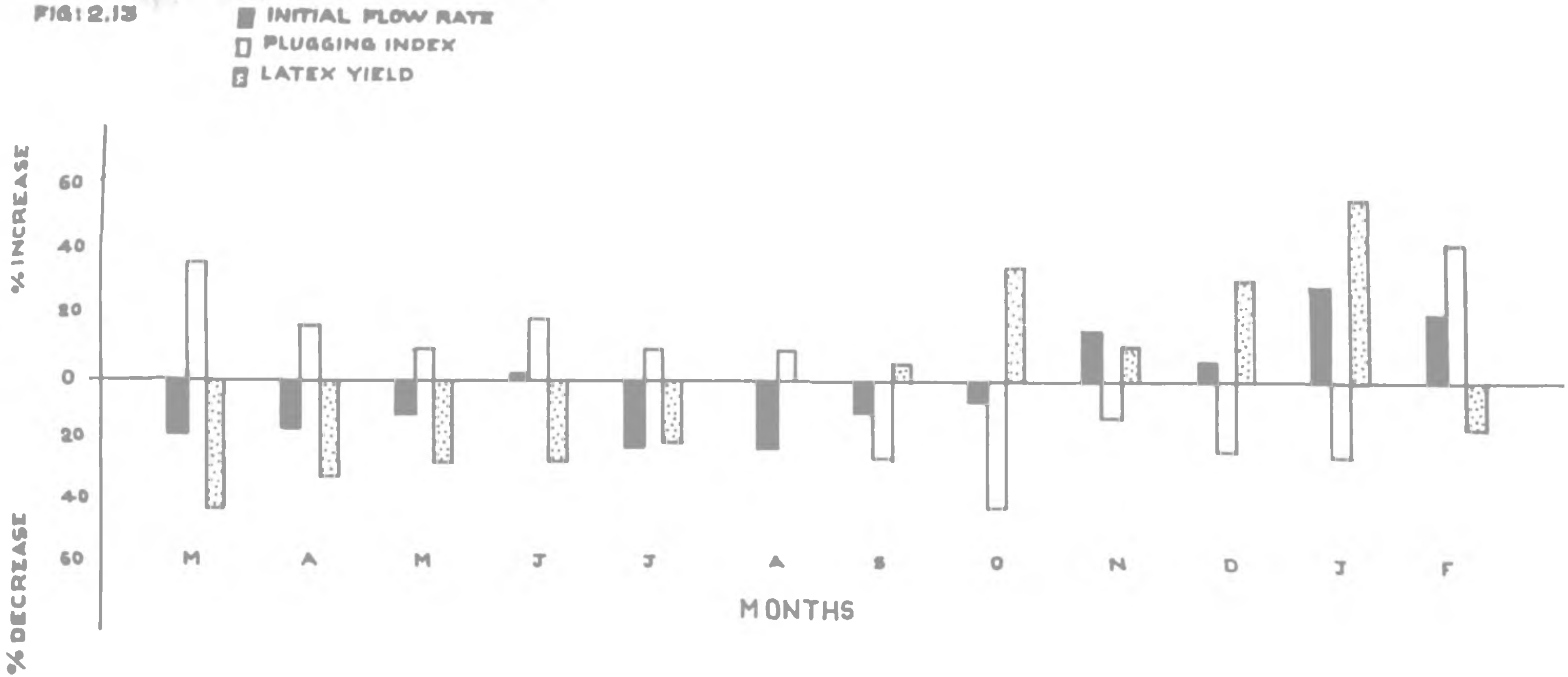

■ INITIAL FLOW RATE
▯ PLUGGING INDEX
▨ LATEX YIELD
% INCREASE
% DECREASE
100
80
60
40
20
0
20
40
60
80
100
M
A
M
J
J
A
S
O
N
D
J
F
MONTHS

Fig. 2.13 : Variations in initial flow rate, plugging index and latex yield in different months of the year compared to annual average in clone PB 86.

FIG: 2.13



■ INITIAL FLOW RATE
□ PLUGGING INDEX
▨ LATEX YIELD
% INCREASE
% DECREASE
60
40
20
0
20
40
60
M
A
M
J
J
A
S
O
N
D
J
F
MONTHS

correspond with the periods of highest and lowest latex yield in all cases. The periods of highest and lowest latex yields were August and March respectively for clone Tjir 1, October and February respectively in clone [illegible] 10, October and March respectively for clone LCB 1320 and January and March respectively for clone PB 86. In order to get a clearer picture, the latex yields at different recordings were correlated with corresponding recordings of initial flow rate and plugging index and the results revealed (Table 2.8) that there was highly significant negative correlation between plugging index and latex yield. This relationship was more significant in the partial correlation analysis (eliminating the effect of initial flow rate) in the case of clones LCB 1320 and PB 86. Initial flow rate was positively correlated with yield except in the case of clone LCB 1320. Even in this case, the relationship became evident in the partial correlation analysis, eliminating the effect of plugging index.

Effect of soil moisture on latex flow and yield

The results of the study on the effect of soil moisture on latex yield indicated that there was clonal variation in this regard (Figs. 2.14, 2.15). In a correlation analysis relating soil moisture with yield however, the correlations obtained were not significant in both the clones studied (Table 2.9). The lack of significant correlation between soil moisture and yield

Table 2.8

lationship among seasonal variations in yield, initial flow rate and plugging index.

Clones	Correlation with initial flow rate		Correlation with plugging index	
	Simple r 12	Partial r 12.3	Simple r 13	Partial r 13.2
ir 1	0.675*	0.213	-0.960**	-0.928**
10	0.620*	0.046	-0.902**	-0.840**
B 1320	0.234	0.698*	-0.834**	-0.914**
B 86	0.599*	0.860**	-0.842**	-0.940**

Subscripts 1, 2 and 3 denote respectively yield, initial flow rate and plugging index.

* Significant at 5% level of probability

** Significant at 1% level of probability

Table 2.9

Effect of soil moisture on initial flow rate, plugging index and latex yield.

	Simple correlations		
one	Latex yield r 12	Initial flow rate r 13	Plugging index r 14
ir 1	+0.320	+0.021	-0.516 *
I 1	+0.227	+0.117	-0.203

Subscripts 1, 2, 3 and 4 denote respectively soil moisture, latex yield, initial flow rate and plugging index.

* Significant at 1% level of probability.

Fig. 2.14 : Relationship between soil moisture variations (histogram) and yield (graph) in clone Tjir 1.

Fig. 2.15 : Relationship between soil moisture variations (histogram) and yield (graph) in clone Gl 1.

FIG: 2.14

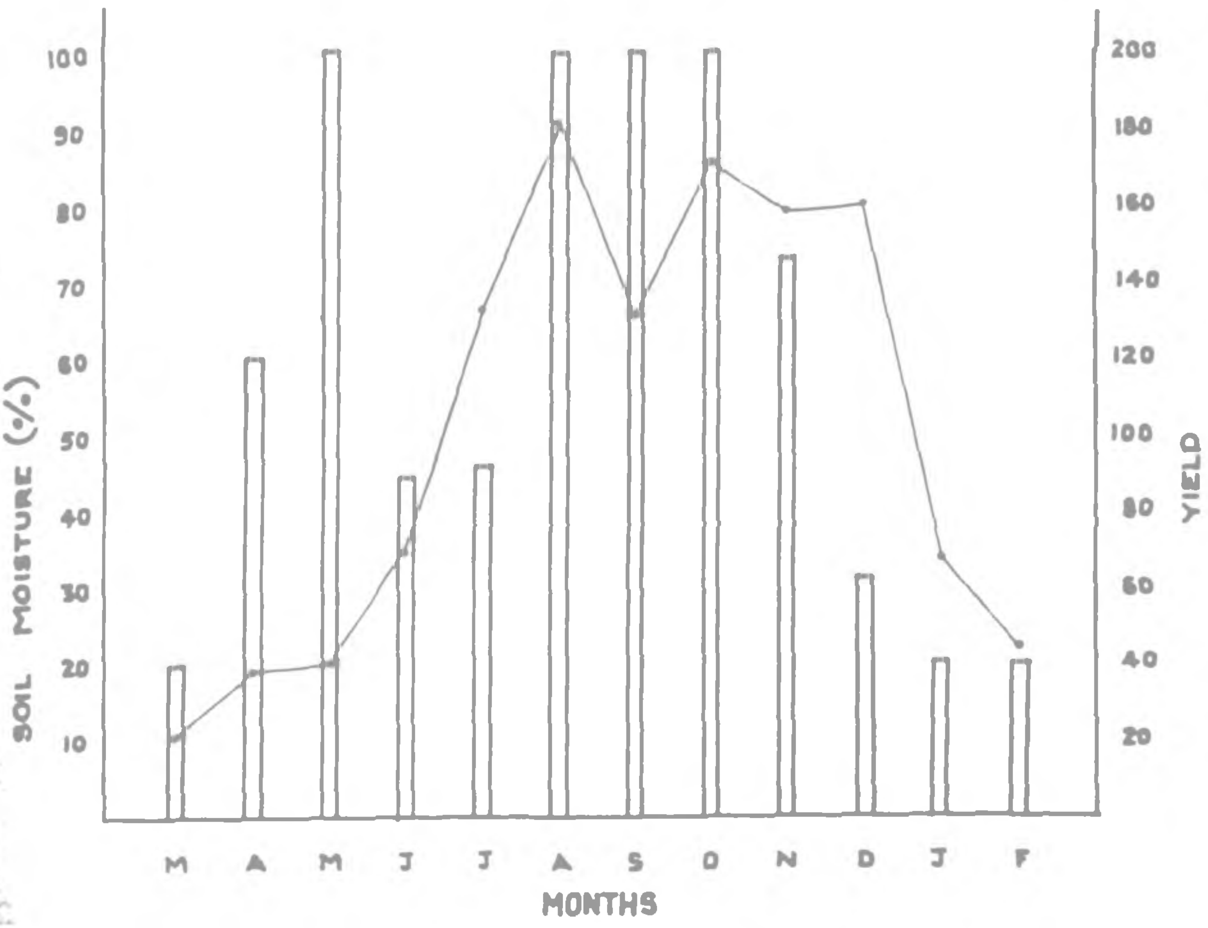
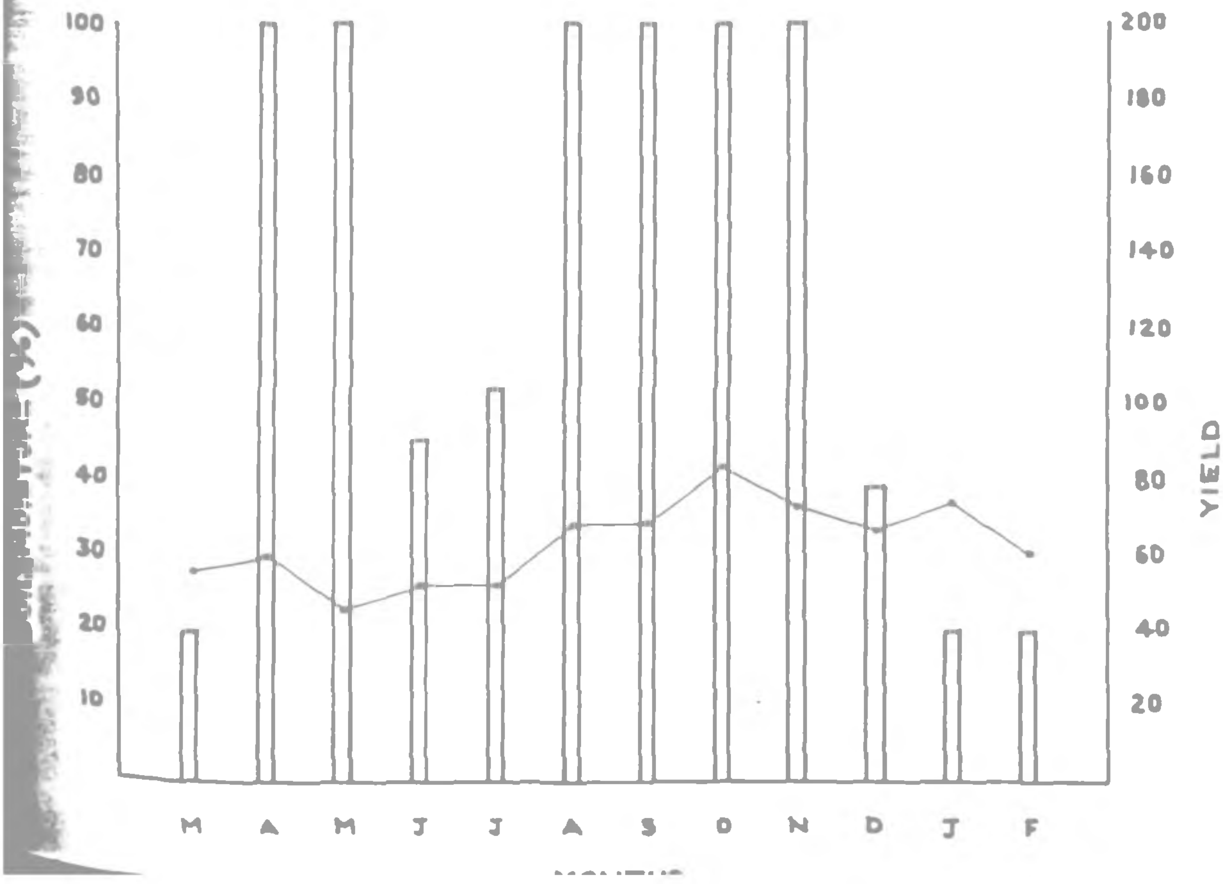


FIG: 2.15



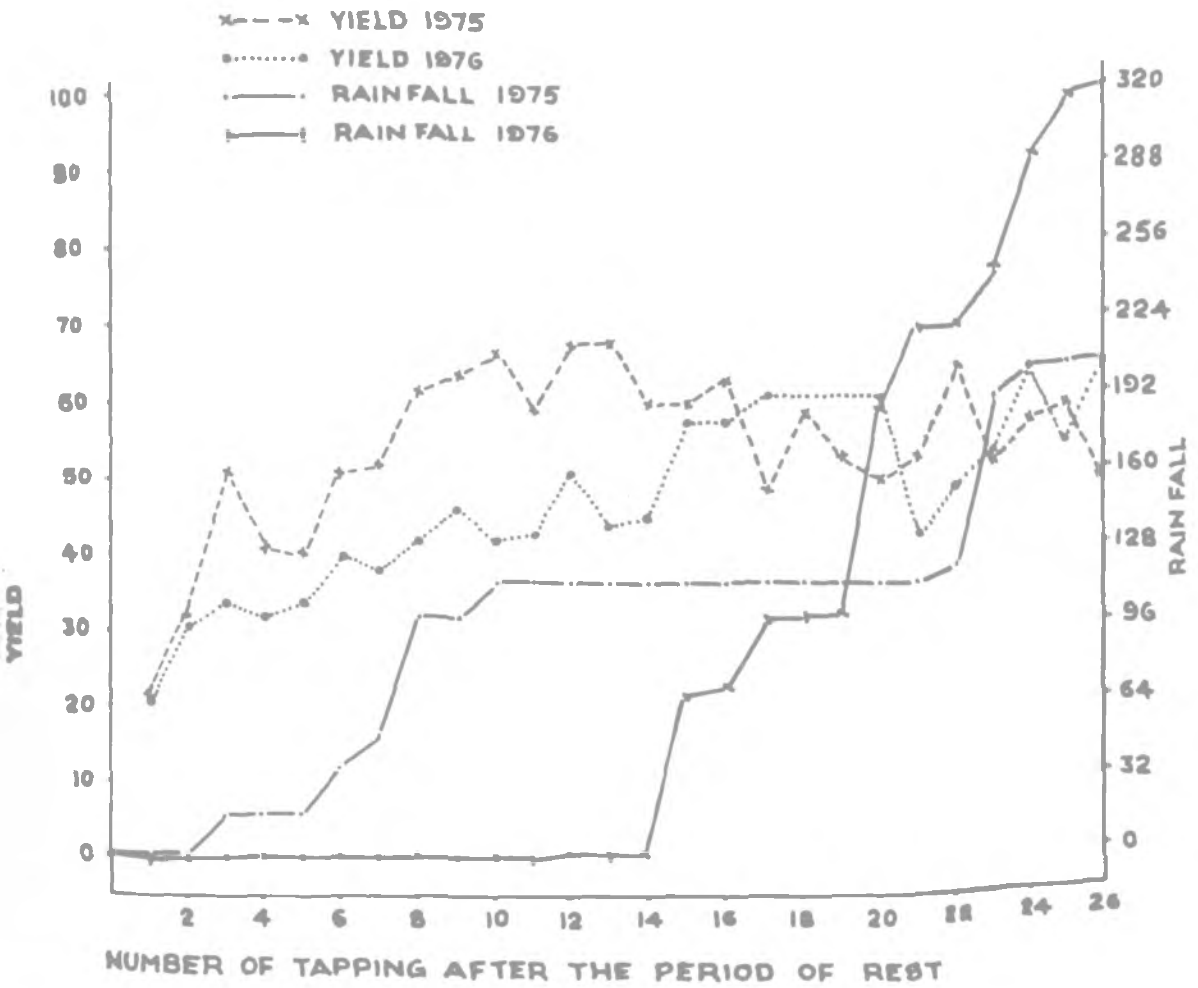
is presumably due to the fact that yield is affected only when soil moisture becomes a limiting factor. The drop in yield during the month of October in the case of Tjir 1 cannot be accounted by any fall in soil moisture. Compared to Tjir 1, Gl 1 is less susceptible to moisture variations (Figs. 2.14, 2.15). The correlation between plugging index and soil moisture was significant only in the case of Tjir 1.

Effect of rain fall on the rate of yield increase after the annual tapping rest

The years 1975 and 1976 differed significantly in the rain fall pattern. During the period January to April the rain fall recorded during 1976 was markedly less compared to that in the previous year. Figure 2.16 presents the yield and rainfall data during the period immediately after the annual tapping rest in 1975 and 1976. From this data, the number of tappings required for enhancing the yield per tap by 100 and 200 percent as compared to the yield obtained on the first tapping was found out (Table 2.10). The total rainfall during this period is also presented in the same Table. The number of tappings required for enhancing yield by 100 percent was three and eight during the years 1975 and 1976 respectively. In 1975, the total rainfall during this period was 18.2 mm while during 1976 it was only 0.8 mm. It was also observed that eight and seventeen

Fig. 2.16 : Pattern of yield increase and rainfall after annual tapping rest.

FIG: 2.16



YIELD 1975
YIELD 1976
RAINFALL 1975
RAIN FALL 1976
YIELD
RAIN FALL
0
10
20
30
40
50
60
70
80
90
100
0
32
64
96
128
160
192
224
256
288
320
2
4
6
8
10
12
14
16
18
20
22
24
26
NUMBER OF TAPPING AFTER THE PERIOD OF REST

tappings were needed in 1975 and 1976 respectively to increase the yield to 200% of the first day's yield. The total rain fall obtained during these periods in both cases was 101 mm. The results indicated that the stage of leaf maturity alone could not influence the increase in yield and that rainfall or the soil moisture status *per se* might play a role in the pattern of yield increase when tapped after the annual tapping rest.

Effect of environmental factors on yield - Path coefficient analysis

The simple correlation analysis indicated that out of the nine environmental factors studied, only two factors have statistically significant correlation with yield. Yield was negatively correlated with minimum temperature and soil temperature in the morning (Table 2.11). The path coefficient analysis on the other hand indicated that soil temperature (morning) was the most important single factor influencing the day-to-day variations in yield. Relative humidity in the morning also had strong positive influence on yield; this effect was masked by the influence of other factors in the simple correlation analysis. The direct effect of other environmental factors on yield was not very significant. The positive effect of day temperature and sunshine as well as the negative effect of rainfall were not statistically significant. Wind velocity also did not appear to be an important factor influencing [illegible] correlation coefficients between climatic factors and yield

Y Variables	X Variables									Yield
	Maxi. Temp.	Mini. Temp.	Soil Temp. (Morn.)	Soil Temp. (A.N.)	Humidity (Morn.)	Humidity (A.N.)	Wind velocity	Sun shine	Rainfall (previous fortnight)	
Maxi. Temp.	-	+0.175	+0.549**	+0.773**	-0.498**	-0.690**	-0.096	+0.655**	-0.496**	-0.021
Mini. Temp.	-	-	+0.759**	+0.148	+0.356	+0.169	+0.303	-0.003	+0.059	-0.571**
Soil Temp. (Morn.)	-	-	-	)0.593**	+0.015	-0.242	+0.303	+0.422**	-0.260	-0.551**
Soil Temp. (A.N.)	-	-	-	-	-0.650**	-0.845**	-0.012	+0.873**	-0.627**	-0.036
Humidity (Morn.)	-	-	-	-	-	+0.789**	+0.323	-0.726**	+0.647**	-0.193
Humidity (A.N.)	-	-	-	-	-	-	+0.108	-0.867**	+0.625**	-0.202
Wind velocity	-	-	-	-	-	-	-	-0.011	+0.277	-0.295
Sun shine	-	-	-	-	-	-	-	-	-0.618**	+0.072
Rainfall (previous fortnight)	-	-	-	-	-	-	-	-	-	-0.192

** Significant at 1% level of probability yield. Another interesting finding was that the significant negative correlation between yield and minimum temperature obtained in simple correlation analysis, was not very significant when this effect was partitioned by path coefficient analysis indicating that the effect was mediated through the influence on soil temperature (Figure 2.17). The data in Table 2.12 present the indirect effect of individual factors on yield through other factors along with simple correlation value. The residual value obtained ie. 0.416 (Fig. 2.17) would give R^2 value of 0.327 indicating that approximately 63% of the yield variations could be accounted by the variations in climatic factors.

DISCUSSION

Monthly variations in yield

Irrespective of the clonal variation in seasonal yield fluctuations, the period of the highest and lowest yields followed the same trend for all the three clones during the three years of study with a single exception in the case of Gl 1 in 1973. While no direct relationship between rainfall and yield of a particular month was observed, the effect of rain fall on yields of the subsequent months, possibly by maintaining a higher soil moisture build up, was apparent from the data (Figs. 2.1, 2.2 and 2.3). The pattern of monthly distribution of production obtained in the present study is strikingly

[illegible]

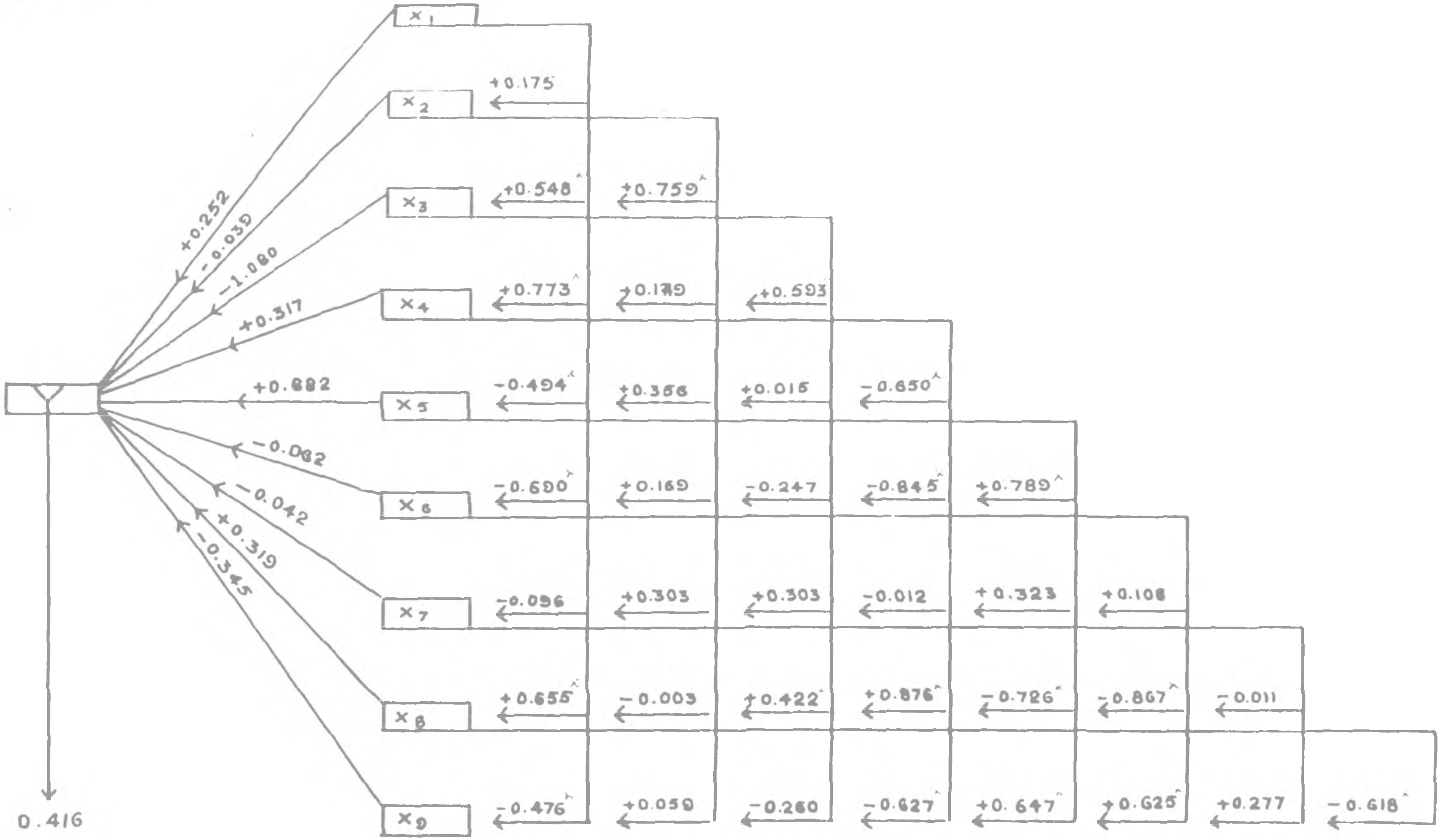
Direct and indirect effects of climatic factors on yield

X Variables	Maxi. Temp.	Mini. Temp.	Soil Temp.	Soil Temp.	Humidity (Morn.)	Humidity (A.N.)	Wind velocity	Sun shine	Rainfall previous fortnight	Correlation with yield
Maxi. Temp.	+0.252	−0.006	−0.592	+0.240	−0.339	+0.042	+0.004	+0.208	+0.170	−0.021
Mini. Temp.	+0.044	−0.039	−0.820	+0.046	+0.242	−0.010	−0.012	−0.001	−0.020	−0.571**
Soil Temp. (Morn.)	+0.138	−0.029	−1.080	+0.184	+0.010	+0.014	−0.012	+0.134	+0.089	−0.551**
Soil Temp. (A.N.)	+0.194	−0.005	−0.640	+0.312	−0.443	+0.051	+0.001	+0.279	+0.215	−0.036
Humidity (Morn.)	−0.125	−0.014	−0.016	−0.202	+0.682	−0.048	−0.013	−0.231	−0.222	−0.193
Humidity (A.N.)	−0.173	−0.006	−0.261	−0.263	−0.538	−0.061	−0.004	−0.277	−0.214	−0.202
Wind velocity	−0.024	−0.011	−0.327	−0.003	+0.220	−0.006	−0.042	−0.003	−0.095	−0.295
Sun shine	+0.164	+0.001	−0.455	+0.272	−0.495	+0.053	+0.001	+0.319	+0.212	+0.072
Rainfall previous fortnight	−0.124	−0.002	+0.280	−0.195	+0.441	−0.038	−0.011	−0.197	−0.344	−0.192

** Significant at 1% level of probability.

Fig. 2.17 : Path coefficient analysis for direct and indirect effects of environmental factors on yield.

Y - yield
X_1 - max. temp. °C
X_2 - min. temp. °C
X_3 - morning soil temp. °C
X_4 - afternoon soil temp. °C
X_5 - morning relative humidity
X_6 - afternoon relative humidity
X_7 - wind velocity
X_8 - sunshine
X_9 - rainfall mm. during previous fortnight.


x1
x2
x3
x4
x5
x6
x7
x8
x9
0.416
+0.252
-0.039
-1.080
+0.317
+0.882
-0.082
-0.042
+0.319
-0.345
+0.175
+0.548
+0.759
+0.773
+0.179
+0.593
-0.494
+0.356
+0.015
-0.650
-0.690
+0.169
-0.247
-0.845
+0.789
-0.096
+0.303
+0.303
-0.012
+0.323
+0.108
+0.655
-0.003
+0.422
+0.876
-0.726
-0.867
-0.011
-0.476
+0.059
-0.260
-0.627
+0.647
+0.625
+0.277
-0.618

different from that reported by Maas and Bokma (1950) under Indonesian conditions. The fluctuations in yield are much less pronounced there, probably due to the absence of any prolonged dry season. Under the conditions of the present study, the yield obtained during the period of highest yield is almost three times the yield obtained during the period of lowest yield. The magnitude of seasonal variation of yield, however, seems to vary as a function of clonal characteristic; it is less in the case of Gl 1 compared to Tjir 1 and PB 86.

Seasonal variations in initial flow rate, plugging index and latex yield

Seasonal variations in yield can be largely explained by the variations in the plugging index and to some extent by the variations in initial flow rate. The inverse correlation between plugging index and yield was highly significant in the case of all the clones studied. A relationship between variations in yield and variations in initial flow rate was also evident, though less pronounced. While some clonal variations in the seasonal effect on plugging index was apparent, further studies would be desirable to confirm this. Milford *et al* (1969) did not consider day-to-day variations in plugging index to be a prominent feature though Paardekooper and Samosorn (1969) reported high plugging index during the later parts of the year. The present study confirms the importance of plugging index in seasonal variations in yield.

Effect of soil moisture on latex flow and yield

Saraswathy Amma and Sethuraj (1975) reported that soil drought conditions would influence yield and plugging index. In the present study no correlation was obtained between soil moisture and yield in clones Tjir 1 and Gl 1, when the data from recordings spread over a period of one year were used for the correlation analysis. Significant correlation was however obtained between soil moisture and plugging index in Tjir 1. In Gl 1 this correlation also was not significant. This indicates that at least in certain clones, soil moisture can be an important factor influencing plugging index. It is however quite likely that this effect of soil moisture would operate only when the level falls below a certain threshold value. In other words, the soil moisture will influence the plugging index when it becomes a limiting factor. Effect of irrigation on plugging index during periods of drought has already been reported (Sethuraj and George, 1975). The higher plugging index recorded during the earlier part of the year by Paardekooper and Samosorn (1969) could also be explained assuming a lower soil moisture status during that period.

Effect of rain fall on the rate of yield increase after annual tapping rest

The results of the present studies indicated that the rain fall pattern might influence the rate of yield increase after the annual tapping rest. A higher rain fall during this period would result in a higher soil and plant moisture content. A higher humidity level can also be expected. It is known that humidity will influence the rate of transpiration. As it has already been reported that a low soil moisture level will reduce yield and increase the plugging index (Saraswathy Amma and Sethuraj, 1975), the favourable effect of rain fall on the rate of yield increase after the annual tapping rest can well be expected. The results also indirectly indicate that the depression in yield during the summer defoliation period (wintering) might be more due to drought conditions prevailing than to the leafless phase of the tree for a relatively short period.

Effect of environmental factors on yield

The results of the simple correlation analysis and path coefficient analysis, when considered together indicate that the morning soil temperature is perhaps the most important factor influencing the day-to-day variations in yield. A significant negative correlation between yield and minimum temperature appears to be the result of the effects of other influencing factors. The result of path coefficient analysis confirms such a contention as the value obtained for the direct correlation of minimum temperature with yield was low. When the indirect effects are considered it would become clear that the influence of minimum temperature through soil temperature becomes greater. The interdependence of relative humidity with many other environmental factors was also evident from the path coefficient analysis. Although the influence of relative humidity on yield did not show any significance in the simple correlation analysis, path coefficient analysis, in which the interfering influences of other factors were eliminated, brought out the fact that relative humidity (Morning) is an important factor influencing day-to-day variations in yield. Ninane (1967 b) held that the output from a tapping could be predicted, taking into account the wind speed and saturation deficit of the air during the two days before tapping. In the present analysis, however, the relative humidity or the wind velocity during the day previous to tapping was not considered. The exact mode of action of the soil temperature on yield can be ascertained only after further study. The correlation analysis however indicated that the soil temperature might exert its influence through its effects on relative humidity. The possibility of its direct effect on water uptake by the plant cannot be ruled out.

It is also conceivable that a high relative humidity would reduce the rate of transpiration which in turn might improve the water status of the bark tissues. The apparently unexpected effect of rainfall, a slight negative effect on yield, might have occured due to its adverse effect by wetting the bark as the trees were non-rainguarded. A longer sunshine and a higher temperature are conditions which are not associated with rainfall and as such their positive effect on yield, though of a small order, is understandablo. The general conclusion that can be drawn from the study is that the factors which contribute to the water status of the tree directly or indirectly, are important in determining the yield. It may also be mentioned that the rain fall might not have become a limiting factor during the course of this study.

SUMMARY

The influence of environmental factors on yield was evaluated. It was found that the pattern of yield variation in different periods of the year was generally similar in all the clones studied. However, there was clonal variation in the magnitude of response to such seasonal effects. Clone Gl 1 appeared to be less susceptible to seasonal effects on yield than clones Tjir 1 and PB 86.

The monthly variations in yield could be explained by the variations observed in the initial flow rate and plugging index. The influence of soil moisture on yield becomes apparent only when the soil moisture level drops below a particular level. The effect of soil moisture may be mediated through its influence on plugging index at least in the case of clones susceptible to soil drought conditions. Another finding of interest was the role of rain fall pattern in the rate of yield increase after the annual tapping rest. The rate of yield increase after tapping rest appeared to be influenced more by the rain fall pattern than by the maturity of new leaves.

Results of path coefficient analysis to relate the environmental factors with seasonal yield variations revealed that the soil temperature (morning) is an important factor influencing yield. The relative humidity in the morning also had a strong positive influence on yield.

SECTION III

STUDIES ON THE INTERNAL FACTORS INFLUENCING LATEX FLOW AND YIELD

INTRODUCTION

In the ultimate analysis, the yield of rubber is a function of the volume of latex obtained on tapping and its rubber content. Paardekooper and Samosorn (1969) could not find any correlation between the dry rubber content of latex and yield. Nevertheless, the possibility of a higher rubber content having an indirect inhibiting effect on yield cannot be ruled out as a direct correlation between dry rubber content and plugging index has been reported (Milford et al. 1969). It would however appear that the yield of rubber is largely determined by the volume of latex obtained.

The volume of latex is a function of both the rate as well as the duration of flow. The initial flow rate and the intensity of latex vessel plugging would influence these two flow characteristics. Therefore an examination of the relationship of factors like initial flow rate, plugging index and dry rubber content of latex and the factors which influence these would be rewarding. Relationship between initial flow rate and latex yield has been established by Sethuraj et al (1974 b) and they have indicated that the initial flow rate might be a heritable clonal character. Studies on the factors influencing initial flow rate are however limited. Sethuraj et al (1974 b) obtained evidence that number of latex vessel rows would positively influence the initial flow rate. While the effect of plugging process on yield is well established (Sethuraj, 1968; Milford et al, 1969; Paardekooper and Samosorn, 1969; Saraswathy Amma and Sethuraj, 1975) the internal or external factors which influence plugging have attracted only limited attention. Studies of Sethuraj and George (1976) on the effect of irrigation on latex flow have indicated the relationship between moisture status of the tree and plugging index. Lutoid stability has also been implicated in the efficiency of plugging process (Ribaillier, 1972). Of the external factors, the influence of the length of the cut on plugging index also is generally recognised (Milford et al, 1969; Southorn and Gomez, 1970). The influence of the length of the tapping cut on plugging index might be mediated through an extension of the drainage area (Sethuraj and George, 1975).

A further elucidation of the factors which would influence initial flow rate, plugging index and dry rubber content was considered imperative and in the present section the relationship was assessed by correlation analysis wherever possible.

Another aspect which required evaluation was the claims on the relationships between yield and certain biochemical characteristics of latex. Tupy (1973 a, b) and Tupy and Primot (1974) have stressed time and again that latex production is intimately related to the sucrose level in latex. He was prompted to this conclusion from the findings that yield increase after chemical stimulation was associated with an increase in sucrose level and invertase activity. While Tupy (1973 c) reported a lower sucrose concentration in bark near the tapped area, D'Auzac and Pujarniscle (1961) failed to detect any effect of tapping on carbohydrate content. No attempt has, however, been made so far to relate the clonal variations in yield with the carbohydrate level in bark or latex. Tupy (1969) also had reported relationship between nucleic acids in latex and productivity. His study, however, was based on comparisons between a few high yielding and low yielding trees only of the same clone. Till now, no systematic effort to correlate variations in nucleic acid content in latex with clonal variations in yield has been made. In the present study, therefore, an attempt was also made to relate the levels of carbohydrates and ribonucleic acid in latex with clonal variations in yield employing correlation analysis.

MATERIALS AND METHODS

1. Experimental materials and locations

(a) Two experiments were separately carried out to relate latex yield with initial flow rate and plugging index. In one experiment, four families of intraspecific crosses of *Hevea brasiliensis* in which clone Tjir 1 was the female parent, was selected. These cross combinations were:- Tjir 1 x Gl 1, Tjir 1 x Avros 255, Tjir 1 x Mil 3/2 and Tjir 1 x HC 28. The hand pollinations had been carried out in 1954 and the seedlings obtained were cloned by budgrafting in 1955. The budded trees came into tapping in 1964.

(b) Six clones each were chosen from each group and under each clone, 3 trees were selected. The trees were being tapped on Panel B (the second half of the virgin bark). These trees were also used to study the effect of latex vessel rows on initial flow rate.

(c) Thirtytwo mother trees of RRII hand pollinated clones, tapped in Panel C, were employed in the other experiment to relate yield with initial flow rate and plugging index. These trees were also used to study the relationship between:

i) initial flow rate and anatomical characteristics
ii) initial flow rate and plugging index
iii) initial flow rate and turgor pressure in the phloem region
iv) plugging index and bursting index
v) mineral content of latex and plugging index
vi) dry rubber content of latex and yield of rubber
vii) dry rubber content and plugging index
viii) sugar content in latex and yield and
ix) RNA content in latex and yield.

(d) In order to study the effect of drainage area on plugging index, the technique employed was to open one S/6 cut near another S/6 cut assuming that the drainage areas of the two cuts would merge resulting in an extended drainage area with respect to any one of the S/6 cuts. Three clones, RRIM 601, RRIM 603 and RRIM 620 were selected and the following treatments imposed:

i) One S/6 cut alone tapped
ii) Both S/6 cuts tapped alternating the panel [S/6 d/1 (2xd/2)]
iii) As in treatment 2, but the two cuts separated by grooves.

There were four replications.

(e) The effect of the amount of latex extracted on dry rubber content was studied using clones RRIM 602, RRIM 603, RRIM 604, RRIM 609 and RRIM 612. Eight trees each were selected from each clone with two replications for the following treatments: S/2 d/2, S/4 d/1, S/1 d/1, S/2 2 d/1. The trees were being tapped in Panel C. Latex yield and d.r.c. were recorded.

All the above experiments were conducted at the experiment station of RRII.

2. Recording procedure

a) Yield (dry rubber): Yield per tree was recorded by the cup coagulation method as already described in page 81.

b) Yield (latex): The total volume of latex per tree was measured after cessation of latex flow.

c) Estimation of initial flow rate: As has already been described in page 83.

d) Estimation of plugging index: As has already been described in page 83.

e) Measurement of turgor pressure: Measurement of turgor pressure in the phloem region containing the laticiferous system was made using the manometer technique of Buttery and Boatman (1967). This involves measurement of the change in the length of an air bubble trapped in a capillary manometer after insertion in a small hole bored in the tree bark. The readings were taken for 10-20 minutes after insertion, although the observed pressure usually approached a stable value within 2 minutes. A fresh set was used for each determination. Three recordings were taken for each tree, and the maximum pressure obtained, rather than the mean, was taken as the best estimate as suggested by Buttery and Boatman (1967).

3. Estimation of dry rubber content in latex

Dry rubber content in latex was determined by the standard ISI:3708 (Part I)-1966.

About 10 g of well mixed latex was taken and weighed accurately in a beaker. Distilled water was added until the total solid content of latex was about 20%. Two percent acetic acid solution (w/v) was slowly added with stirring till the latex coagulated. The coagulum was rolled into sheet and dried at 70±2°C till constant weight was obtained.

$$\text{d.r.c.} = \frac{\text{weight of dry rubber(g)} \times 100}{\text{weight of latex taken(g)}}$$

4. Estimation of Bursting index

For determining the bursting index, latex fractions during the period between 15-20 mts after tapping were collected in test-tubes covered with ice and brought to the laboratory. The method adopted by Ribaillier (1968) was followed for the determination of bursting index using the formula:

$$\text{Bursting index} = \frac{\text{Activity of liberated phosphatase} \times 1}{\text{Activity of total phosphatase}}$$

The anionic surfactant used was, however, Teapol B 300 instead of Triton X114.

Determination of the activity of liberated phosphatase and total phosphatase:-

To 2.9 ml of substrate solution (50 ml of 0.8 M disodium p-nitrophenyl phosphate in acetate buffer, pH5 + 200 ml of 0.6 M mannitol solution + 145 ml water) was added 0.1 ml of latex and incubated for 10 mts at 27±2°C. 1 ml of 2N TCA was added and filtered. To 2 ml filtrate was added 1 ml of 1N NaOH and made upto 10 ml. The optical density was measured at 400 nm. A control was kept for each sample. The activity of liberated phosphatase was calculated from the difference in O.D. between the test and control, using a standard curve obtained by plotting n mole of P-nitrophenol against optical density.

The total phosphatase was determined by the same procedure but using a substrate solution comprising of 50 ml of 0.3 M disodium p-nitrophenyl phosphate in acetate buffer, pH5 + 100 ml 0.5% Teepol B 300 + 245 ml water.

5. Estimation of mineral elements

Mineral elements were estimated in the rubber phase and bottom fraction of the latex separately. Latices were collected and centrifuged at 16,000 rpm for one hour in a Remi-24 centrifuge. The rubber cream with C-serum and bottom fraction were separated and dried. The extract was prepared by the dry ashing method of Piper (1943). Phosphorus was estimated colorimetrically by the molybdenum blue method (Jackson, 1958). Flame photometer was used for the estimation of potassium (Jackson, 1958). The amount of calcium + magnesium was determined by EDTA titration and calcium alone using

Patton and Readers reagent by the method of Poidevion and Robinson (1964).

5. Estimation of sugars in latex

Reducing sugar:- Reducing sugar was estimated by the method of Nelson (1944). One ml of a mixture of 25 parts of copper reagent A (25 gm anhydrous sodium carbonate + 25 gm Rochelle salt + 20 gm sodium bicarbonate and 200 gm anhydrous Na_2SO_4 in one litre water) to one part of copper reagent B (15% copper sulphate containing a little conc. sulphuric acid) was added. A blank was also set up using 1 ml of distilled water instead of the extract. The solutions were mixed and heated for 20 minutes in a boiling water bath. Subsequently, the tubes were cooled using cold water. One ml of arsenomolybdate colour reagent was then added to develop the colour, diluted to 25 ml and read at 520 nm. From a standard graph the amount of reducing sugar was determined.

Non-reducing sugar:- One ml of suitably diluted alcoholic extract of latex was pipetted into a boiling tube, evaporated to dryness and 1 ml distilled water and 1 ml 1 N sulphuric acid were added and heated at 60-62°C for ½ hour. This was neutralised with 1 ml of N NaOH and the total sugar was determined following the method described for reducing sugar. Non-reducing sugar was calculated by the formula:

Non-reducing sugar = (Amount of total sugar — Amount of reducing sugar) x 0.95.

7. Estimation of ribonucleic acid in latex

The ribonucleic acid was extracted from latex after Tupy (1969). The pH of the latex was made up to 7.0 - 7.5 with NaOH and the nucleic acid extracted with a solution of 0.02 M TRIS buffer, 0.02 M EDTA, 0.1 M NaCl, 3.6% SDS; pH 8.0. To 1.8 ml of latex 2.5 ml of this solution was added and the mixture vigorously shaken for about 3 minutes and centrifuged at 16,000 rpm for one hour. The supernatant was treated with 2 volumes of alcohol containing 0.56 N $HClO_4$. The fine precipitate was washed three times with 50% alcohol - 0.2 N $HClO_4$. The nucleic acid was now extracted with 0.5 N $HClO_4$ for 30 minutes at 70°C. The amount of RNA present in the extract was colorimetrically determined using Orcinol method as described by Militzer (1946).

RESULTS

1. Effect of latex flow pattern on yield

(a) Effect of initial flow rate on yield

Studies conducted in four progeny groups of inter-clonal crosses have revealed that initial flow rate is positively correlated with yield (Table 3.1). This effect was evident in the partial correlation analysis also, eliminating the effect of plugging index - indicating the independent effect of initial flow rate on yield.

Table 3.1

Effect of initial flow rate on yield in
the progenies of four crosses with
Tjir 1 as the female parent

Cross	Correlations	
	Simple r_{12}	Partial $r_{12.3}$
Tjir 1 x Gl 1	0.8027**	0.8639**
Tjir 1 x Avros 255	0.7142**	0.7240**
Tjir 1 x Mil 3/2	0.6972**	0.6132**
Tjir 1 x HC 28	0.7257**	0.6993**

Subscriptions: 1,2 and 3 denotes respectively final volume yield, initial flow rate and plugging index.

** Significant at 1% level of probability.

The results of the studies carried out using 32 clonal mother trees also showed the same trend (Fig. 3.1). The positive correlation obtained between initial flow rate and yield was independent of the interaction between initial flow rate and plugging index as evidenced in the partial correlation analysis (Table 3.2). The data also revealed that the influence of initial flow rate on yield was independent of the effect of girth on initial flow rate. The effect of girth on yield however was dependant on its effect on initial flow rate; when the initial flow rate was eliminated in the partial correlation analysis, the correlation between girth and yield was not significant.

(b) Factors influencing initial flow rate

i) Effect of anatomical structure of bark on yield

Studies on the relationship between initial flow rate and latex vessel rows utilising four progeny groups of inter-clonal crosses with Tjir 1 as female parent revealed that the number of latex vessel rows is correlated positively with initial flow rate (Table 3.3). Number of latex vessel rows influenced the volume yield of latex also. This relationship was again confirmed from the studies conducted in a population of 32 clonal mother trees (Table 3.4). The results of this study indicated that the diameter of latex vessels was not

Table 3.2

Effect of initial flow rate on yield in a population of 30 clonal mother trees

Correlations	Recording I	Recording II
r12	0.6411**	0.5752**
r12.3	0.8532**	0.8849**
r12.4	0.5508**	0.4642**
r14.2	0.3025	0.3156

Subscriptions: 1,2,3 and 4 denote respectively final volume yield, initial flow rate, plugging index and the girth of the tree.

** Significant at 1% level of probability

Table 3.3

Correlation of number of latex vessel rows with initial flow rate and latex yield.

Cross	Correlations	
	r12	r13
Tjir 1 x Gl$_1$	0.7409**	0.5660**
Tjir 1 x Avros 255	0.7048**	0.5013**
Tjir 1 x Mil 3/2	0.5560**	0.3686**
Tjir 1 x HC 28	0.5311**	0.4774**

Subscriptions: 1,2 and 3 denotes respectively latex vessel rows, initial rate of flow and latex yield.

** Significant at 1% level of probability.

Table 3.4

Simple, partial and multiple correlations of initial flow rate with number of latex vessel rows, diameter of latex vessels, and thickness of soft and hard bast.

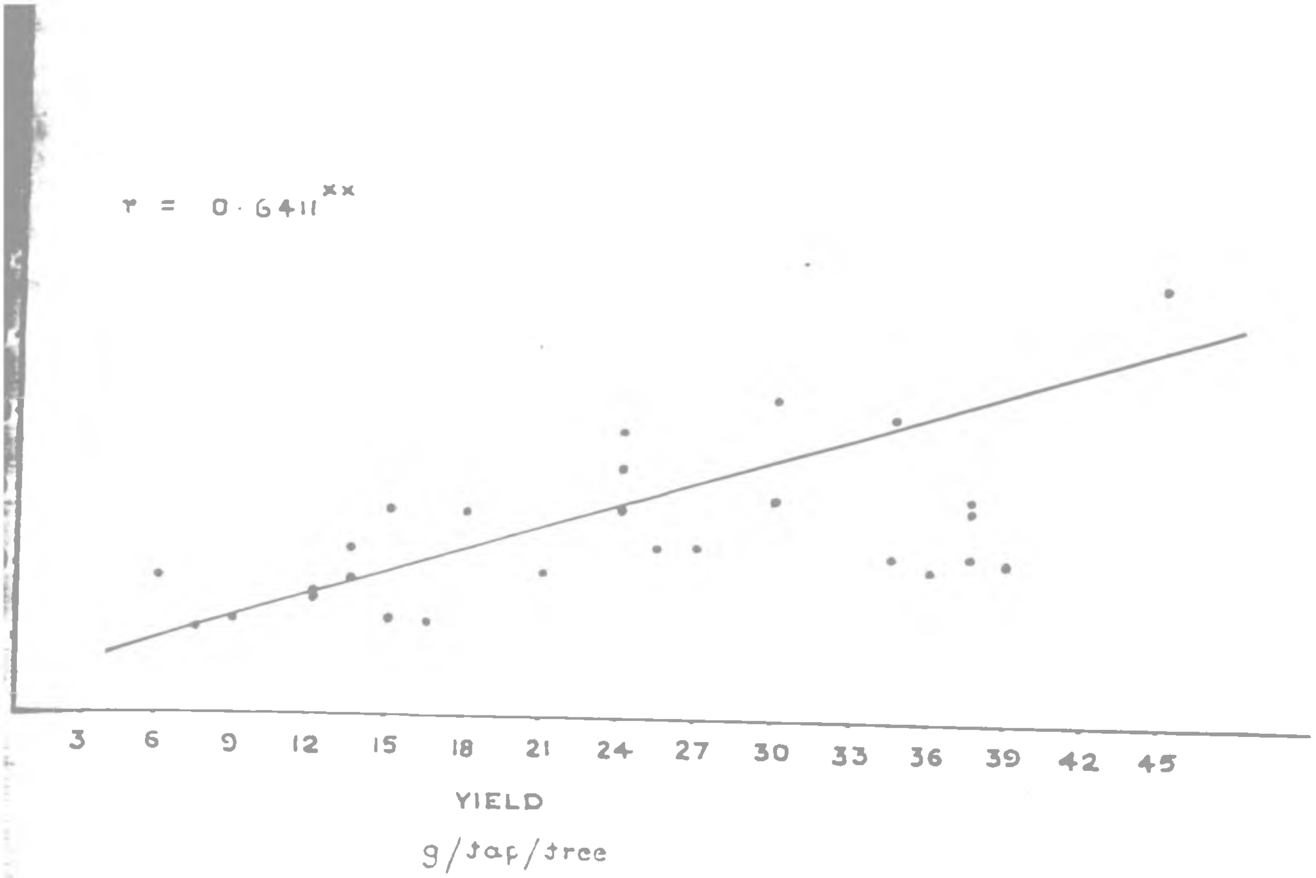
Factors	Correlations		
	Simple	Partial	Multiple
Latex vessel rows	r12 =0.3698*	r12.3456 =0.0706	
Diameter of latex vessels	r13 =0.1897	r13.2456 =0.2314	R1(23456) =0.594*
Thickness soft bast	r14 =0.3860*	r14.2356 =0.1694	
Thickness hard bast	r15 =0.3838*	r15.2346 =0.2613	
Girth	r16 =0.4299*	r16.2345 =0.2026	

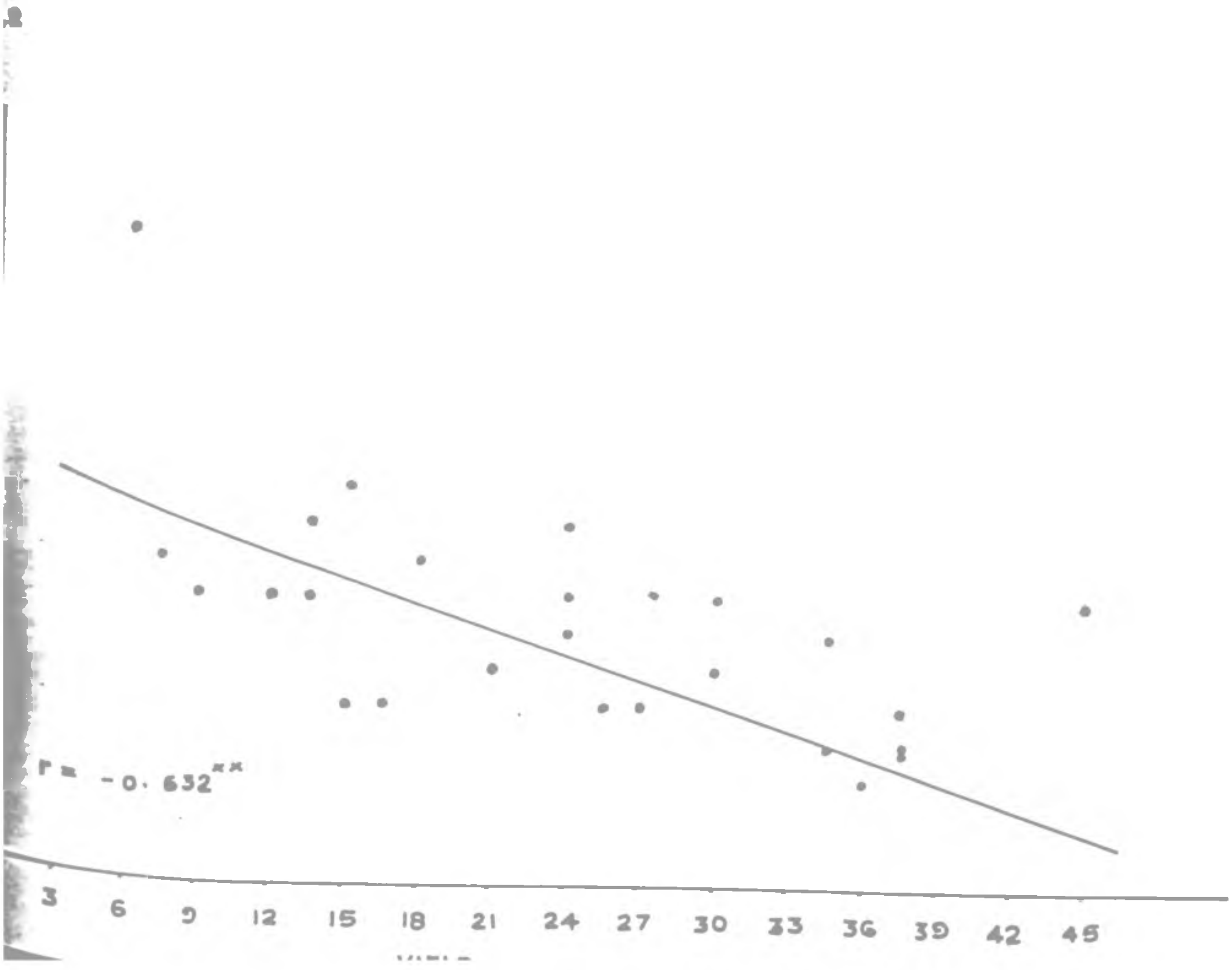
Subscripts 1,2,3,4,5 and 6 denote initial flow rate, number of latex vessel rows, diameter of latex vessels, thickness of soft bast, thickness of hard bast and girth respectively.

* Significant at 5% level of probability

Fig. 3.1 : Relationship between initial flow rate and yield.

Fig. 3.2 : Relationship between plugging index and yield.


r = 0·6411^{xx}
3
6
9
12
15
18
21
24
27
30
33
36
39
42
45
YIELD
g/tap/tree


r = -0·632^{xx}
3
6
9
12
15
18
21
24
27
30
33
36
39
42
45

correlated with initial flow rate. Thickness of hard and soft bast however are related to initial flow rate. The interdependence of characters such as latex vessel rows, diameter of latex vessels, thickness of soft and hard bast and girth in their individual effects on initial flow rate became clear from the partial correlation analysis. When the effects of other dependant factors were eliminated, none of these characters was significantly correlated with initial flow rate. The fact that factors other than these anatomical characters were operative in determining the initial flow rate became clear from the multiple correlation analysis which revealed that these characters together could account only for 35 percent of the variations in the initial flow rate.

ii) Effect of plugging index on initial flow rate.

Among the four progeny groups of inter-clonal crosses with Tjir 1 as female parent, three groups showed a significant negative correlation between initial flow rate and plugging index. In the progeny group of cross Tjir 1 x Gl 1 however, the correlation was not significant (Table 3.5). The additive effect of initial flow rate and plugging index on yield was however significant in all the progeny groups as brought out in the multiple correlation analysis.

iii) Effect of turgor pressure on initial flow rate

In simple correlation analysis, turgor pressure did not show any significant correlation with initial flow rate (Table 3.6). On further partial correlation analysis, eliminating the effect of number of latex vessel rows, the correlation between turgor pressure and initial flow rate became significant. Likewise the effect of the number of latex vessel rows on turgor pressure was also apparent when the effect of initial flow rate was eliminated in the partial correlation analysis.

(c) Effect of plugging index on yield

Table 3.7 summarises the results of correlation analysis between plugging index and yield utilising the data from four progeny groups of inter-clonal crosses. Yield is negatively correlated with plugging index in all cases. This relationship was significant even in the partial correlation analysis eliminating initial flow rate. In the progeny group of cross Tjir 1 x Gl 1, a strong interaction between initial flow rate and plugging index was evident as the correlation between plugging index and initial flow rate was more stable in the partial correlation analysis. This effect of initial flow rate was evident in other groups also but to lesser extent.

This inverse relations between yield and plugging index was also evident when the data collected from a population of clonal mother trees were used for the

Table 3.5

Simple correlation between initial flow rate and plugging index and multiple correlation of these characters with yield in the progenies of the crosses with Tjir 1 as the female parent.

Crosses	Correlations	
	Simple r23	Multiple R1(23)
Tjir 1 x G1$_1$	-0.1678	0.9074**
Tjir 1 x Avros 255	-0.4385**	0.8736**
Tjir 1 x Mil 3/2	-0.3254**	0.8400**
Tjir 1 x HC 28	-0.3574**	0.8451**

Subscripts 1, 2 and 3 denote respectively latex yield initial flow rate and plugging index.

** Significant at 1% level of probability.

Table 3.6

Correlations among turgor pressure, initial flow rate and latex vessel rows.

Correlations	Initial flow rate	Latex vessel rows
Simple	r12=0.242	r13 =0.343
Partial	r12.3 =0.4211*	r13.2 = -0.4785*

Subscripts 1,2 and 3 denotes turgor pressure, initial flow rate and latex vessel rows.

* Significant at 5% probability.

correlation analysis (Fig. 3.2). This relationship held good even after the effects of initial flow rate and girth on yield were eliminated in the partial correlation analysis (Table 3.8).

(d) Factors influencing plugging index

i) Relationship between bursting index and plugging index

The results of the study to evaluate the relationship between the bursting index (a measure of lutoid stability) and plugging index revealed that bursting index had a strong influence on plugging index (Table 3.9). The correlation value was higher when the effect of initial flow rate was eliminated.

ii) Effect of drainage area on plugging index

The effect of opening a second S/6 tapping cut opened at a distance on the latex flow from the first S/6 cut is presented in Table 3.10. It was assumed that opening of the second S/6 cut would result in the development of a drainage area which in turn might merge with the drainage area of the first cut. This possibility was prevented in the third treatment where grooves were put to severe the connections between the two drainage areas. Results indicated that by facilitating an extension of drainage area, the plugging index was reduced, as in the case of the second treatment. On the other hand in the third treatment opening of the second cut had little effect on the plugging index of the first cut. There was

Table 3.7

Correlation between plugging index and latex yield in the progenies of the crosses with 'Tjir 1' as the female parent.

Cross	Correlations	
	r12 (Simple)	r12.3 (partial)
Tjir 1 x Gl$_1$	−0.5520**	−0.7098**
Tjir 1 x Avros 255	−0.7081**	−0.7188**
Tjir 1 x Mil 3/2	−0.7268**	−0.8636**
Tjir 1 x HC 28	−0.6639**	−0.6295**

Subscripts 1,2 and 3 denote final volume yield, plugging index and initial flow rate.

** Significant at 1% level of probability.

Table 3.8

Simple and partial correlations of plugging index with yield in a population of clonal mother trees.

Correlations	Recording I	Recording II
r12	−0.6320**	−0.6067**
r12.3	−0.8501**	−0.8317**
r12.4	−0.6913**	−0.6751**

Subscripts 1,2,3 and 4 denote yield, plugging index, initial flow rate and girth respectively.

** Significant at 1% level of probability.

Table 3.9

Relationship between bursting index and plugging index

Simple and partial correlation	
Simple r12	0.6994 **
Partial r12.3	0.7309 **

Subscripts 1,2 and 3 denote respectively plugging index, bursting index and initial flow rate.

** Significant at 1% level of probability.

Table 3.10

Influence of the drainage area on plugging index

Clones	Treatment 1		Treatment 2		Treatment 3	
	One S/6 cut alone tapped		Both S/6 cuts tapped (S/6 d/1 (2x1d/2)		Both S/6 cuts tapped but the two cuts separated by grooves	
	Plugging index before opening of the second S/6 cut	Plugging index after opening of the second S/6 cut in treatments 1 and 2	Plugging index before opening of the second S/6 cut	Plugging index after opening of the second S/6 cut	Plugging index before opening of the second S/6 cut	Plugging index after opening of the second S/6 cut
RRIM 620	4.00	5.36	5.15	3.06	4.95	4.33
RRIM 601	7.95	10.40	9.00	6.86	7.35	7.43
RRIM 603	5.50	6.20	5.30	4.50	5.00	5.70

also clonal difference in the response to the opening of the second S/6 cut. In clone 603, the response was less compared to other two clones. The higher post-treatment values in the control trees (Treatment 1) was due to seasonal changes.

iii) Effect of mineral concentration in the latex fractions on plugging index

Table 3.11 gives the comparative values of phosphorus, potassium, magnesium and calcium in the bottom fraction and rubber phase (including C-serum) in low-plugging clones and high-plugging clones. Clones with higher plugging index have recorded higher values of calcium both in the bottom fraction and rubber phase. Contrary to this, the concentrations of phosphorus and potassium were lower in the case of high plugging clones. This was so for both the fractions. The variation in the magnesium content between high and low plugging clones did not appear to be very significant.

(e) Effect of dry rubber content in latex on yield

In a study utilising the data on d.r.c. and yield from a population of 32 clonal mother trees, no significant correlation between dry rubber content and yield was obtained (r = 0.385).

(f) Factors influencing dry rubber content of latex

i) Effect of plugging index on dry rubber content

Table 3.11

Effect of the mineral composition of latex fractions on plugging index (concentrations expressed as percentage of total solids)

[illegible]	Mineral composition in bottom fraction (average of clones)				Mineral composition in rubber phase & serum (average of clones)			
	[illegible]	[illegible]	Mg	Ca	P	K	Mg	Ca
plugg- [illegible] PI =	2.015	5.045	0.883	0.2146	0.106	0.438	0.016	0.0028
lugg- [illegible] =	2.055	7.030	0.878	0.1588	0.135	0.559	0.015	0.0026

Plugging index *per se* could influence the dry rubber content as evident from the simple correlation analysis between plugging index and initial flow rate (Table 3.12). Plugging index in turn was also negatively correlated with volume yield.

ii) Effect of system of tapping and amount of latex extraction on dry rubber content

The effects of extraction of latex adopting different intensities of tapping on the dry rubber content of latex, as observed in clones RRIM 602, 603, 604, 609 and 612 are presented in Tables 3.13, 3.14, 3.15, 3.16 and 3.17 respectively. Although S/2 d/2 and S/4 d/1 systems of tapping have the same intensity, the fall in dry rubber content was more pronounced with higher frequency of tapping (d/1) in all the clones, except RRIM 602. This fall in d.r.c. was not entirely the result of higher extraction of latex as in clone RRIM 612, the amount of latex extracted with S/4 d/1 system was less than that with S/2 d/2 system.

A comparison of two high intensity systems (400 %) namely S/1 d/1 and S/2 2 d/1 indicated that lengthening of the cut to full spiral resulted in lowering of the dry rubber content more drastically in all clones. This has happened irrespective of a comparatively lower amount of latex extraction in S/1 d/1 system compared to S/2 2 d/1 system.

Table 3.12

Correlation between d.r.c. and plugging index

Factors	Simple correlation	Partial correlation
d.r.c. and plugging index	$r_{12} = 0.469^{*}$	$r_{12.3} = 0.590^{*}$
Plugging index and volume yield	$r_{23} = -0.845^{**}$	......

Subscripts 1, 2, 3 denotes respectively d.r.c., plugging index and volume yield.

* Significant at 5% level of probability.

** Significant at 1% level of probability.

Table 3.13

Effect of system of tapping and amount of latex extraction on the dry rubber content in Clone RRIM 602.

of	Total extraction of latex till different periods after imposition of treatment and the dry rubber content					
	1 week		4 weeks		8 weeks	
	Latex extracted/ tree (ml)	d.r.c.	Latex extracted/ tree (ml)	d.r.c.	Latex extracted/ tree (ml)	d.r.c.
/2 ..	66	34.9	476	32.3	903	30.0
/1 ..	205	38.8	1329	33.2	2721	31.7
/1 ..	687	34.6	3708	27.1	5528	17.4
/1 ..	555	32.8	3486	28.8	6867	23.1

Table 3.14

Effect of system of tapping and amount of latex extraction on the dry rubber content in Clone RRII 603.

of ing	Total extraction of latex till different periods after imposition of treatment and the dry rubber content					
	1 week		4 weeks		8 weeks	
	Latex extracted/ tree (ml)	d.r.c.	Latex extracted/ tree (ml)	d.r.c.	Latex extracted/ tree (ml)	d.r.c.
/2 ..	242	30.0	1696	34.9	3283	34.5
/1 ..	283	31.4	1882	28.6	3939	30.0
/1 ..	749	31.9	3214	21.0	4079	19.0
/1 ..	611	32.7	3705	27.0	8105	27.0

Table 3.15

Effect of system of tapping and amount of latex extraction on the dry rubber content in Clone RRIM 604

System of tapping	Total extraction of latex till different periods after imposition of treatment and the dry rubber content					
	1 week		4 weeks		8 weeks	
	Latex extracted/ tree (ml)	d.r.c.	Latex extracted/ tree (ml)	d.r.c.	Latex extracted/ tree (ml)	d.r.c.
S/2 d/2	229	35.9	932	34.4	1694	38.2
S/4 d/1	390	33.9	1655	32.5	3524	34.5
S/1 d/1	1270	27.3	3410	22.3	5032	16.6
S/2 2 d/1	1114	29.3	4326	24.4	7772	27.0

Table 3.16

Effect of system of tapping and amount of latex extraction on the dry rubber content in Clone RRIM 609

System of tapping	Total extraction of latex till different periods after imposition of treatment and the dry rubber content					
	1 week		4 weeks		8 weeks	
	Latex extracted/ tree (ml)	d.r.c.	Latex extracted/ tree (ml)	d.r.c.	Latex extracted/ tree (ml)	d.r.c.
S/2 d/2	276	39.1	1091	35.6	1908	35.9
S/4 d/1	660	30.0	2501	30.5	5797	33.2
S/1 d/1	539	22.4	2044	19.5	3924	19.3
S/2 2d/1	1607	26.7	4851	24.7	8774	25.4

2. Relationship between biochemical composition of latex and yield

(a) Relationship between non-reducing sugar content in latex and yield

The correlation analysis indicated that the non-reducing sugar content in latex was not correlated either with latex yield or with the dry rubber content. In the partial correlation analysis also no evidence was obtained to assume any effect of non-reducing sugar content on latex yield or dry rubber content (Table 3.18).

(b) Relationship between ribonucleic acid content in latex and yield

The results of the correlation analysis of ribonucleic acid with latex yield and dry rubber content are presented in Table 3.19. Highly significant correlation was obtained between latex yield and RNA content of latex. The correlation between d.r.c. and RNA was not, however, significant. This would mean that the relationship of RNA with yield was not due to any change in the d.r.c. This has become more evident from the partial correlation analysis eliminating the effect of dry rubber content. As the volume of latex is a function of plugging index, simple, partial and multiple correlation of RNA with latex yield and plugging index was carried out and the results are presented in Table 3.20. There was significant negative correlation between plugging index and RNA. Partial correlation analysis showed highly significant correlation between latex yield and RNA, after eliminat-

Table 3.18

Simple and partial correlations of non-reducing sugar content in latex with latex yield and d.r.c.

Correlations	Latex yield	d.r.c.
Simple	r12 = 0.1106	r13 = 0.1118
Partial	r12.3 = 0.1423	r13.2= 0.1433

Subscripts: 1,2 and 3 denotes respectively non-reducing sugar content, lated yield and dry rubber content.

Table 3.19

Simple, partial and multiple correlations of RHA content in latex with latex yield and dry rubber content

rrelations	Latex yield	d.r.c.
Simple	r12 = 0.850**	r13 = -0.150
Partial	r12.3 = 0.348**	r13.2 = 0.209
Multiple	R1(23) = 0.752**	

bscripts: 1,2 and 3 denotes respectively RHA content, latex yield and dry rubber content.

** Significant at 1% level of probability.

Table 3.20

Simple, partial and multiple correlations of RHA content in latex with latex yield and plugging index.

Correlations	Latex yield 2	Plugging index 3
Simple	r12 = 0.850**	r13 = -0.498*
Partial	r12.3 = 0.799**	r13.2 = -0.147
Multiple	R1(23) = 0.732**	

bscripts: 1,2 and 3 respectively denotes RHA content, latex yield and plugging index.

* Significant at 5% level of probability.
** Significant at 1% level of probability.

ing the effect of plugging index. In the partial correlation analysis between plugging index and RNA, eliminating the effect of yield, however, the value obtained was not significant. The multiple correlation of RNA with latex yield and d.r.c. also was significant.

DISCUSSION

Effect of latex flow pattern on yield

Effect of initial flow rate on yield

The volume yield of latex obtained on tapping is a function of both the rate of flow and the plugging index. Sethuraj et al (1974 b) have reported clonal variation in the initial flow rate and as such an assessment of the comparative influence of this character on yield in different planting materials is worth making. The results of the present study confirm the earlier findings of Paardekooper and Samosorn (1969) that initial flow rate is significantly correlated with yield. The highly significant correlations between initial flow rate and yield in all the progenies of the four cross combinations are indicative of the possibility of initial flow rate being a clonal character, because the common female parent Tjir 1 is characterised by a high initial rate of flow. The general notion that the clonal variation in yield is largely governed by variations in plugging index requires modification in the light of the partial correlation analysis. The partial analysis eliminating the plugging index were highly significant and in the progenies of the cross Tjir 1 x Gl 1, about 74% of the yield variations were accountable by variations in initial flow rate. The same trend of results were obtained from the studies on a population of clonal mother trees also. As significant correlation between the length of the tapping cut and initial flow rate has been reported by Paardekooper and Samosorn (1969) the results of the partial correlation analysis eliminating the effect of girth has special significance. The effect of initial flow rate on yield is independent of girth. On the other hand, the present data indicate that the effect of girth on yield is mediated through its effect on initial flow rate.

Factors influencing initial flow rate

The correlation of initial flow rate with latex vessel rows and girth was found to be significant. The reported effect of latex vessel rows on yield (Milford et al, 1969) is assumably mediated through its influence on initial flow rate. The number of latex vessel rows, thickness of soft and hard bast as well as girth are factors which would influence the extent of latex vessels affected on tapping, and thus the flow. The difference in the degree of correlations in different groups of the population studied is expected as latex vessel number is only one of the factors that influence the initial flow rate. As is evident from Table 4.5, the thickness of the hard and the soft bast as well as the girth are equally important factors. While the former two characters are directly related to the latex vessel rows, girth influences the total volume occupied by the latex vessels. The inter-dependence of these characters in their effect on initial flow rate is evident from the non-significant correlations obtained in partial correlation analysis. The involvement of other factors is clear from the multiple correlation analysis which show that all these characters together account only for about 35% of the variations in the initial flow rate.

The results also indicate that plugging index itself can regulate initial flow. While the data from the progenies of the crosses between Tjir 1 x AVROS 255, Tjir 1 x Mil 3/2 and Tjir 1 x HC 28 show significant negative correlation between these two factors, the correlation turned out to be non-significant in the case of progenies of Tjir 1 x Gl 1 cross. Such variations can be seen from earlier studies also. Paardekooper (1966) reported a positive correlation between initial flow rate and plugging index for hundred clones. But in another experiment no significant correlation was however obtained (Paardekooper and Samosorn, 1969). The present study on the other hand shows a negative correlation at least in three groups. This can be expected if one assumes that a high initial rate of flow might delay the process of plugging by sweeping out the minute flocs that are progressively formed in the latex vessels along with the surge of flow. A high initial rate of flow would thus be associated with a lower plugging. The reason for not obtaining a significant correlation in the clones under the group Tjir 1 x Gl 1, might be that the plugging mechanism of these clones is strong even in the high yielding group of these clones.

It is conceivable that turgor pressure might influence at least the initial part of latex flow. The initial surge of latex, on tapping, is actually due to the release of pressure inside the vessels. While this holds true for a given latex vessel, the total initial flow rate would be dependant on other characteristics such as the number of latex vessel rows, density of latex vessels in each row etc. This is presumably the reason why no correlation between turgor pressure and initial flow rate was obtained. But the correlation between turgor pressure and initial flow rate became significant in partial correlation analysis, where the effect of number of latex vessel rows was eliminated. The finding that the number of latex vessel rows is negatively correlated with turgor pressure also is interesting. It could be assumed that with an increasing volume of the laticiferous system distributed in the bark, the turgor pressure of a particular vessel may be comparatively low.

Effect of plugging index on yield

The relationship between plugging index and yield is well documented (Sethuraj, 1968; Milford *et al.* 1969; Paardekooper and Samosorn, 1969). As the latex yield is a function of both the rate and duration of flow, the relative contribution of the plugging process on yield would vary, depending on the variations in the factors influencing the flow rate. As the initial flow rate is now considered a clonal character (Sethuraj *et al.* 1974 b), the relative importance of plugging index on yield in different genetic materials can also be expected to vary. It is evident from the partial correlation analysis that irrespective of the effect of initial flow rate, plugging index has strong influence on yield in all the progeny groups studied.

Factors influencing plugging index

Bursting index was developed by Ribaillier (1968) as a quantitative measure of lutoid stability. As the process of plug formation is triggered by the bursting of lutoid particles (Southorn, 1969) a correlation between plugging index and bursting index is quite expected. While the stability of lutoids would directly affect the process of plugging, the plugging index would be influenced by other factors, such as the rate of flow, as well (Sethuraj *et al.* 1974 b). The higher correlation obtained between plugging index and bursting index in partial correlation analysis, eliminating the effect of initial flow rate, indicates such a possibility.

The results from the experiment designed to study the effect of drainage area *per se* on the latex flow indicate that greater the drainage area lesser would be the plugging index. The biophysical properties of latex in the drainage area are known to be different from that of the latex far away from the cut (Philpott, 1951). This change in the biophysical properties is triggered by the physiological stimulus induced by tapping or application of certain chemicals. Effect of tapping, which in a sense is wounding of the tissue, is in many respects similar to the responses obtained from the growth regulating substances. It is reported that the changes in the biophysical properties of cytoplasm result in enhanced protoplasmic streaming (Sweeney and Thimann, 1938). Drawing an anology from such results, it could be assumed that the rheological properties of latex might be altered by such stimulus - received through tapping or chemical stimulation. Elucidation of this problem has experimental limitations as it is difficult to change the drainage area of a particular length of tapping cut. In the present study, however, an indirect approach was made to facilitate extension of drainage area by putting multiple tapping cuts at a distance from each other. Opening of another cut adjacent to the first cut, would have resulted in the merging of the two drainage areas. Once this is achieved, opening of any of the cuts would lead to drainage of latex from the newly developed and extended drainage area. The change in the rheological properties of latex in an extended area of bark triggered by opening another cut could be the causative factor in the extension of drainage area.

Relationship between yield and drainage area is now well recognised (Pakianathan et al. 1975). While the larger drainage area can be the consequence of greater drainage of latex in high yielders, the present study indicates that conditions which result in an extension of drainage area may act directly on plugging index and hence on yield. The speed and extent of development of drainage area on tapping might vary according to clonal characteristics as the present results indicate.

Studies on the relationship between mineral composition of latex and flow pattern indicated that mineral composition in the bottom fraction (largely composed of lutoids) and rubber phase including C-serum also would influence the plugging process. A high concentration of phosphorus and potassium both in the bottom fraction and rubber phase appeared to represent a condition favouring low plugging. On the other hand a higher calcium content was associated with high plugging character. Pushparajah *et al* (1975) have found that a high K content and a lower Mg content also resulted in low plugging. Application of higher doses of Rock phosphate increased the plugging index. This effect of rock phosphate was considered to be due to the presence of calcium. No work however seems to have been made to relate the clonal variation in yield to changes in the mineral composition in different fractions of latex. Clonal variation in the mineral composition, although known (Beaufils, 1954) is not adequately explained as the situation is complicated by the fact that the root system of all the clones necessarily belong to some seedling materials. It could however be assumed that mineral uptake would be influenced by the sink demand and that there is clonal differences in the sink demand for mineral elements. While the role of cations in the lutoid serum on the process of plugging is known (Southorn and Yip, 1968) the mechanism of effect of potassium in lowering the plugging index is still obscure.

Effect of dry rubber content on yield

While the dry rubbercontent is a reflection of a clone's capacity to withstand a particular system of exploitation, it is not an important determinant of yield as variations in yield are related more to the volume of latex. Therefore, absence of any correlation between yield and d.r.c. is not surprising. Paardekooper and

Samosorn (1969) also could not find any correlation between d.r.c. and yield. The situation may however change with intensive systems of tapping, when the fall in d.r.c. alone might influence yield.

Factors influencing dry rubber content.

A direct correlation between d.r.c. and plugging index has already been reported by Milford *et al* (1969). As there is an inverse relationship between yield and plugging index any effect of d.r.c. on yield, if at all it exists, would be mediated through changes in the plugging index. This would mean that a higher d.r.c. might indirectly reduce the total volume of latex collected. On the other hand, it could also be assumed that variations in d.r.c. might be the consequence of variations in the volume of latex extracted. With higher yield, the regeneration of rubber before the subsequent tapping may not completely replenish the loss resulting in a lower d.r.c. (Paardekooper and Samosorn, 1969).

The extent of latex extraction from the tree as influenced by the intensities of tapping also would influence the dry rubber content of latex. The influence of intensive tappings on d.r.c. has been studied in detail (Paardekooper *et al*, 1975). As the intensity of tapping depends both on the length of the cut and on the frequency it would be interesting to find out which of these factors is more effective in bringing down the d.r.c. The present studies indicated that fall in d.r.c. is more pronounced with tapping systems with longer cuts. This effect cannot be explained in terms of total amount of latex drained, as the lowest values should have been recorded by trees under 3/2 2d/1 system of tapping. In spite of such high frequency of tapping and excessive withdrawal of latex, the d.r.c. under this tapping system was comparatively higher than that in full spiral daily tapping system. This would indicate that the length of the tapping cut *per se* might influence the dry rubber content. The full spiral tapping cut can be expected to impair the efficient translocation of photosynthates downwards and this in turn might result in a lesser availability of the precursor substances for the regeneration of rubber particles.

Relationship between non-reducing sugar content in latex and yield

The importance of sucrose concentration in latex as a limiting factor of yield has been stressed time and again by Tupy (1973 a, 1973 b, 1973 c). While it has been established that the breakdown products of glycolysis form the basic precursor of rubber synthesis (Lynen, 1969), the contention that the sucrose concentration in latex may act as a limiting factor needs further evaluation. In the present study, correlation analysis between yield and non-reducing sugar content in latex was carried out with the objective of assessing whether the variations in yield between trees of different genotypes are reflected in the sugar content of their latices. The lack of any correlation of sugar content either with the yield or with the dry rubber content should be considered as evidence that this factor may not form an influencing factor in determining yield, between clones. As yield is determined by both d.r.c. and volume of latex, the relationship between non-reducing sugar content and d.r.c. eliminating the effect of latex volume was studied in partial correlation analysis. The results further confirm that the dry rubber content of a particular clone need not necessarily be the function of the level of non-reducing sugars in latex.

Relationship between RNA content in latex and yield

The highly significant correlation obtained between latex yield and RNA is in agreement with the findings of Tupy (1969). He compared high yielding and low yielding trees of the same clone and obtained significant variations in nucleic acid contents; high yielders had higher content of nucleic acid. An examination of his data however reveals that the high yield of the high yielding trees was not due to a higher rubber content in latex. This would indicate that the high yield was due to a higher volume of latex. It is difficult to comprehend how a high RNA content in latex would result in a higher volume of latex. But it is conceivable that a greater loss of latex from the tree might induce the tree to step up its metabolic activity to replenish the lost latex. A higher RNA content can well be expected to be associated with a higher metabolic activity of the laticiferous tissue. The present study was aimed to separate out the partial relationships of RNA with volume yield and dry rubber content. The partial correlation analysis depreciates the possibility of any direct influence of RNA on the dry rubber content. On the other hand, the variations in RNA are closely related to the variations in the latex yield. Plugging index is an important factor influencing yield (Milford et al. 1969). The correlation analysis between plugging index and RNA denotes their significant inverse relationship. But, in the partial correlation analysis, eliminating volume yield, there was no significant correlation between plugging index and RNA content. This would mean that the relationship of plugging index with RNA content is mediated through the volume yield of latex. The following sequence of relationship among these factors can be enviaaged: (1) A low plugging index will lengthen the duration of the latex flow resulting in an enhanced loss of latex from the tree (as in high yielders). (2) An enhanced extraction of latex from the tree in turn would trigger a higher metabolic activity in latex vessels leading to enhanced rubber biosynthesis. Such an effect by excessive withdrawal of latex is quite expected as the feedback inhibition of rubber biosynthesis by the concentration of rubber in latex is reported (Lynen, 1969). The higher content of RNA need only be considered as an indication of such a higher rate of metabolic activity in high yielding trees as a result of excessive withdrawal of latex. The pattern of results obtained from the correlation analysis would support this contention.

SUMMARY

Latex flow characteristics such as initial flow rate and plugging index are important factors which determine the yield. The yield was positively correlated with initial flow rate and negatively correlated with plugging index. The initial flow rate in turn was influenced by number of latex vessel rows and the proportion of soft bark. Girth is also related with yield, its effect being mediated through its influence on initial flow rate. An inverse relationship between initial flow rate and plugging index was also observed. The effect of turgor pressure on initial flow rate became clear only on partial correlation analysis eliminating the influence of number of latex vessel rows. The studies also indicated that drainage area *per se* might influence the plugging index. The lutoid stability as assessed by bursting index, was found to be related to plugging index, greater the stability lower being the plugging index. Role of mineral composition in latex on plugging index was also noted and high plugging clones had high phosphorus and potassium contents and low calcium content in the two centrifuged fractions of latex while the reverse was true with low plugging clones. The dry rubber content of latex had no direct correlation with yield. High intensity of tapping especially with longer cuts tends to lower the dry rubber content.

Reducing and non-reducing sugars in latex did not influence the yield. The RNA content however was correlated with yield. It also became evident that the higher RNA content in high yielding trees is a consequence of high yield (excessive loss of latex) rather than the cause of high yield.

SECTION IV

STUDIES ON EXPLOITATION METHODS AS FACTORS INFLUENCING YIELD

INTRODUCTION

Latex flow is an abnormal physiological phenomenon induced by tapping. When a tree is tapped for the first time there is very little flow of latex. With subsequent tappings the latex flow is stimulated. This effect of tapping depends on the length of the cut, the number of cuts on the trunk and frequency of tapping. Considerable work has already been done with a view to selecting the best tapping system from a commercial angle. Literature on tapping experiments include only certain selective combinations of length of cut and frequency of tapping. The design of these early experiments did not have the objective of identifying the individual effects of the factors such as length, number of cuts and frequency of tapping. In recent years however some efforts have been made to carry out factorial experiments to study the effects of the length of the cuts and tapping intensity. (Tan and Menon, 1973; Paardekooper et al. 1975). In these experiments also the concept of tapping intensity was given emphasis. It is quite conceivable that the physiological strain at the drainage area would be influenced by the frequency of tapping and number of cuts for any given tapping intensity. A reduction in the frequency of tapping or sharing of the intensity by two tapping panels would alleviate the physiological strain. While the length and number of cuts determine the drainage area, the frequency of tapping would influence the latex regeneration. There may also be clonal variation in the development of drainage area for a given length of tapping cut. Considering the relationship between length of the cut and plugging index (Milford et al. 1969) and the fact that there is seasonal variation in plugging index (Saraswathy Amma and Sethuraj, 1975) seasonal variations in response to tapping systems also are theoretically possible.

The tapping experiments in the present study were designed with the objective of elucidating some of these aspects. In the experiment involving eight systems of tapping in two clones comparisons were made among three lengths of cut in single cut systems, two lengths of cut in double cut systems, four systems at 100% intensity, two systems at 200% intensity, one system at 133% and another system at 67% intensity. Monthly variations in response to these systems of tapping as well as the comparative performance of two clones were studied. In another experiment it was examined if the harmful effects of daily tapping, a system followed by majority of small holders, would be mitigated if two panels are opened at opposite side and alternately tapped [S/2 d/1 ($\frac{2x1d}{2}$)].

Use of yield stimulants is now a common practice in plantations and this is one of the area in *Hevea* Physiology which has been comprehensively studied and the work has been reviewed from time to time (Chapman, 1951; Blackman, 1961; Abraham and Tayler, 1967; Sethuraj, 1968; Southorn, 1969). Of the factors which affect the effectiveness of yield stimulation, the declining trend in response with prolonged use of stimulants (Abraham *et al*, 1972; George *et al*, 1974; Abraham *et al*, 1975; George *et al*, 1976), concentration of the chemicals used (Abraham, 1970; Abraham *et al*, 1972; Abraham *et al*, 1975) interaction with tapping systems (Abraham, 1970; Abraham *et al*, 1972; George *et al*, 1974; Abraham *et al*, 1975; George *et al*, 1976) and seasonal variation in response (Abraham and Tayler, 1967; Sethuraj and George, 1975) have been considered. It is however imperative that further work should be carried out to get an insight into the physiological reason for this declining trend as well as on the interaction between concentration and declining trend. Whether the optimum concentration would vary with different intensities of tapping should also be examined. As it has now been established that action of stimulants might mediate through extending the drainage area (Sethuraj *et al.* 1975) the methods of applications aimed at enhancing the drainage area deserve intensive attention. It was with these objectives in mind that some of the experiments on stimulation, included in this study, have been planned.

MATERIALS AND METHODS

1. Experimental materials and locations

(a) Two clones, Tjir 1 and LCB 1320, were employed for the study on the effect of eight systems of tapping on yield. The location of the trial was Sittar Estate, Quilon District, Kerala.

(b) The experiment on intensive tapping (daily tapping) was carried out at the Central Experiment Station, Chethakkal, the clone being PR 107. The trees were under S/2 d/2 system of tapping on Panel A before the imposition of treatments.

(c) In order to assess the normal range of effect of Ethrel stimulation, four large scale experiments were laid out at three locations namely Nilambur, Thodupuzha and Palipalli. The clones studied were Tjir 1 (Nilambur and Palipalli) and PB 86 (Thodupuzha and Palipalli). The trees under two experiments at Palipalli and Nilambur were on Panel C while the PB 86 trees at Thodupuzha were on Panel D. The trees were under S/2 d/2 system of tapping.

(d) The experiment to determine the optimum concentration of Ethrel with two intensities of tapping (50% and 100%) was conducted at Kodumon estate located in Quilon District. The clone studied was PR 107 and the trees were being tapped on Panel B. System of tapping before the imposition of treatments was S/2 d/2.

(e) Clone Gl 1 was chosen, considering its known susceptibility to higher intensities of tapping, for stimulation with two frequencies of tappings. The experiment was conducted at Kinalur Estate (Calicut District) considering the good performance of this clone at that location. The trees were being tapped on Panel C, and under S/2 d/3 system of tapping before the imposition of treatments.

The possibility of using higher intensities of tapping along with stimulation was assessed in an experiment at New Ambadi estate, in clone Tjir 1 tapped in Panel D.

(f) Seasonal variations in the effectiveness of stimulation was studied using twenty trees each from clones Tjir 1 and Gl 1, planted at the RRII experiment station. The trees were under S/2 d/2 system of tapping on Panel C.

(g) Effect of prolonged use of Ethrel on yield was studied in two clones (Tjir 1 and PB 86). The locations of the experiments were Pullengode and Thodupuzha. Both clones were being tapped under S/2 d/2 system. The tapping panels were C and D for clones Tjir 1 and PB 86 respectively.

(h) Influence of the length of the stimulated band on yield increase was studied in clone RRIM 605, tapped on Panel A, tapped under S/2 d/2 system and planted at the Central Experiment Station.

Effect of multiple band applications of Ethrel (Sethuraj et al. 1975) was assessed in a large scale experiment at the New Ambadi estate at Kulasekharam, Kanyakumari District. The clone was Tjir 1, being tapped on Panel D. System of tapping was S/2 d/2.

2. Experimental details and design of the lay out

(a) The eight systems of tapping compared were:

i. S/3 d/2 (one third spiral cut, alternate daily tapping)

ii. S/2 d/2 (half spiral cut, alternate daily tapping)

iii. S/1 d/2 (full spiral cut, alternate daily tapping)

iv. S1 d/4 (full spiral cut, once in four days tapping)

v. S/2 d/2 $(\frac{2x2d}{4})$ - (Two opposite half spiral cuts at a distance of 75 cm; tapping once in two days, but alternating the panels)

vi. 2 S/2 d/4 - Two opposite half spiral cuts, once in four days tapping.

vii. 2 S/2 d/2 - Two opposite half spiral cuts, alternate daily tapping.

viii. 2 S/3 d/2 - Two 1/3 spiral cuts, alternate daily tapping.

A randomised block design was adopted for this experiment. Each plot consisted of eight trees and there were five replications. Pre-treatment yield data for one year was used for co-varience analysis.

(b) In the experiment on the daily tapping systems, the following treatments were imposed, with 24 replications (single tree plot) for each treatment.

i. S/2 d/2 (half spiral, alternate daily tapping)

ii. S/2 d/1 (half spiral, daily tapping)

iii. S/2 $(\frac{2x1d}{2})$ (Two half spiral cuts on opposite sides at a distance of 75 cm; tapped daily, but alternating the panels)

The lay out was randomised block design.

(c) In all the experiments to study the effect of Ethrel stimulation, tapping blocks of comparable yields were selected and treatment imposed keeping one of the blocks as untreated control. Ethrel (manufactured by M/s Amchem Products, Inc. USA), containing 10% ethephon (2 chloroethyl phosphonic acid) was used.

(d) In the experiment to assess the optimum concentration of Ethrel with two tapping intensities, randomised block design was adopted with fifty replications (single tree plot). The clone was PR 107. The treatments were:

i. 2.5% Ethrel - S/2 d/2 tapping
ii. " - S/2 d/4 tapping
iii. 5% Ethrel - S/2 d/2 tapping
iv. " - S/2 d/4 tapping
v. 10% Ethrel - S/2 d/2 tapping
vi. " - S/2 d/4 tapping

2.5, 5 and 10 % Ethrel were prepared by mixing with appropriate quantity of coconut oil.

(e) Stimulation with d/3 and d/4 systems of tapping in clone Gl 1 was studied in block-wise experiments. Three tapping blocks of comparable yields were selected and the following treatments imposed:

i. S/2 d/3 - Unstimulated
ii. S/2 d/3 + Ethrel 10%
iii. S/2 d/4 + Ethrel 10%

(f) Effect of Ethrel application made at four different periods of the year (March, June, September and December) was studied in clones Tjir 1 and Gl 1. Thus there were five treatments including unstimulated control, with four replications. Pre-treatment and post-treatment yield was recorded by cup coagulation method. One pre-treatment and one post-treatment (15 days after treatment) recording of plugging index was also carried out.

(g) Studies on the effect of prolonged use of Ethrel were also conducted in block-wise experiments. Tapping blocks of comparable yields were selected and treatments imposed, keeping one block as untreated control. Ready-to-use Ethrel Latex Stimulant (Aachem) was used in these trials.

(h) In order to study the effect of the length of the stimulated band on yield the following treatments with five replications were imposed:

i. Normal application of Ethrel (1.5 g) per tree below the tapping cut (bark application)

ii. Application of Ethrel (1.5 g) per tree on a 30 cm long vertical band.

iii. Application of Ethrel (1.5 g) per tree on a 90 cm long vertical band.

iv. Unstimulated control.

The effect of multiple band application of Ethrel on yield was assessed in block-wise experiments. Three tapping block of clone Tjir 1 and of comparable yields were selected. The trees were tapped under S/2 d/2 system. The following treatments were imposed:

i. Unstimulated control

ii. Ethrel (10% ai.), normal bark application and

iii. Ethrel (10% a.i.), multiple band application (Plate 4.1)

The extent of latex drainage at a height of 3 meters was assessed by determining the *in situ* dilution.

Plate 4.1 : Multiple band application of Ethrel.

3. Recording Procedure

(a) Yield:- Yield per tapping block or yield per tree was recorded as per the methods already described in Section II pp. 81.

(b) Initial flow rate and plugging index:- As per the methods described in Section II pp. 83.

(c) Determination of in situ dilution after tapping:- In order to get an idea about the extent of latex drainage when multiple band application of Ethrel was adopted, the variations in total solids of the first two drops of latex collected by microtapping with a needle, before and three hours after tapping were determined by the method of Ferrand (1941).

RESULTS

Comparative performance of eight systems of tapping

The differential effects of eight systems of tapping on yield/tap/tree and yield/tree/year are presented in Fig. 4.1. Considering S/2 d/2 system of tapping as control, the comparative performance of the other systems is given in Table 4.1. Among the eight systems of tapping studied, four systems have a relative tapping intensity of 100%. Irrespective of the same intensity, systems with either full spiral cut or two half spiral cuts have given a higher yield per tapping both in Tjir 1 and in LCB 1320. The annual yield is however less in the fourth daily

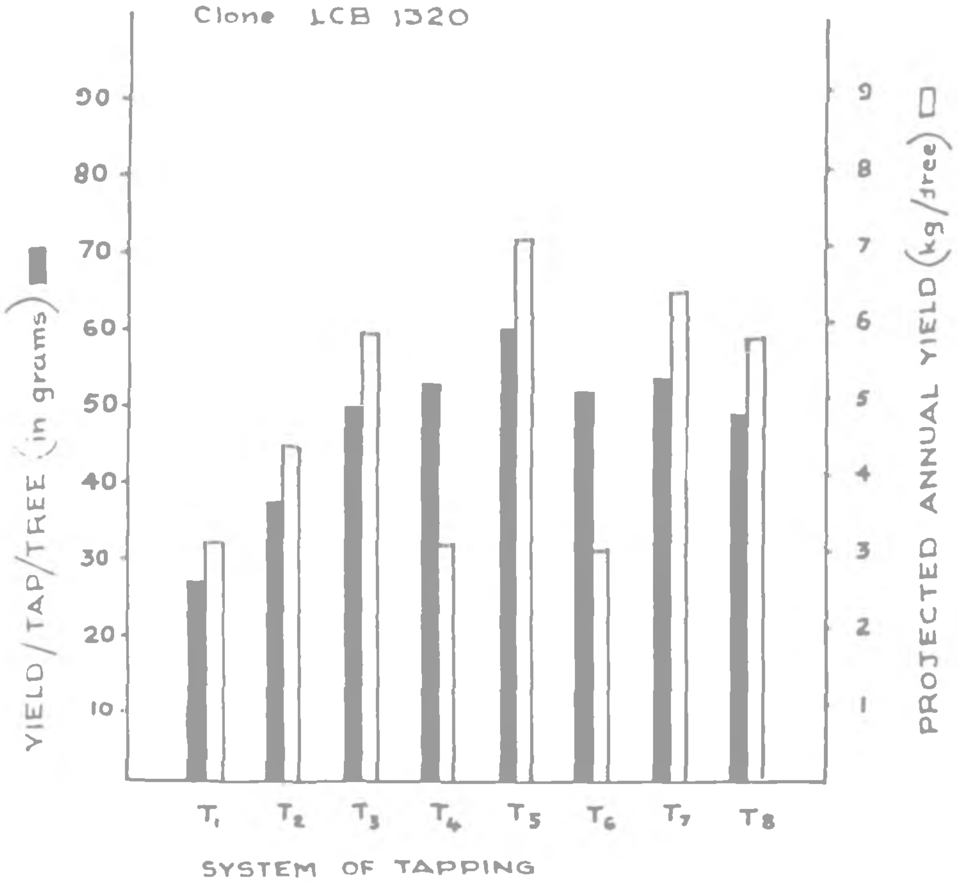
Table 4.1

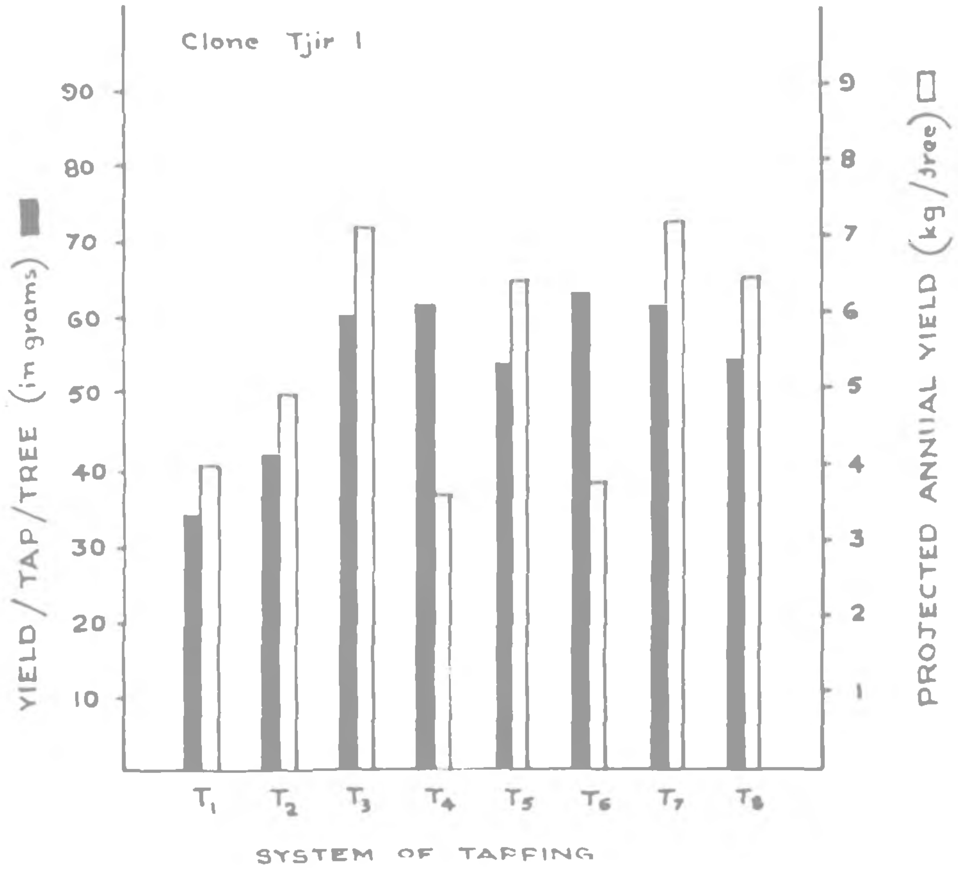
Comparative performance of eight systems of tapping.
Yield as percentage of control (S/2 d/2)

Systems of tapping	Tapping intensity	Tjir 1		LCB 1320	
		Yield/ tap/ tree	Yield/ tree/ annum	Yield/ tap/ tree	Yield/ tree/ annum
S/3 d/2	67	81.0	81.0	71.69	71.69
S/2 d/2	100	100.0	100.0	100.00	100.00
S/1 d/2	200	143.1	143.1	133.6	133.6
S/1 d/4	100	147.2	73.8	141.4	70.7
S/2 d/2($\frac{2x2d}{4}$)	100	129.4	129.4	162.3	162.3
2 S/2 d/4	100	151.9	76.0	140.1	70.0
2 S/2 d/2	200	145.0	145.0	145.1	145.1
2 S/3 d/2	133	130.1	130.1	131.8	131.8

Fig. 4.1 : Response of clones LCB 1320 and Tjir 1 to eight systems of tapping.

(T_1 - S/3 d/2 T_2 - S/2 d/2
T_3 - S/1 d/2 T_4 - S/1 d/4
T_5 - S/2 d/2(2x2d/4) T_6 - 2 S/2 d/4
T_7 - 2 S/2 d/2 and T_8 - 2 S/3 d/2)


Clone LCB 1320
YIELD / TAP / TREE (in grams) ▮
PROJECTED ANNUAL YIELD (kg/tree) ☐
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
T1
T2
T3
T4
T5
T6
T7
T8
SYSTEM OF TAPPING


Clone Tjir 1
YIELD / TAP / TREE (in grams) ▮
PROJECTED ANNUAL YIELD (kg/tree) ☐
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
T1
T2
T3
T4
T5
T6
T7
T8
SYSTEM OF TAPPING

systems. S/2 d/2 $\left(\frac{2x2d}{4}\right)$ tapping system appears to be superior to other three systems of the same intensity in both clones, more so in clone LCB 1320. In LCB 1320, this system recorded the highest yield/tap/tree as well as the highest yield/tree/year. Increasing the intensity of tapping has resulted in an increase in the yield/tree/year in both the clones. But in LCB 1320, S/2 d/2 $\left(\frac{2x2d}{4}\right)$ with a relative intensity of 100% gave a higher yield than the two tapping systems with 200% intensity. The lowest yield/tap/tree was recorded in both clones by the S/3 d/2 system. However, the comparative yield performance of these systems of tapping was not the same for all the months. Monthly variations in the effect of tapping systems were also evident. (Table 4.2, 4.3, 4.4 and 4.5). An interesting observation on the clonal variation in response to tapping system as a function of a particular period of the year was that while in clone Tjir 1, there was no statistical difference between the systems of tapping during the months of June, July, August, December and January (Table 4.2), in clone LCB 1320, the differential effects of tapping systems were evident during all the months (Table 4.3).

A comparison of different length of the cut (S/3, S/2 and S/1) indicated that yield increases with an increase in the length of the cut (Table 4.6). This increase, however, was not proportionate to the length of

Table 4.2

Comparative effect of different systems of tapping* on yield

Clone Tjir 1

Month	Results of statistical analysis							
April	3	7	8	5	2	4	6	1
May	3	7	4	8	5	2	6	1
June	6	4	3	5	7	2	8	1
July	5	7	8	1	6	2	4	3
August	4	6	1	5	7	8	2	3
September	7	8	6	4	3	5	2	1
October	6	3	4	7	8	5	2	1
November	4	6	3	5	8	7	2	1
December	6	5	7	8	4	1	3	2
January	6	5	4	8	1	3	7	2

1. S/3 d/2
2. S/2 d/2
3. S/1 d/2
4. S/1 d/4
5. S/2 d/2 $(\frac{2x2d}{4})$
6. 2 S/2 d/4
7. 2 S/2 d/2
8. 2 S/3 d/2

Table 4.3

Comparative effect of different systems of tapping* on yield
Clone LCB 1320

Month	Results of Statistical analysis							
April	3	7	4	5	8	6	2	1
May	4	6	5	3	7	8	2	5
June	5	6	7	4	8	3	2	5
July	5	8	7	3	6	4	2	1
August	5	6	7	4	8	3	2	1
September	7	5	8	6	4	3	2	1
October	5	7	6	8	4	3	2	1
November	5	7	3	4	6	8	2	1
December	5	8	4	2	3	7	6	1
January	5	3	6	4	7	8	2	1

*

1. S/3 d/2
2. S/2 d/2
3. S/1 d/2
4. S/1 d/4
5. S/2 d/2 $\frac{(2x2d)}{4}$
6. 2S/2 d/4
7. 2S/2 d/2
8. 2S/3 d/2

Table 4.4

Monthly average yield as percentage of annual average yield
in eight different systems of tapping
(Clone - Tjir 1)

Tapping system	Tapping intensity.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.
S/3 d/2	67%	39.5	42.5	106.6	140.3	96.3	108.1	81.9	49.9	171.8	123.3
S/2 d/2	100%	71.2	73.1	116.4	116.4	87.5	95.2	93.5	85.9	163.7	96.0
S/1 d/2	200%	117.0	89.7	93.2	107.4	69.4	95.1	96.3	106.2	119.9	105.8
S/1 d/4	100%	101.1	114.8	100.0	90.6	92.5	94.6	94.1	98.4	123.4	91.2
S/2 d/2 (2x2d/4)	100%	67.4	86.1	109.8	111.9	92.3	88.3	103.5	123.3	120.1	97.4
2 S/2 d/4	100%	67.9	106.3	125.3	96.3	97.2	95.5	112.5	99.0	103.9	98.2
2 S/2 d/2	200%	103.5	80.2	101.7	99.3	91.6	99.5	112.9	114.4	108.5	88.6
2 S/3 d/2	133%	80.6	64.7	106.6	109.7	89.5	105.2	112.8	102.5	137.8	92.2

Table 4.5

Monthly average yield as percentage of annual average yield
in eight different systems of tapping
(Clone ICB 1320)

Tapping system	Tapping intensity.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.
S/3 d/2	67%	39.5	42.5	106.6	140.3	96.3	108.1	81.9	99.9	171.8	123.3
S/2 d/2	100%	71.2	73.1	116.4	116.4	87.5	95.2	93.5	85.9	164.7	96.0
S/1 d/2	200%	117.0	89.7	93.2	107.4	69.4	95.1	96.3	106.2	119.9	105.8
S/1 d/4	100%	101.1	114.8	100.0	90.6	92.5	94.6	94.1	98.4	123.4	91.2
S/2 d/2 (2x2d/4)	100%	67.4	85.1	109.8	111.9	92.3	88.3	103.5	123.3	120.1	97.4
2 S/2 d/4	100%	67.9	106.3	125.3	95.3	97.2	95.5	112.5	99.0	103.9	98.2
2 S/2 d/2	200%	103.5	80.2	101.7	99.3	91.6	99.5	112.9	114.4	108.5	88.6
2 S/3 d/2	133%	80.6	64.7	106.6	109.7	89.5	105.2	112.8	102.5	137.8	92.2

Table 4.6

Effect of length of cut on yield (g/tap/tree)*

Clone	Length of the cut		
	S/3	S/2	S/1
Tjir 1	33.54 (100)	41.40 (82.28)	59.36 (58.88)
LCB 1320	26.37 (100)	36.78 (92.98)	49.14 (62.11)

* Yield per unit length assuming S/3 as 100 is given in brackets

the cut. The percentage efficiency of S/2 and S/1 system compared to S/3 in terms of yield per unit length of the cut are given in brackets. These results indicated that the yield per unit length of cut decreases with lengthening of the cut. The effect of lengthening of the cut is slightly more pronounced in LCB 1320 than in Tjir 1. There is however monthly variation in the effectiveness of lengthening of the cut on yield (Fig. 4.2 a and b). This effect is more pronounced in clone Tjir 1 compared to LCB 1320. A comparison of two lengths of cuts (S/3 and S/2) in double cut systems indicated that the monthly fluctuations in the effectiveness of lengthening of the cut was less apparent (Tables 4.7 and 4.8; Fig. 4.3 a and b).

Reduction in the frequency of tapping to d/4 from d/2 for a given length of cut, though resulted in a slight initial depression in yield gave higher yield per tap in clone Tjir 1 both in the case of single cut (Fig. 4.4) and double cut system (Fig. 4.5). Such difference was not apparent in clone LCB 1320 (Figs. 4.6 and 4.7).

The intensity of tapping is a product of length of the cut and frequency of tapping. Comparison of four intensities of tapping (67%, 100%, 133% and 200%) indicated an increase in yield per tap with increasing intensity (Fig. 4.8). But in terms of 'tapping efficiency' for unit of intensity as defined by

Table 4.7.

Seasonal variations on the comparative performance of different tapping systems in Tjir 1 (Monthly yield of different systems of tapping as percentage of average monthly yield of all tapping systems)

Tapping system	Tapping intensity.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.
S/3 d/2	67%	14.97	9.73	59.18	99.19	114.60	34.51	22.25	48.30	79.63	89.19
S/2 d/2	100%	66.13	72.00	92.48	90.30	85.80	86.59	68.27	66.60	78.84	70.24
S/2 d/2	200%	285.33	166.38	117.24	85.02	71.40	124.22	129.51	126.42	86.86	88.52
S/1 d/4	100%	27.73	151.54	127.36	88.91	122.73	136.71	129.06	137.36	102.23	108.63
S/2 d/2 (2x2d/4)	100%	68.27	74.43	93.68	115.63	98.86	103.02	86.11	108.30	108.15	120.87
2 S/2 d/4	100%	24.00	63.49	127.81	97.67	117.99	137.04	159.10	134.91	134.30	134.79
2 S/2 d/2	200%	221.87	164.19	93.61	113.50	91.10	149.36	117.04	83.96	106.31	86.00
2 S/3 d/2	133%	91.73	98.27	87.08	106.50	90.34	145.75	88.56	94.91	103.68	101.76

Table 4.8

Seasonal variations on the comparative performance of different tapping systems in LCB 1320 (Monthly yield of different systems of tapping as percentage of average yield of all tapping systems)

Tapping system	Tapping intensity.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.
S/3 d/2	67%	26.3	27.8	55.5	73.7	60.3	62.4	44.7	48.1	75.7	70.7
S/2 d/2	100%	66.3	66.8	84.6	85.3	76.4	76.6	71.1	64.1	100.0	76.8
S/1 d/2	200%	145.5	109.6	90.5	105.3	81.1	102.3	97.8	105.9	100.0	113.1
S/1 d/4	100%	133.1	148.4	102.7	93.9	114.9	107.7	99.0	103.9	107.3	103.1
S/2 d/2 (2x2d/4)	100%	101.7	127.8	129.6	133.2	130.7	115.4	127.7	149.4	119.8	126.3
2 S/2 d/4	100%	88.5	136.2	127.6	96.9	118.8	107.7	119.9	103.5	89.54	110.6
2 S/2 d/2	200%	139.6	93.7	107.2	105.6	115.9	116.3	124.6	123.9	100.0	102.9
2 S/3 d/2	133%	98.9	123.2	102.1	106.0	102.9	111.6	113.1	100.9	111.4	97.2

Fig. 4.2(a) : Influence of length of the tapping cut on yield at different periods of the year in clone Tjir 1.

Fig. 4.2(b) : Influence of length of the tapping cut on yield at different periods of the year in clone LCB 1320.

FIG: 4.2.(a)

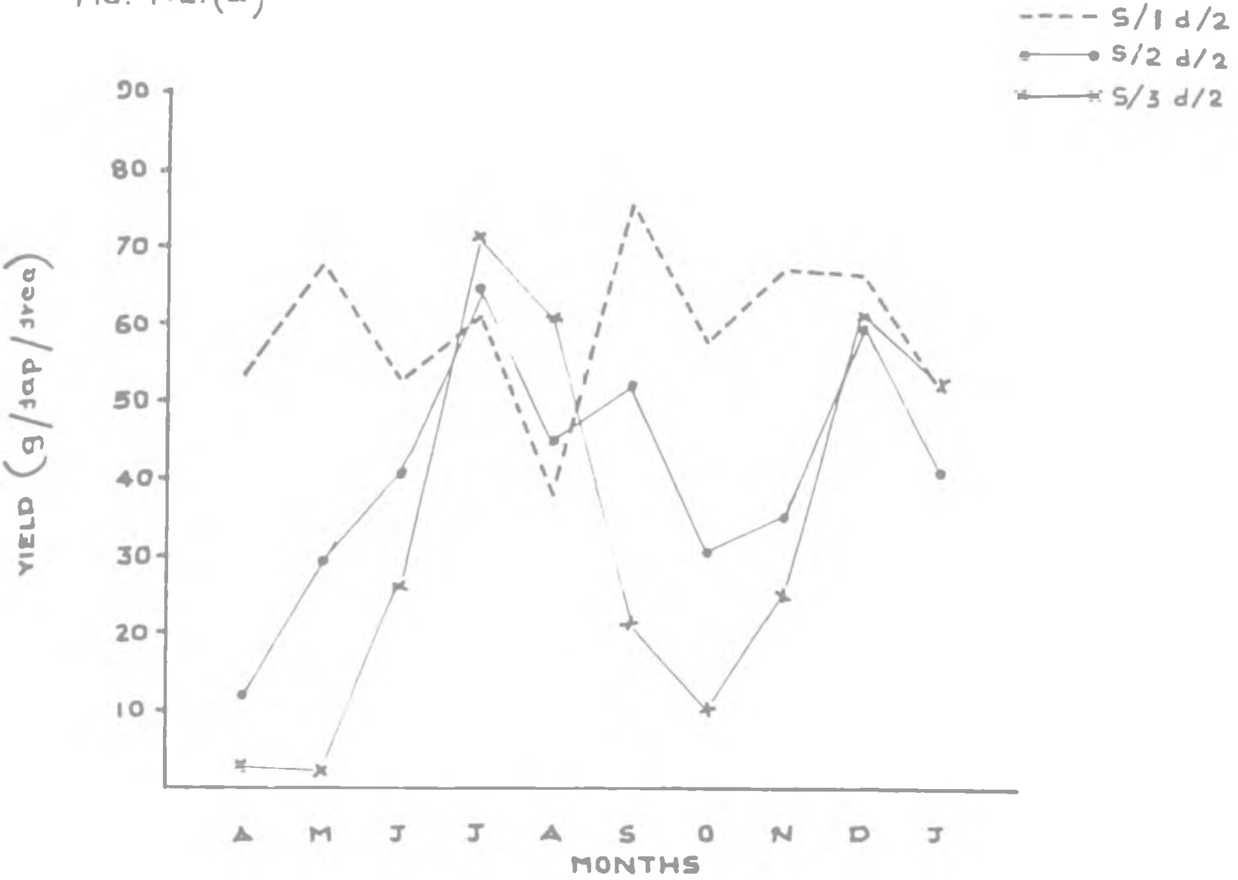


FIG: 4.2 (b)

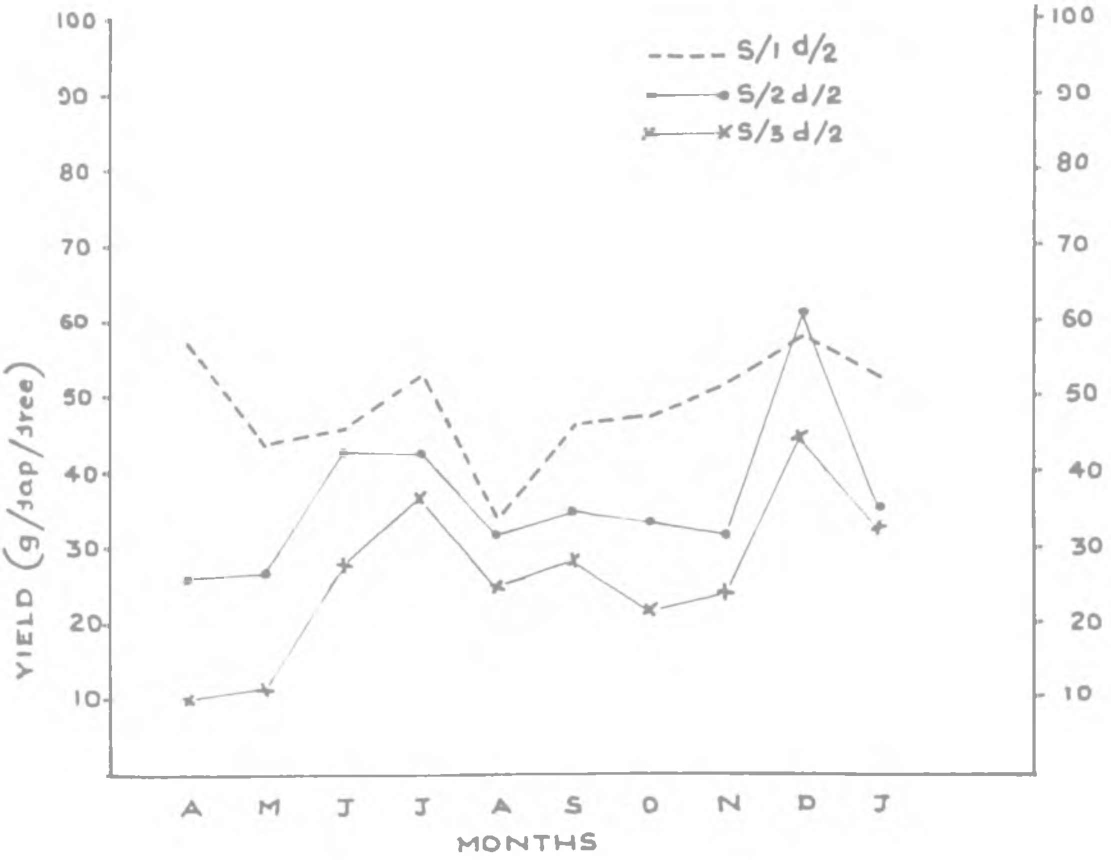


Fig. 4.3(a) : Influence of length of the tapping cut in double-cut tapping systems at different periods of the year in clone Tjir 1.

Fig. 4.3(b) : Influence of length of the tapping cut in double-cut tapping systems at different periods of the year in clone LCB 1320.

FIG. 4.3 (a)

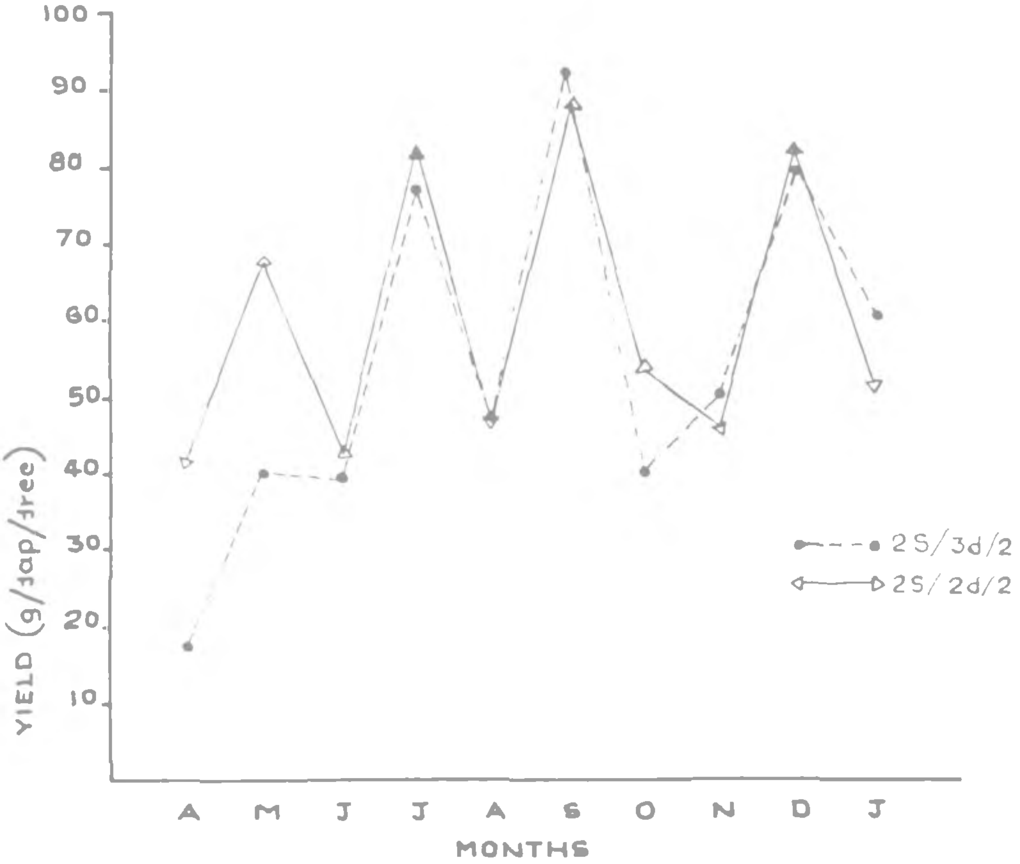


FIG: 4.3 (b)

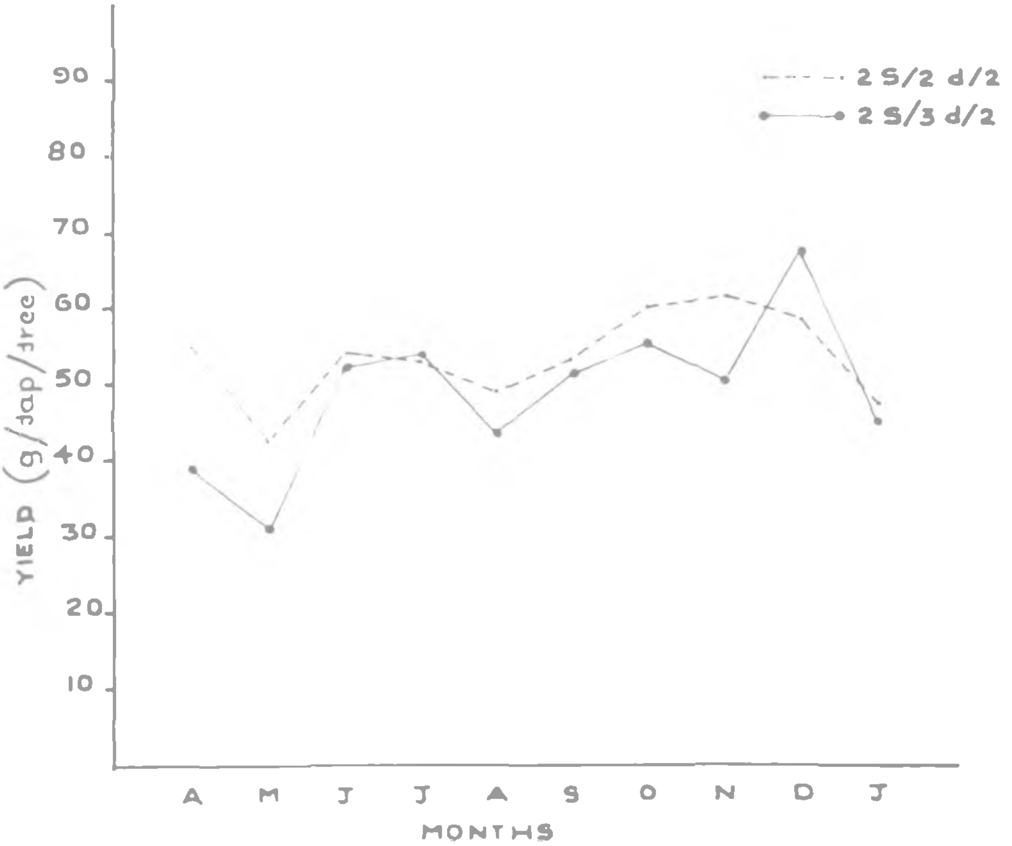
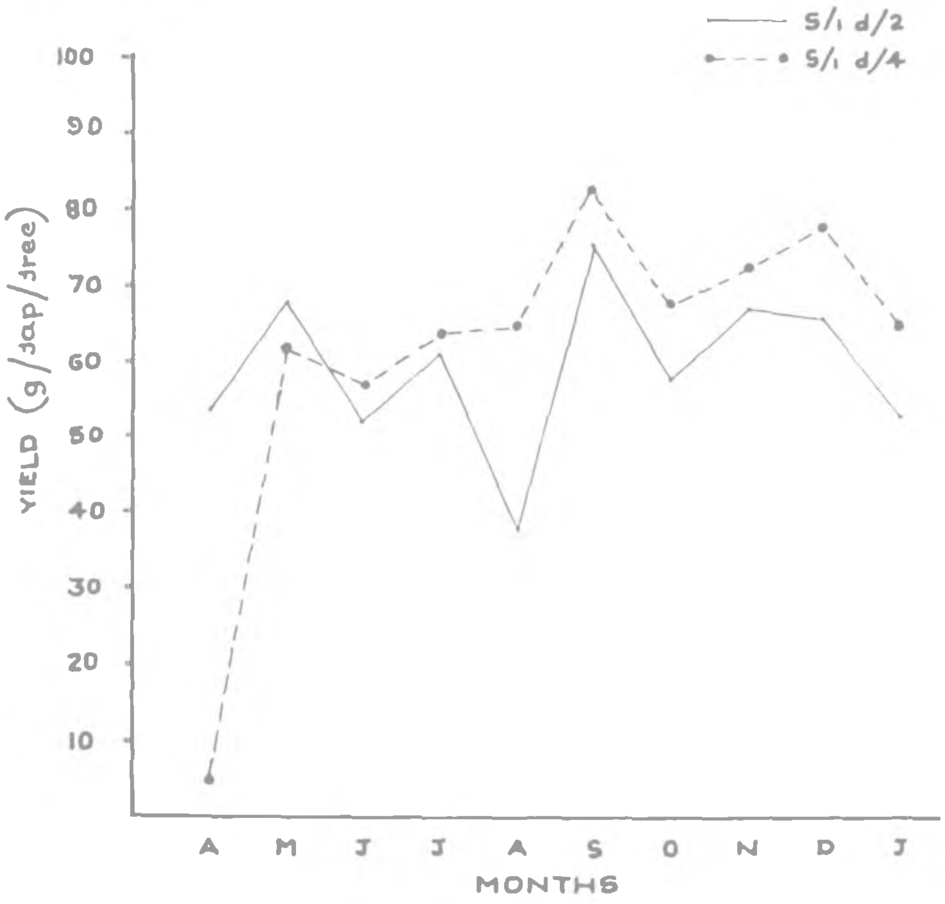


Fig. 4.4 : Influence of frequency of single-cut tapping on yield at different periods of the year in clone Tjir 1.

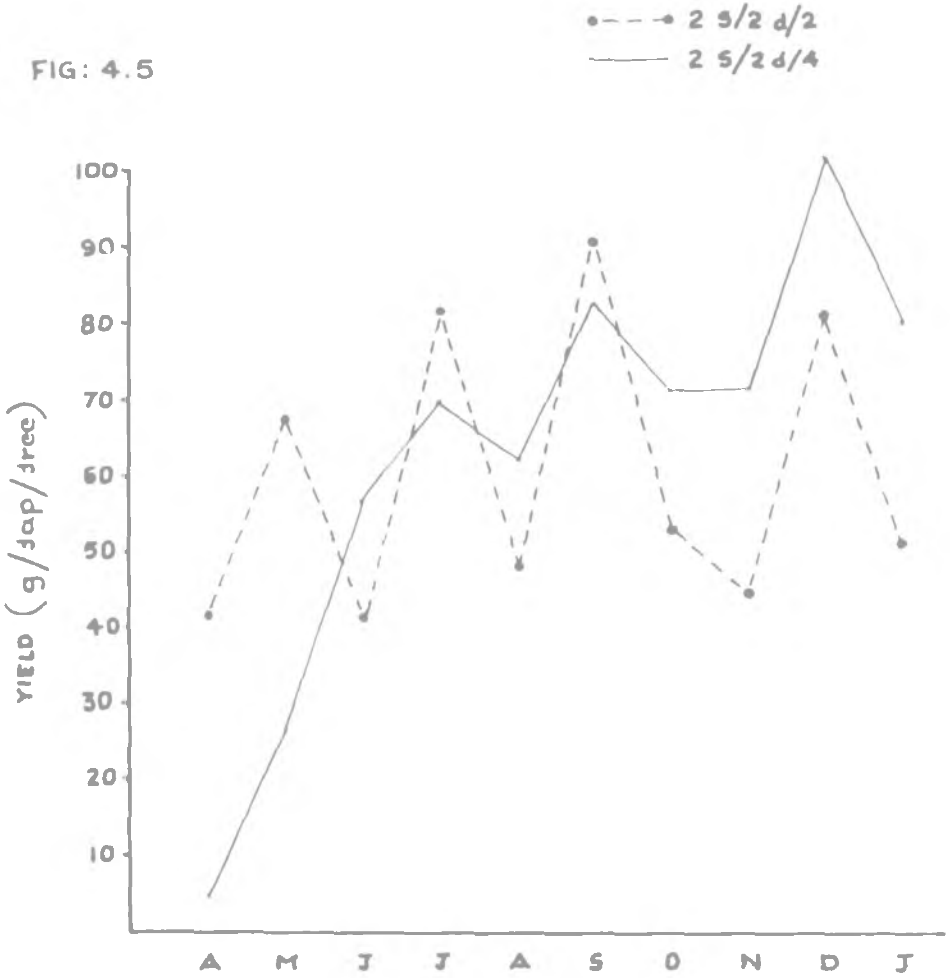
Fig. 4.5 : Influence of frequency of double-cut tapping on yield at different periods of the year in clone Tjir 1.

FIG: 4.4



S/1 d/2
S/1 d/4
YIELD (g/tap/tree)
100
90
80
70
60
50
40
30
20
10
A
M
J
J
A
S
O
N
D
J
MONTHS

FIG: 4.5



2 S/2 d/2
2 S/2 d/4
YIELD (g/tap/tree)
100
90
80
70
60
50
40
30
20
10
A
M
J
J
A
S
O
N
D
J

Fig. 4.6 : Influence of frequency of single-cut tapping on yield at different periods of the year in clone LCB 1320.

Fig. 4.7 : Influence of frequency of double-cut tapping on yield at different periods of the year in clone LCB 1320.

FIG: 4.G

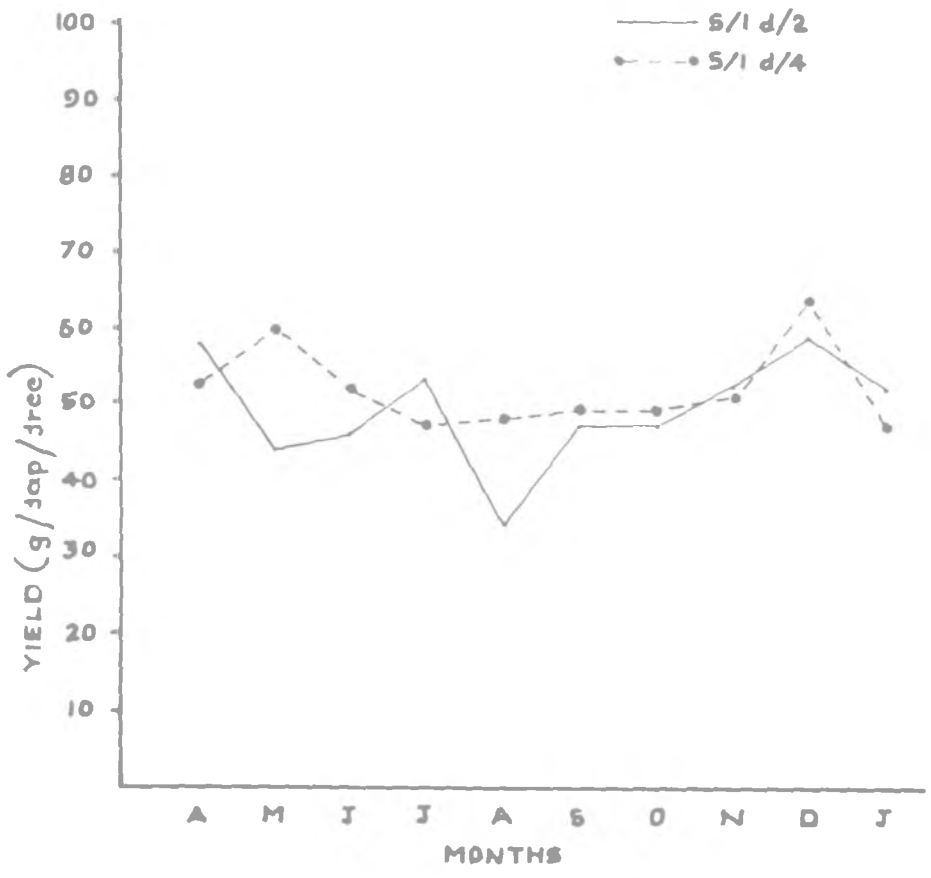
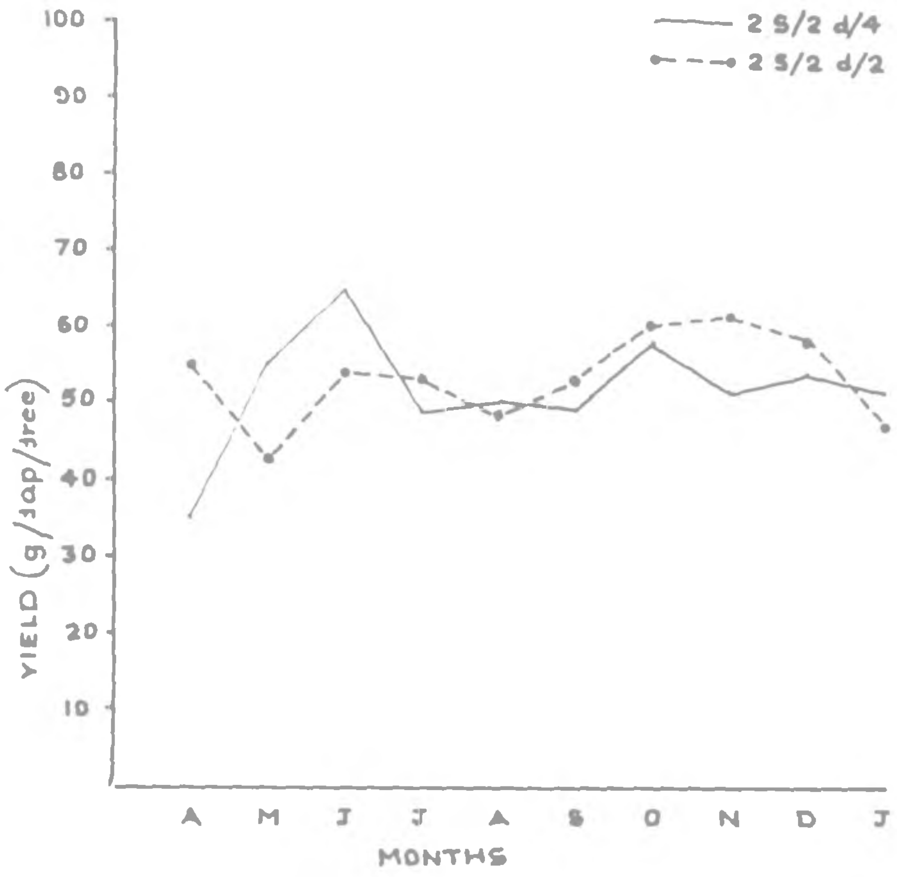

S/1 d/2
S/1 d/4
100
90
80
70
60
50
40
30
20
10
YIELD (g/tap/tree)
A
M
J
J
A
S
O
N
D
J
MONTHS

FIG: 4.7


2 S/2 d/4
2 S/2 d/2
100
90
80
70
60
50
40
30
20
10
YIELD (g/tap/tree)
A
M
J
J
A
S
O
N
D
J
MONTHS

Paardekooper *et al* (1975), the efficiency decreases with increasing intensity (Fig. 4.9). The effect of two cuts as compared to one cut is summarised in Table 4.9. The relative increase in yield in two cuts compared to single cut was more pronounced with shorter cuts.

Effect of a new system of daily tapping (S/2 d/1 (2x1d/2) on the incidence of dry trees

Table 4.10 summarises the total yield obtained and incidence of dry trees in two daily systems of tapping and S/2 d/2 control. The results indicated that by adopting S/2 d/2 ($\frac{2x1d}{2}$) system of tapping yield could be increased by 51% as compared to S/2 d/2 system of tapping. With half spiral daily tapping however the yield was increased by 77%. But this system resulted in a high incidence of brown bast; 12.5% of the experimental trees turning dry within a period of one year. On the contrary there was no incidence of dryness in S/2 d/2 ($\frac{2x1d}{2}$) system of tapping.

Effect of stimulants on yield

(a) Normal range of response to ethephon (Ethrel) applications.

The data on the increase in yield over a period of four years obtained by application of Ethrel indicated that the range of response varied from 29 to 65 percent. The higher response shown by the clone PB 86 planted at Thodupuzha as compared to that of the same clone planted at Palipalli was either due to the difference in tapping

Table 4.9

Effect of two cuts as compared to single cut on yield (g/tap/tree)

(Percentage yield increase in double cuts is given in brackets)

Clone	Systems of tapping			
	S/3 d/2	2 S/3 d/2	S/2 d/2	2 S/2 d/2
Tjir 1	33.54 (100)	53.88 (160.6)	41.9 (100)	60.07 (143.4)
LCB 1320	26.37 (100)	48.49 (183.8)	36.78 (100)	53.38 (143.4)

Table 4.10

Effect of two systems of daily tapping on yield and incidence of dry trees.

Systems of tapping	Total annual yield (Kg/tree)	Percentage of dry trees
S/2 d/2	4.03	0
S/2 d/1	7.14	12.5
S/2 d/1 ($\frac{2x1d}{2}$)	6.12	0

Panel (Panels D and C respectively) or due to other agro-climatic factors as indicated by the higher yield recorded by the control trees also (Table 4.11).

(b) Effect of concentration of ethephon on yield and declining trend in response

Ethrel, at all concentrations (2.5, 5.0 and 10.0%), increased yield in the first as well as second year - Table 4.12. During the first year, the effect of 5% and 10% concentrations was superior to that of 2.5% concentration. But there was no significant difference between 5% and 10% concentrations. During the second year, however, the difference in the effectiveness between 2.5% and higher concentrations disappeared and there was no statistical difference among the three concentrations tested.

The difference in effect between 2.5% and 10% Ethrel was slightly more pronounced under S/2 d/2 system compared to S/2 d/4 system. Irrespective of the concentrations, repeated applications of the stimulant had a declining trend on its effect. The results indicated that the declining trend in response to continuous application for two years was more pronounced for higher concentrations (Table 4.13).

(c) Effect of prolonged use of Ethrel

Effects of prolonged use of Ethrel on clones Tjir 1 and PB 86 are presented in Tables 4.14 and 4.15 respectively. While a declining trend was evident in

<u>Table 4.11</u>

Normal range of response to Ethrel applications.
(Relative yield as percentage of control
is given in brackets)

Location of experiment	Planting material	Yield per annum (kg/block) average of 4 years	
		Without Ethrel	With Ethrel
Nilambur	Tjir 1	1682(100)	2203(130.3)
Thodupuzha	PB 86	1268(100)	2098(165.4)
Palappilli	PB 86	874(100)	1127(128.9)
Palappilli	Tjir 1	768(100)	1009(131.8)

Table 4.12

Effect of different concentrations of Ethrel on yield with two systems of tapping

Treatments		Yield (g/tap/tree) 1st year	 2nd Year
3/2 d/2 control		46.3	52.8
3/2 d/2 + 2.5% E		63.4	62.1
3/2 d/2 + 5.0% E		77.5	66.4
3/2 d/2 + 10.0% E		81.5	70.6
3/2 d/4 + 2.5% E		70.7	75.2
3/2 d/4 + 5.0% E		84.6	66.9
3/2 d/4 +10.0% E		84.5	75.8
	CD	5% - 9.0	9.1
		1% -11.8	12.0

Table 4.13

Effect of concentration of Ethrel on the declining trend in response

Treatments	Percentage yield as compared to first year yield
Unstimulated control	118.0
3/2 d/2 + 2.5% E	97.9
3/2 d/2 + 5.0% E	91.1
3/2 d/2 +10.0% E	82.5
3/2 d/4 + 2.5% E	93.9
3/2 d/4 + 5.0% E	88.8
3/2 d/4 +10.0% E	89.7

Table 4.14

Effect of prolonged use of Ethrel on yield in Clone Tjir 1

(Relative yield expressed as percentage of control are shown within brackets)

Treatments	Total yield per year (kg/tapping block)			
	First year	Second year	Third year	Fourth year
S/2 d/2 Without Ethrel(control)	1671 (100)	1696 (100)	1613 (100)	1750 (100)
S/2 d/2 With Ethrel	2801 (167.62)	2026 (119.46)	2091 (129.63)	1896 (108.34)

both the clones the effect was more pronounced in Tjir 1 (Fig. 4.10). The increase in yield fell to 8% by the fourth year as against 67% in the first year.

Results of the studies on the physiological basis of this declining trend in response revealed that there was a marked reduction in the initial flow rate with repeated applications of Ethrel. Changes in plugging index or dry rubber content could not account for the slowly falling trend in response (Table 4.16).

(d) Effect of Ethrel stimulation on clone Gl 1 with reduced intensity of tapping

Results of the effect of continuous application of Ethrel on a clone susceptible to brown bast (Gl 1) in combination with third daily and fourth daily tapping systems are tabulated in Table 4.17. Application of Ethrel under d/3 and d/4 systems of tapping resulted in enhancement of yield. While the highest yield per tap per block was obtained from stimulated trees under d/3 system of tapping in the first year, during subsequent years of experimentation stimulated trees under d/4 system of tapping recorded the highest yield per tap per block. The yield per block per annum was however highest for the stimulated trees under d/3 system of tapping in all the three years. It was also found that the decline in response on prolonged application of stimulation was less pronounced for the trees under d/4 system compared to those under d/3 system. The incidence of dry trees

Table 4.15

Effect of prolonged use of Ethrel on yield in Clone PB 86

(Relative yield expressed as percentage of control are shown within brackets)

Treatments	Total yield per year (kg/block)			
	First year	Second year	Third year	Fourth year
S/2 d/2 Without Ethrel (control)	1255 (100)	1407 (100)	998 (100)	1412 (100)
S/2 d/2 With Ethrel	2376 (189.32)	2374 (168.73)	1634 (163.73)	2008 (142.21)

Table 4.16

Effect of prolonged use of Ethrel on initial flow, plugging index, d.r.c. and yield as percentage of control (=100%)

Average values of five RRII clones

Parameters	Pretreatment data	Post treatment data (average values for the period)		
		1 - 5 months	6 - 10 months	11 - 15 months
Initial flow rate	65	81	67	66
Plugging index	120	27	27	32
d.r.c.	97	79	84	77
Yield	80	255	199	155

Table 4.17

Effect of Ethrel application on yield in Clone Gl 1 as influenced by different systems of tapping

Treatment	First Year		Second Year		Third Year	
	Total yield Kg/block	Average yield per tap/block	Total yield Kg/block	Average yield per tap/block	Total yield Kg/block	Average yield per tap/block
S/2 d/3 Without Ethrel	977.0	11.4	1159.0	13.9	1074	10.5
S/2 d/3 With Ethrel	1426.0	16.6	1475.0	17.8	1167	11.4
S/2 d/4 With Ethrel	999.0	15.4	1309.0	20.8	1087	14.2

Fig. 4.8 : Influence of the intensity of tapping on annual yield in clones Tjir 1 and LCB 1320.

Fig. 4.9 : Annual yield under 67, 100, 133 and 200% intensities of tapping, all adjusted to 100% relative intensity in clones Tjir 1 and LCB 1320.

Fig. 4.10 : Effect of prolonged application of Ethrel on yield in clones Tjir 1 and PB 86.

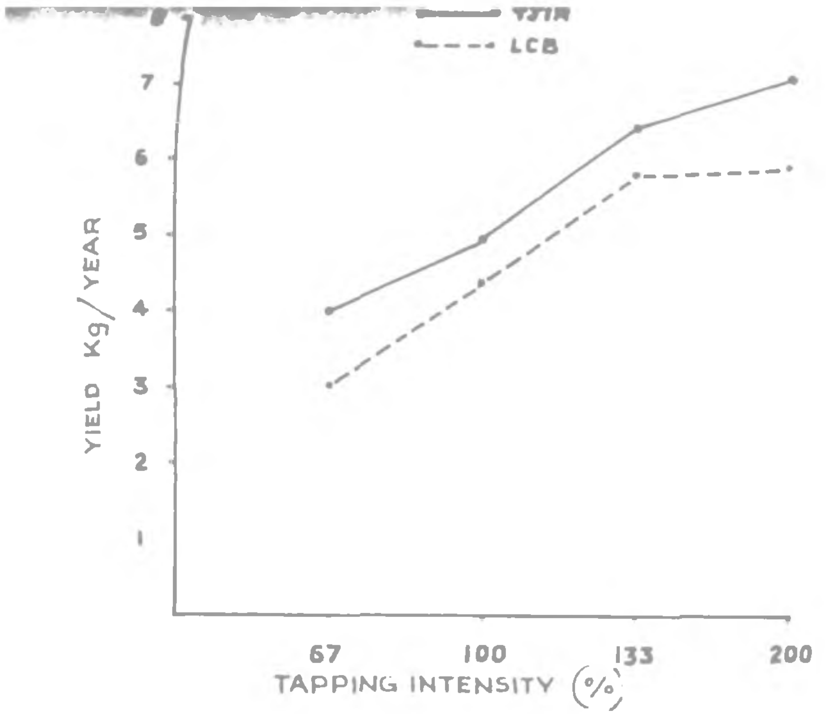


FIG: 4.9

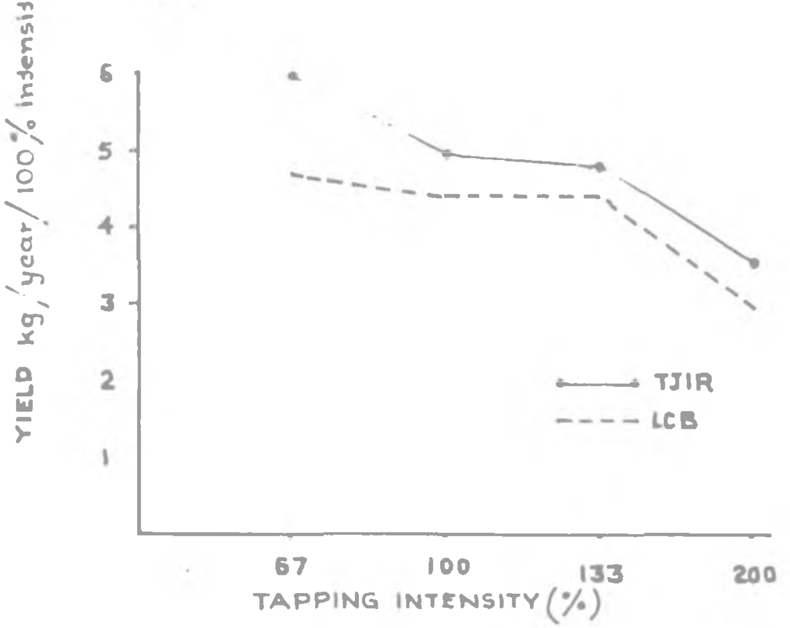
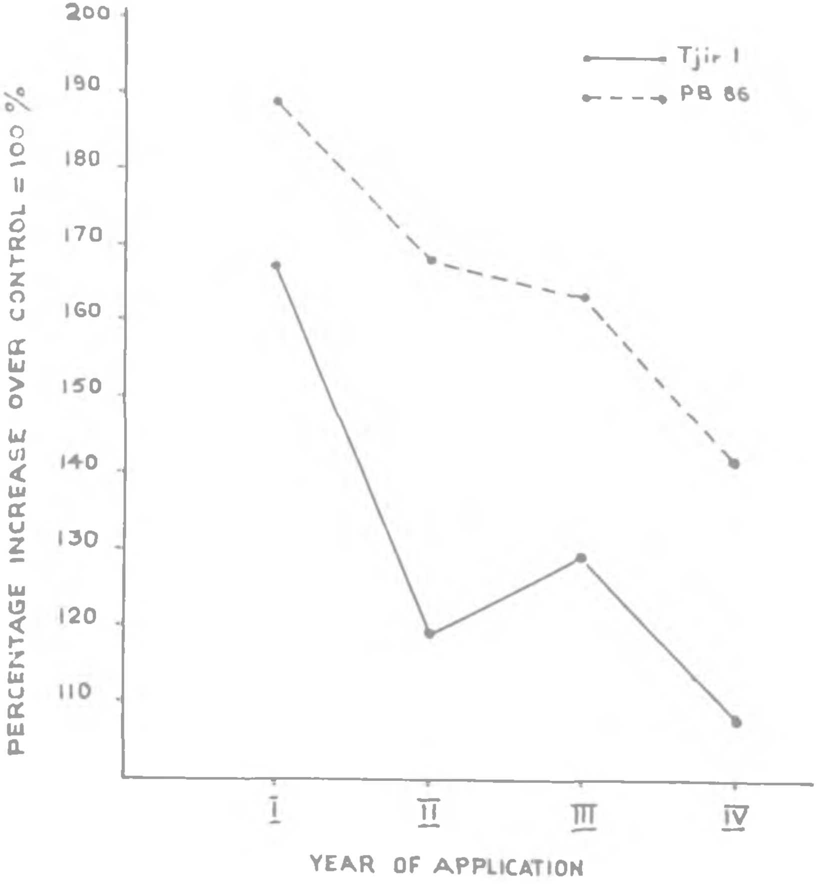


FIG: 4.10



was 5.3%, 17.6% and 11.6% for unstimulated trees, stimulated trees under d/3 frequency of tapping and stimulated trees with d/4 frequency of tapping respectively, thirty months after the commencement of stimulation treatment (Table 4.18).

(e) Effect of stimulation under higher intensity of tapping with two cuts

Effect of Ethrel application on trees under 2 S/2 d/2 system of tapping (200% intensity) is presented in Table 4.19. The results indicated that response to stimulant application would be obtained even at high intensity of tapping if the increase in tapping intensity was achieved by opening two tapping cuts. The percentage increases in yield during the first, second and third year of stimulation showed a declining trend in response.

(f) Period of application as a factor influencing the effectiveness of yield stimulation with Ethrel

It was observed that the period of stimulant application could influence the magnitude of the response. This was more marked for clone Tjir 1 (Table 4.20) compared to Gl 1 (Table 4.21). The results also indicated that the response was relatively greater when the yield was low. In clone Gl 1, the seasonal variations in yield also was not very pronounced as in the case of clone Tjir 1. Although the response in terms of percentage increase in yield relative to control was greater in March, the actual increase in yield was higher when the application was made in June, in the case of Tjir 1, and in September, in the case of Gl 1.

Table 4.18

Effect of stimulation on the incidence of dry trees under two frequencies of tapping in clone Gl 1.

Treatments	Percentage dry trees		
	After 12 months	After 24 months	After 30 months
3/2 d/3 unstimulated	3.0	5.0	5.3
3/2 d/3 + Ethrel	11.6	15.0	17.6
3/2 d/4 + Ethrel	8.0	10.6	11.6

Table 4.19

Effect of Ethrel application on yield in intensively tapped trees

(Percentage yield relative to unstimulated control is given in brackets)

Treatments	Average yield in first year kg/tap/block	Average yield in second year kg/tap/block	Average yield in third year kg/tap/block
2 S/2 d/2 Without Ethrel	12.0 (100)	9.7 (100)	7.4 (100)
2S/2 d/2 With Ethrel	18.4 (153.3)	12.9 (132.9)	9.2 (124.3)

Table 4.20

Response to Ethrel stimulation in Clone Gl 1 as influenced by the period of application.

(Percentage increase in yield relative to unstimulated control (100%) is given in brackets)

Period of Ethrel application.	Yield (g/tap/tree), day before stimulation.		Post-treatment yield, (g/tap/tree), average of two months	
	Control trees	Stimulated trees	Control trees	Stimulated trees
March	16.2	15.8	18.2	30.9 (170.0)
June	17.8	17.0	17.2	28.8 (167.6)
September	18.8	18.4	24.8	38.4 (155.0)
December	20.4	21.0	23.2	34.7 (150.0)

Table 4.21

Response to Ethrel stimulation in Clone Tjir 1 as influenced by the period of application.

(Percentage increase in yield relative to unstimulated control (=100%) is given in brackets)

Period of Ethrel application.	Yield (g/tap/tree), day before stimulation		Post-treatment yield (g/tap/tree), average of two months	
	Control trees	Stimulated trees	Control trees	Stimulated trees
March	7.2	7.0	9.8	25.3 (257.5)
June	24.2	23.5	33.6	64.4 (191.6)
September	43.8	44.0	50.5	73.7 (146.0)
December	52.8	53.3	37.6	46.6 (123.9)

Tables 4.22 and 4.23 summarise the pretreatment and post-treatment values of plugging index in Tjir 1 and Gl 1 respectively. It would appear that the response was higher when the plugging index was higher. This relationship was more clear in Tjir 1 compared to Gl 1 (Fig.4.10).

(g) Mode of application of ethephon as a factor influencing its effectiveness

i. Influence of the length of the stimulated band

The results of the studies with different lengths of stimulated bands using the same quantity of Ethrel per tree revealed that the response to simulation would vary according to the length of the vertical stimulated band (Table 4.24). While no difference in response was observed between normal bark application (below tapping cut) and the short vertical band (30 cm), the yield was increased when the same quantity of Ethrel was applied on a 90 cm vertical band.

ii. Effect of multiple band application of of Ethrel on yield increase

The data on the average yield of dry rubber is influenced by single and multiple band applications of Ethrel are summarised in Table 4.25. The yield was over 400% compared to control during the month after the first application. This increase in yield gradually reduced to 244% during the second month. On the other hand, the yield increase with normal bark application

Table 4.22

Plugging index before and after Ethrel application at different periods of the year.

(Clone Tjir 1)

Period of Ethrel application	Plugging index	
	Day before treatment	15 days after treatment
March	15.9	6.2
June	9.8	4.8
September	4.2	3.5
December	4.3	3.6

Table 4.23

Plugging index before and after Ethrel application at different periods of the year (Clone Gl 1)

Period of Ethrel application	Plugging index	
	Day before treatment	15 days after treatment
March	5.40	3.00
June	5.38	3.30
September	4.90	3.00
December	4.90	3.10

Table 4.24

Effect of the length of stimulated band of bark on yield.

Treatment	Yield(g/tapping/tree)
Control (unstimulated)	40.0
Application of Ethrel Normal	113.4
Application on 30 cm band	113.3
Application on 90 cm band	133.6

Table 4.25

Effect of single and multiple band applications of Ethrel on yield.

(Increase in yield as percentage over control is given in brackets)

Treatment	Yield (kg)/Tapping block/tap			
	1st application		2nd application	
	1st month	2nd month	1st month	2nd month
Control (without Ethrel)	8.93 (100)	8.60 (100)	8.67 (100)	7.50 (100)
Ethrel - Single band application	21.10 (236)	11.83 (138)	19.68 (227)	10.44 (139)
Ethrel - Multiple band application	35.91 (402)	21.01 (244)	31.64 (365)	21.91 (292)

(single band) was only of the order of 23% and 13% as compared to unstimulated control during the first and second months respectively of stimulation. This result indicated that the effect of Ethrel might prolong for a comparatively longer period in the case of multiple band application. Here again there was slight decline in response for the second application.

The data on in situ dilution of latex following tapping at a hight of three metres clearly indicated that stimulation results in an extension of the drainage area (Table 4.26). The extent of dilution after tapping was more pronounced in the case of multiple band application compared to single band application and unstimulated control.

DISCUSSION

Effect of different tapping systems on yield

Among the eight systems of tapping studied, S/2 d/2 $(\frac{2x2d}{4})$ system of tapping had recorded the highest yield in clone LCB 1320. The daily yield as well as the annul yield were higher for this system. Superiority of this system of tapping over half spiral daily system was first reported by Tobin (1965). Although contradictory findings were reported (De Jonge, 1967), Sethuraj and George (1971) contended that opening of two cuts would lead to an extension of drainage area resulting in higher yield. The effectiveness of this system of tapping would assumably

Table 4.26

Effect of single and multiple band applications of Ethrel on *in situ* dilution at a height of 3 metres, 3 hours after tapping.

Mode of Ethrel application	Total solids %		
	Before tapping	3 hours after tapping.	% dilution
Control (unstimulated)	47.8	48.9	-2.0
Single band application	45.9	43.8	+4.5
Multiple band application	40.8	31.9	+21.8

depend on the distance between the two cuts as well as the intrinsic characteristics of the clone with regard to the factors influencing development of the drainage area. This clonal difference in response to this system was evident from the results obtained from clone Tjir 1. In clone Tjir 1, the highest daily yield was obtained in 2 S/2 d/4 system of tapping. The annual yield was however highest for S/1 d/2 system of tapping. Both these systems would drain latex from an extended area of bark. A full spiral cut would also reduce the plugging index resulting in enhanced yield (Milford *et al*, 1969). The contention of Paardekooper *et al* (1975) that the tapping intensity has over riding influence in determining the yield compared to the system of tapping does not hold good when the intensity is determined by the number of cuts. Comparing the double cut and single cut systems with the same tapping intensity, it would become apparent that putting more cuts results in higher daily yield and lower annual yield in both clones. The S/2 d/2 ($\frac{2x2d}{4}$) system is however an exception. This system has two cuts and a frequency of alternate daily tapping, but a lower tapping intensity because only one panel is tapped on any tapping day.

It was also observed that while lengthening of the cut results in yield increase, the yield per unit length of the cut decreases. This is in agreement with the findings of Ham (1940). Clones with smaller drainage areas might respond better to lengthening the cut. The slightly overall better performance of LCB 1320, compared to Tjir 1, for longer cuts could perhaps be explained assuming differences in the pattern of development of the drainage area. Ng et al (1969) and Milford et al (1969) also have provided evidence for differential clonal reactions in yield response to variations in the length of the cut.

The observation that clone Tjir 1 responded better to longer cuts during periods of low yield is interesting. It could be assumed that modulations in plugging index as influenced by season would be more pronounced in clone Tjir 1. (Saraswathy Amma and Sethuraj, 1975). It is also known that plugging index and response to lengthening of the cut are related (Milford et al. 1969). During the period of low yield, the plugging index of Tjir 1 could be higher compared to that of LCB 1320 and as such lengthening of the cut is likely to fetch better response. When there are two cuts however, lengthening of individual cuts would have only limited effect on the drainage area and plugging index and consequently the variations in effect of the length of the cut at different periods of the year would be less. The fluctuating effects of other systems of tapping are also evident from the results that during certain months, when the yield was higher the difference in effect between tapping systems was not significant in clone Tjir 1.

The general findings that yield per task would be higher with lower frequency of tapping (Ng et al, 1969) were not reflected in the present results. When the yield per tap per tree was considered the difference between d/2 and d/4 systems was not significant. Understandably, however, the annual yield was reduced with lower frequency of tapping in both the clones. The finding that the tapping efficiency decreased with increasing intensity (Fig. 4.9) is in agreement with the results obtained by Paardekooper et al (1975). Another finding of interest was that the relative increase in yield with two cuts was more when the length of the cuts was shorter. Schweizer (1941) and Vollema (1941) considered that the drainage areas of the two cuts might operate independently. If however the two cuts are closer the drainage areas of the two cuts might merge (Sethuraj and George, 1971). Under such a situation, effect of another cut would be more pronounced with shorter cuts with smaller individual drainage areas.

Effect of a new system of daily tapping on incidence of dry trees.

It is generally known that daily tapping usually leads to high incidence of brown bast. Brown bast has long been considered as a physiological disorder caused by over exploitation (Rands, 1921; Sharples and Lambourne, 1924;

Bealing and Chua, 1972). While the exact cause of brown bast is not well understood, the contention of Schwizer (1941) that intensive tapping would upset the balance between loss of latex and latex regeneration, is physiologically sound. Conceivably, the extraction of latex per unit area of bark would be the determining factor. When daily tapping is done alternating the panel, as in the case of S/2 d/1 $\left(\frac{2x1d}{2}\right)$ system of tapping, each panel is tapped only once in two days. As the drainage areas of the two cuts might operate independently, tapping of one cut might not influence the drainage area of the other cut and as such daily drainage of latex from the same area of bark is avoided. This could be the reason when this system of daily tapping was less harmful compared to S/2 d/1. With a single cut, the area drained is the same on all tapping days and the drainage area of the cut would naturally be more affected. While 12.5% of the trees turned dry within an year under this system of tapping, none of the trees under the new system of daily tapping (S/2 d/1 $\frac{2x1d}{2}$) was affected by this disorder.

Chemical stimulation of yield and the factors contributing to its effectiveness.

The extent of response obtained from the application of Ethrel is within the normal range of response reported by different workers (Abraham, 1970; George *et al.* 1974). The finding from the present study, that lower concentrations than 10% a.i. may also be equally effective, is in agreement with the recent report of Abraham *et al* (1975). But a finding of interest was that the declining trend in response by repeated applications might be less pronounced with lower concentrations. As there was no statistical difference between the yields obtained with 5% and 10% Ethrel, this difference in the rate of decline in response can be attributed to some direct effect of the chemical. With higher concentrations, this direct effect might be greater.

The declining trend in response with repeated applications of Ethrel, as observed in the present study is generally recognised. Clonal variation in the rate of decline in response also is reported (Abraham *et al*, 1975). Recently, George *et al* (1976) carried out an economic analysis and found that because of this declining trend in response Ethrel application after three or four years of continuous stimulation might cease to be economical.

Further studies on the physiological basis of this declining trend in response have revealed that the initial flow rate was affected by prolonged use of stimulants. As there was no fall in the rubber content of latex to account for this declining response, possibility of any physiological exhaustion can be discounted.

Investigators in other countries have not paid much attention to the use of stimulants on clone Gl 1, as this clone is no longer recommended for large scale planting.

But this clone deserves attention in India, as one identified for its drought tolerant character (Saraswathy Amma and Sethuraj, 1975), and prolonged drought period is a problem in many rubber growing tracts in India. A lower tapping intensity (S/2 d/3) is recommended for the clone Gl 1. This was in recognition of the fact that in this clone, higher incidence of brown bast is often associated even with normal intensities of tapping (S/2 d/2). Therefore the results on the Ethrel stimulation of this clone is of some significance. The results indicated that the incidence of brown bast would be greater with stimulation even under reduced intensity of tapping. The percentage of dry trees obtained in this experiment was substancially higher compared to reported data on other clones (Abraham et al. 1975).

The results of Ethrel application in combination with a high intensity tapping system (2 S/2 d/2) indicated that the generally accepted view (Abraham, 1970; Abraham et al. 1975) that the stimulant must be used only in conjunction with tapping intensities of less than 100% needs re-examination. 2 S/2 d/2 tapping system has a relative intensity of 200%. But as there are two cuts, the total latex drain from the tree would be shared by two panels, assumably having independent drainage areas. This could be the reason for the observed long term response to stimulation in spite of a higher tapping intensity.

The observation that the period of application would influence the magnitude of response to stimulation is also of significance.

Abraham and Tayler (1967) have reported that during the period of wintering the response to stimulation (with 2,4,5-T), in terms of percentage increase over control, is greater. Sethuraj and George (1975) also have reported seasonal variations in the effectiveness of yield stimulants, including Ethrel. In the present study, the different treatments (periods of application) were imposed on separate sets of trees of comparable yield as repeated stimulant application on the same set of trees might influence the observations. The results clearly indicated that lower the yield at the time of application, higher would be the response. In a clone like Gl 1 with negligible fluctuations in yield the influence of the period of application also is relatively small. It would however be stressed that the profitability of stimulation would depend on the actual increase in yield and not on the response in terms of relative yield increase.

The studies also indicated that the mode of application of Ethrel also can influence the yield increase. Using the same quantity of Ethrel, differential response can be obtained by altering the length of the stimulated band, longer the band the greater being the response. When multiple bands are stimulated, covering the bark area upto the branches, substantial yield increase was obtained. This method was first proposed by Sethuraj <u>et al</u> (1975). The present results are from large-scale studies utilising this method of application. It was contended by Sethuraj <u>et al</u> (1974 c, 1975) that the action of yield stimulants, may mediate through the extension of drainage area. The direct action of stimulants might be on the rheological properties of latex resulting in the extension of the drainage area. However, our present knowledge on the sequence of biophysical and biochemical changes brought about in latex by chemical stimulation is still fragmentary. Nevertheless, the present results do confirm the contention that methods of Ethrel application facilitating greater extension of drainage area would result in higher response to stimulation.

SUMMARY

Among the eight systems of tapping — S/3 d/2, S/2 d/2, S/1 d/2, S/1 d/4, S/2 d/2 $(\frac{2x2d}{4})$, 2 S/2 d/4, 2 S/2 d/2 and 2 S/3 d/2 — the highest yield per tap per tree was obtained from S/2 d/2 $(\frac{2x2d}{4})$ and 2 S/2 d/4 systems for LCB 1320 and Tjir 1 respectively. The highest yield per tree per annum was obtained from 2 S/2 d/2 systems in Tjir 1. In LCB 1320, S/2 d/2 $(\frac{2x2d}{4})$ system gave the highest annual yield. While lengthening of the tapping cut resulted in higher yields, the increase was not proportionate to the length. The degree of response to lengthening of the cut was more in LCB 1320 than in Tjir 1. The effect of lengthening of the cut was more pronounced during period of comparatively lower yield. The interaction between tapping system with different periods was more clear in the case of Tjir 1. Among systems of the same tapping intensity, double cut systems resulted in higher yields. It was also found that tapping efficiency decreased with increasing intensity.

The harmful effect of daily system of tapping (S/2 d/1) could be alleviated by opening two cuts and alternating the panels (S/2 d/1 $\frac{2x1d}{2}$).

Over a period of four years, the response to Ethrel stimulation was within the range of 29-65%, depending on the clones and locations. There was a declining trend in response with prolonged use of Ethrel. This declining response was less pronounced with lower concentrations of Ethrel (2.5% a.i.). The results also indicated that lower concentrations of Ethrel (2.5% and 5%) could be as effective as 10% a.i. by the second year of stimulation. Stimulation on clone Gl 1 resulted in abnormally higher incidence of brown bast. Seasonal variation in the effectiveness of Ethrel was also evident, the response being low during periods of high yield. Low yield is generally associated with high plugging index and action of Ethrel which

SECTION V

STUDIES ON YIELD DEPRESSION DURING THE PERIOD OF SUMMER DEFOLIATION

INTRODUCTION

The phenomenon of annual leaf fall in *Hevea brasiliensis* is commonly known as 'wintering'. The para rubber tree is classified as "summer deciduous" by Addicott and Lynon (1973). The word 'summer' is used to indicate the dry period rather than any particular months of the year. The abscission of leaves in summer deciduous plants is correlated with moisture stress prevailing during that period. As the dry period occurs at different times at different parts of the tropics, the period of defoliation varies from place to place (Polhamus, 1962).

It has been generally recognised that the period of lowest yield is synchronised with the period of summer defoliation. On this basis there is a practice of giving tapping rest during this period in many plantations. The simple relationship between the period of lowest yield and defoliation is complicated by the fact that defoliation occurs during the dry months of the year and moisture stress *per se* might influence yield.

One possible route through which the defoliation might influence yield is by reducing the supply of photosynthates which form the precursor of rubber biosynthesis. There is however no experimental evidence that rubber biosynthesis is affected by defoliation. Wimalaratna and Pathiratna (1974) did not find any meaningful relationship between the extent of yield depression and leaf fall pattern in different clones. They also observed that the reduction in yield is greatest at the time of commencement of bud-break. While no detailed study on the variations of d.r.c. during the period of defoliation is reported, Sethuraj (1968) observed that the depression in yield during the period of defoliation is mediated through a shorter duration of flow. Saraswathy Amma and Sethuraj (1975) also have furnished data to show that the yield depression during summer defoliation is the result of a higher plugging index and that the clonal variation in yield depression also could be explained on the basis of variations in plugging index. The possibility that drought conditions prevailing during the period of defoliation might have a direct role in yield depression comes from the finding that soil moisture would influence plugging index (Sethuraj and George, 1976). The proportionate roles of the drought conditions and defoliation on yield depression can be assessed only with further enquiry into the changes in the different physiological factors affecting yield during this period.

In the present study, experiments were conducted to evaluate the extent of yield depression and the clonal variation in this regard as well as to monitor the physiological changes associated with yield depression. The physiological factors which were examined include latex flow pattern, carbohydrate and protein levels in latex, concentration of mineral elements in latex, dry rubber content, bursting index and dilution reaction. The effect of tapping rest during summer defoliation on subsequent yield also has been studied. The possibilities for counteracting the yield depression, by using stimulants, antitranspirants and irrigation have been investigated. Thus the objectives of these studies were to get a better insight into the physiological basis of yield depression as well to evaluate possible methods to counteract the reduction in yield during the period of summer defoliation.

The expression 'period of summer defoliation' is used to denote the entire period starting from the first signs of leaf senescence till the new leaves attain an age of approximately one month.

MATERIALS AND METHODS

1. Experimental details and locations

Nine clones namely Gl 1, GT 1, LCB 1320, PB 86, PR 107, RRIM 600, RRIM 605, RRIM 623 and Tjir 1 planted at Pullengode estate and five clones, Gl 1, PB 86, RRIM 605, RRIM 623 and Tjir 1 planted at Kinalur estate were selected for assessing the extent of yield depression during the period of defoliation. The area under each clone was approximately one hectare (one tapping block of 350 trees). The trees were under S/2 d/2 system of tapping on Panel C. One tapping block for each clone was selected for the yield recording, on all tapping days for one year.

In order to study the pattern of yield variation as related to the different stages of defoliation and refoliation, clones Tjir 1, PB 86, Gl 1, BD 10 and LCB 1320 were selected. Visual scoring of the different stages of defoliation and refoliation such as (1) 50% defoliation (2) 100% defoliation (Plate 5.1) (3) bud-break (Plate 5.2) (4) one week old leaves (Plate 5.3) (5) 2 week old leaves (Plate 5.4) and (6) one month old leaves (Plate 5.5), was carried out in four selected trees of each clone. The visual screening was assisted by actual counting of leaves in a few twigs marked for the purpose. The date of bud-break was noted in these selected twigs to determine the age of the new leaves.

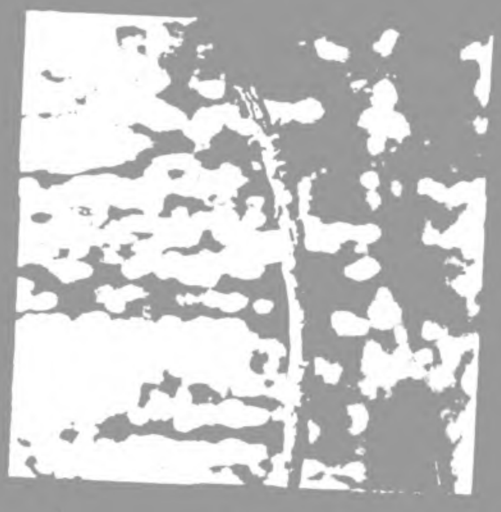
Plate 5.1 : Complete defoliation.

Plate 5.2 : Bud-break.

Plate 5.3 : One-week old leaves.

Plate 5.4 : Two-week old leaves.

Plate 5.5 : One-month old leaves.



Yield recording of individual trees started before any signs of leaf senescence appeared and continued till the leaves were one month old.

In order to study the effect of artificial defoliation during the period of normal yield ten Tjir 1 trees were selected and of which 5 trees were subjected to a foliar spray of 2,500 ppm 2,4-D during the month of October. Recording of pre-treatment yield was started 3 weeks earlier to the date of spraying and post-treatment yield was recorded for 30 tappings covering a period of ten weeks.

The effect of tapping rest during the period of summer defoliation on subsequent yield was studied in four clones namely RRIM 501, 602, 605 and 612, planted at RRII Experiment Station. The trees were under S/2 d/2 system of tapping on Panel B. Pre-treatment yield was recorded for three weeks prior to the period of tapping rest. Twelve trees were selected from each clone, out of which six trees were given tapping rest while tapping was continued in the other six. The period of tapping rest was for 3 weeks from 10th February 1976. Post-treatment yield was recorded for three weeks.

The studies on the changes in the physiological factors such as latex flow, mineral and biochemical composition, bursting index and dilution reaction were conducted in five clones, Tjir 1, PB 86, Gl 1, BD 10 and

LCB 1320, at the RRII Experiment Station. Four replications were there for each clone. The trees were under S/2 d/2 system of tapping on Panel C. No tapping rest was given during the period of summer defoliation. Yield was recorded on all tapping days for one year. Latex flow, mineral and biochemical composition, bursting index and dilution reaction were determined on different days covering the period of normal yield (November) as well as the summer defoliation period (February). The significance of variation was assessed by 't' test.

In order to assess the effect of Ethrel in counteracting the yield depression during summer defoliation, sixteen Tjir 1 trees of comparable yield, planted at the RRII Experiment Station, were selected. Ethrel (10% a.i.) was applied to half the number of trees at monthly intervals from January to March in 1975 and 1976. Yield was recorded by cup coagulation on all tapping days from January 1974 to April 1976.

Effect of watering in counteracting the yield depression during summer defoliation was studied using sixteen trees belonging to RRII-HP clone No.285 planted at the experiment station of which eight were irrigated from January to April in 1975 and 1976. The control trees were 100 metres away from the group of irrigated trees. The method of irrigation was to water the plants with a hose pipe in an area of 10' radius around each status was measured by gypsum blocks and was maintained at 100%. The yield was recorded by cup coagulation on all tapping days during the period of experimentation.

The effectiveness of foliar spray of an anti-transpirant-phenyl mercuric acetate (PMA) - on counter-acting the yield depression during summer defoliation was studied utilising eight Tjir 1 trees planted at RRII Experiment Station. Foliar spray of PMA (10^{-3}M in water) was carried out during the month of February when the yield had already been at a low level. The spraying was carried out using a Micron 420 power sprayer. Pre-treatment and post-treatment yield was recorded by cup coagulation. The effect of PMA spray on stomatal opening was assessed in another experiment in which the effect of three concentrations, 10^{-2}M, 10^{-3}M and 10^{-4}M was assessed. The stomatal opening and resistance were also assessed.

Recording Procedures

Yield per tap per block or yield per tap per tree, as the case may be, was recorded by the methods described in Section II.

The initial flow rate and plugging index were determined as has been already described (Sec. II, p 83).

Soil moisture was determined by the method described in Section II (p 83).

Estimation of protein

Suitably diluted KOH - extract (0.5 N KOH) of the latex sample was used for the estimation of protein by the usual biuret reaction (Gornall *et al*, 1949). 5 ml of the KOH extract was pipetted out into a test tube, to which 10 ml of biuret reagent was added, mixed, and allowed to stand for 30 minutes. The optical density was measured in a systronics photo-electric colorimeter at 540 nm (Filter No.625) and the concentration calculated using a standard graph.

Estimation of reducing and non-reducing sugar, d.r.c. and bursting index has been made as per the methods described in Section III. The dilution reaction also was assessed as per the methods described in Section III.

Measurement of stomatal opening and stomatal resistance

Stomatal opening was measured by the stomatal impression method (Zelitch, 1961).

Stomatal resistance was measured by an aspirated diffusion porometer manufactured by Wren Instruments, U.S.A. (Slayter, 1967).

RESULTS

Clonal variation in relation to yield depression

In all clones studied at Pullengode estate, the symptoms of leaf aging was evident from the month of December or January. Time of complete defoliation and refoliation differed slightly from clone to clone. Complete defoliation occured within a short period in all the clones, except in LCB 1320, in which case the leaf fall was gradual, spread over a period of 3-4 weeks.

The data on the yield during November, taken as control, as well as the yield during January, February, March and April representing the period of summer defoliation and low yield, have been presented in Table 5.1. Clones GT 1, PR 107, Gl 1 and Tjir 1 recorded slightly higher yields during January as compared to November. In the other clones the lowering trend in yield was already evident from the month of January. All clones recorded lower yields during the months of February to April, although the extent to which the yield was affected varied from clone to clone. The clone which was least affected was Gl 1 while the yield depression was greatest in the case of RRII 623. The performance of five clones, Tjir 1, Gl 1, PB 86, RRII 605 and RRII 623 planted in a severely drought affected area (Kinalur) is presented in Table 5.2. Drastic depression in yield was evident in the case of RRII 623 : during the month of March the yield was only 7% of the yield obtained during November. All the clones except Gl 1 were more drastically affected in this area compared to Pullangode estate. The leaf fall pattern was observed to be more or less on the same trend as described for the other estate. Complete defoliation occurred in the case of all the five clones. The yield was least affected in Gl 1. On the contrary, slightly higher yields were recorded during the months of January and February.

Table 5.1

Yield pattern of nine clones during the period of defoliation and refoliation (January to April) as compared to the yield in November.

Clone	Average monthly yield (Kg/block/tap)*				
	November	January	February	March	April
RRIM 600	6.30	6.23 (98)	3.73 (59)	2.30 (33)	3.15 (50)
GT 1	4.4	5.69 (128)	2.63 (59)	1.56 (35)	1.80 (40)
PR 107	5.84	7.20 (123)	4.19 (71)	3.23 (55)	3.71 (63)
RRIM 605	9.01	6.26 (69)	2.91 (32)	3.28 (36)	5.07 (56)
RRIM 623	10.45	6.24 (59)	2.80 (26)	3.03 (29)	3.62 (34)
PB 86	6.79	6.56 (96)	3.95 (58)	3.67 (54)	3.88 (57)
GL 1	12.05	12.62 (104)	10.75 (89)	8.23 (68)	8.18 (67)
Tjir 1	10.84	11.76 (108)	6.00 (55)	4.89 (45)	5.93 (54)
LCB 1320	7.11	6.40 (90)	4.02 (56)	3.27 (45)	3.50 (49)

* Figures in parenthesis indicate the percentage yield as compared to the yield in November (=100%)

Yield fluctuations at different stages of defoliation and refoliation.

The pattern of yield variation during different stages of defoliation and refoliation is presented in Table 5.3. It is evident from the data that all clones recorded a higher yield during the period of 50% defoliation. However, when defoliation was complete, the yield dropped to the level prevailed just before defoliation or even less as in the case of Tjir 1. The lowest yield was observed to occur around the two week stage of the new leaves in all clones. There was however clonal variation in the magnitude of the yield depression. In this study also Gl 1 was least affected among the clones studied.

Effect of chemical defoliation during off-season on yield

The results indicated that immediately after defoliation (which occured within a week of 2,4-D spraying), there was a sudden spurt in yield followed by slow decline. The average yield just after defoliation was slightly higher than the pre-treatment yield (average of 10 tappings). Later a trend of declining yield was evident (Table 5.4). It was observed that after defoliation, refoliation did not occur for a period of more than four months.

Effect of tapping rest during summer defoliation period on subsequent yield

The effect of giving tapping rest during summer defoliation on the subsequent yield is presented in

Table 5.5. Out of the four clones studied, in three clones, the yield during the three week period following the period of annual tapping rest was lower in the case of trees given tapping rest compared to that of the trees which were continuously tapped. In the other clone the difference in yield between the two treatments was not very significant. The continuously tapped trees under clone RRIM 605 recorded a 47% increase in yield as compared to the trees given tapping rest.

Changes in the physiological factors during summer defoliation period

(a) Latex flow

The data on the initial flow rate, plugging index and latex yield during November (considered as normal period) and during the period of summer defoliation (February) with respect to clones PB 6/9 (Table 5.6), Tjir 1 (Table 5.7), Gl 1 (Table 5.8), PB 86 (Table 5.9), BD 10 (Table 5.10) and LCB 1320 (Table 5.11) indicated that in clones in which the yield was affected, the plugging index recorded an increase while initial flow rate was lower (Fig. 5.1). The increase in plugging index was only slight in clones Gl 1 which was not much influenced by summer defoliation. The initial flow rate also recorded significant variation between the two periods, in all clones except Gl 1.

(b) Reducing and non-reducing sugars

The variations in the concentrations of non-reducing and reducing sugars in latex during the period of summer defoliatio

Table 5.2

Yield pattern in six clones during the period of defoliation and refoliation (January to April) as compared to the yield of November.

Clone	Average monthly yield (kg/block/tap)*				
	November	January	February	March	April
Tjir 1	6.16	6.3 (102)	4.5 (73)	1.8 (29)	3.4 (55)
Gl. 1	10.25	14.6 (142)	12.6 (122)	10.3 (100)	11.4 (111)
PB 86	10.40	14.1 (135)	3.0 (28)	2.2 (21)	9.1 (87)
RRIM 605	8.5	3.2 (96)	2.0 (23)	1.4 (16)	4.2 (36)
RRIM 623	7.6	3.7 (48)	1.0 (13)	0.6 (7)	1.6 (21)

* Figures in parenthesis indicate the percentage yield as compared to the yield in November (=100%)

Table 5.3

Yield during different stages of defoliation and refoliation (g/tap/tree) in different clones.

Stages of wintering	Clones				
	Tjir 1	PB 86	Gl 1	BD 10	LCB 1320
Just before defoliation	63.00	28.00	22.00	23.75	43.25
50% defoliation	83.50	39.75	25.25	31.75	51.75
100% defoliation	44.25	26.00	20.75	24.00	34.50
Bud Break	26.00	23.50	17.50	10.50	30.25
One week old leaves	22.75	15.25	19.50	10.50	16.75
Two week old leaves	22.50	13.50	23.75	14.75	26.75
One month old leaves	28.75	18.00	23.00	15.25	28.50

Table 5.4

Effect of chemical defoliation during off-season (November) on yield (g/tap/tree)

Treatment	Average pre-treatment data	Average post-treatment data		
		1st to 10th tapping	10th to 20th tapping	20th to 30th tapping
Control (without defoliation)	23.6	24.0	26.3	24.3
Chemical defoliation.	36.4	40.7	36.8	30.6

Table 5.5

Effect of tapping rest during summer defoliation period on subsequent yield

Clones	Treatments	Pre-treatment yield (g/tap/tree)*	Yield during period of tapping rest (g/tap/tree)*	Post-treatment yield (g/tap/tree)*	Post-treatment yield as % of pre-treatment yield
RRIM 605	Tapping rest	58.00	-	24.8	42.1
	No tapping rest	51.25	57.56	21.8	62.0
RRIM 501	Tapping rest	42.50	-	33.7	79.3
	No tapping rest	48.75	31.10	37.0	75.8
RRIM 602	Tapping rest	54.50	-	40.7	74.7
	No tapping rest	42.50	23.80	36.7	86.4
RRIM 612	Tapping rest	76.60	-	60.3	78.7
	No tapping rest	70.50	39.11	68.0	96.5

*Average yield for periods of 3 weeks

Table 5.6

Variation in latex yield, initial flow rate and plugging index during summer defoliation period in Clone PB 6/9

Parameters	Annual average	During normal period (November) × *	During summer defoliation (February) × *
Latex yield (ml.)	163.38	243.75 (148.7)	89.00 + (54.3)
Initial flow rate (Vol/0–5 mts)	32.70	33.98 (103.9)	31.88 + (97.4)
Plugging index	4.17	2.55 (61.2)	7.92 + (189.9)

* Percentage variation over annual average is given in brackets

\+ Difference Significant

Table 5.7

Variation in latex yield, initial flow rate and plugging index during summer defoliation period in Clone Tjir -1.

Parameters	Annual average	During normal period (November)*	During summer defoliation (February) *
Latex yield (ml)	101.41	171.25 (168.9)	43.75$^+$ (43.1)
Initial flow rate (Vol. 0-5 mts.)	31.43	32.66 (103.9)	26.38 + (83.9)
Plugging index	8.13	3.9 (48.0)	12.72$^+$ (156.5)

* Percentage variation over annual average is given in brackets

\+ Difference Significant

Table 5.8

Variation in latex yield, initial flow rate and plugging index during summer defoliation period in Clone Gl.1

Parameters	Annual average	During normal period (November)*	During summer defoliation (February)*
Latex yield (ml)	81.65	98.9 (121.1)	73.2 (89.7)
Initial flow rate (Vol. 0-5 mts)	21.68	21.03 (97.0)	22.59 (107.4)
Plugging index	5.53	4.25 (76.9)	6.71 (121.3)

* Percentage variation over annual average is given in brackets

Table 5.9

Variation in latex yield, initial flow rate and plugging index during summer defoliation period in Clone PB 86

Parameters	Annual average	During normal period (November)**	During summer defoliation (February)**
Latex yield (ml)	96.14	131.75 (137.0)	82.00 +* (85.3)
Initial flow rate (Vol. 0-5 mts)	27.43	25.77 (93.9)	23.56 +* (91.4)
Plugging index	4.91	2.98 (66.7)	7.0+* (142.0)

** percentage variation over annual average is given in brackets

+* Difference Significant

Table 5.10

Variation in latex yield, initial flow rate and plugging index during the period of summer defoliation in Clone BD-10

Parameters	Annual average	During normal period (November)*	During summer defoliation (February)*
Latex yield (ml)	82.02	106.62 (129.9)	35.0+ (42.7)
Initial flow rate (Vol. 0-5 mts)	20.58	21.35 (103.7)	11.31+ (57.0)
Plugging index	5.98	4.23 (70.7)	11.54+ (122.0)

* average of 4 trees, percentage variation over annual average is given in brackets

\+ Difference Significant

Table 5.11

Variation in latex yield, initial flow rate and plugging index during the period of summer defoliation in Clone LCB 1320.

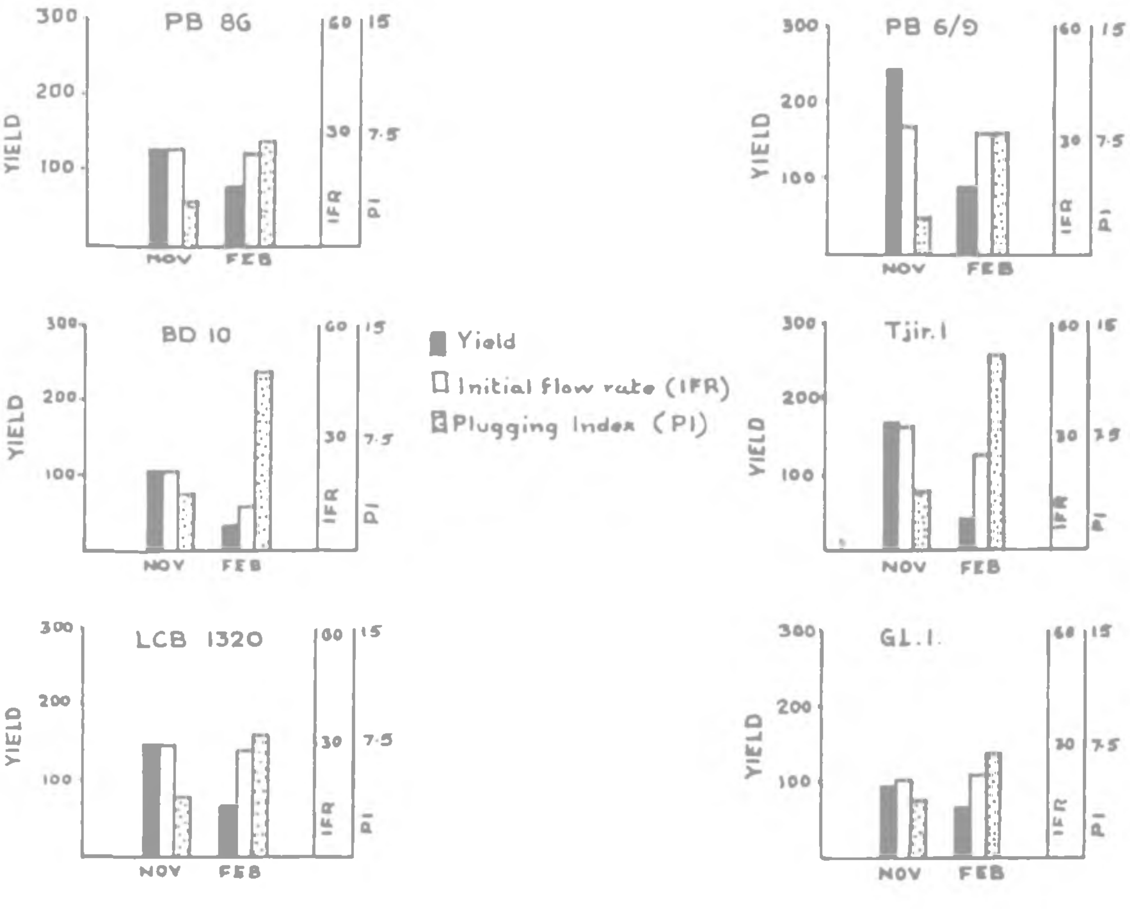
Parameters	Annual average	During normal period (November)+	During summer defoliation (February) +
Latex yield(ml)	99.42	150.50	70.75 * (47.0)
Initial flow rate (Vol. 0.5 mts)	28.06	30.40	28.10* (92.4)
Plugging index	6.34	4.16	8.14 * (195.6)

\+ Average of 4 trees, percentage variation over annual average is given in brackets

* Difference Significant

Fig. 5.1 : Latex yield (ml), initial flow rate and plugging index in five clones during normal and summer defoliation periods.

FIG: 5.1


PB 86
PB 6/9
BD 10
Tjir. I
LCB 1320
GL. I.
YIELD
IFR
PI
300
200
100
60
30
15
7.5
NOV
FEB
Yield
Initial flow rate (IFR)
Plugging Index (PI)

as compared to that during normal period (November) are presented in Table 5.12. The variations in the reducing sugars were not significant in any of the clones. The changes in the non-reducing sugars showed varying trends in different clones. But on statistical analysis by 't' test these variations also turned out to be not significant.

(c) Proteins

Out of the five clones studied the protein content in latex during the period of summer defoliation and low yield (February) as compared to normal period (November) was not significantly different in the case of three clones namely PB 86, GL 1 and LCB 1320. Clones Tjir 1 and BD 10 recorded higher value during this period (Table 5.13).

(d) Mineral elements

The nitrogen concentration in latex just before defoliation as well as 3 weeks after defoliation, as compared to the values in November, is presented in Table 5.14. Only two clones, PB 86 and BD 10 recorded significant higher values of nitrogen just before defoliation. Subsequent to this there was again a fall in the level 3 weeks after defoliation. The variations recorded by other clones, although statistically non-significant, appeared to give the same trend.

In the case of phosphorus, the value obtained 3 weeks after defoliation was significantly lower than

Table 5.12

Variations in carbohydrate content of latex as influenced by period of summer defoliation.

Clone	PERIOD			
	During normal period (November)		During summer defoliation (February)	
	Reducing sugar (mg/g)	Non-reducing sugar (mg/g)	Reducing sugar (mg/g)	Non-reducing sugar (mg/g)
Tjir 1	0.14	0.77	0.23	0.75
PB 86	0.24	0.82	0.26	0.30
Gl. 1	0.17	0.37	0.22	0.41
BD 10	0.14	0.47	0.18	0.41
LCB 1320	0.16	0.77	0.25	0.92

Table 5.13

Variations in protein content in latex (mg/g) as influenced by summer defoliation period.

Clone	PERIOD	
	During normal period (November)	During summer defoliation (February)
Tjir 1	0.57	1.12 *
PB 86	1.05	0.35
Gl. 1	0.65	0.92
BD 10	0.45	0.73 *
LCB 1320	0.68	0.97

* Difference Significant

Table 5.14

Nitrogen content of latex in November and during defoliation and refoliation.

Clone	Nitrogen content (mg/g total solids)		
	November	Before defoliation	3 weeks after defoliation
PB 86	5.88	6.10 *	5.77
Tjir 1	5.60	5.75	5.57
BD 10	4.29	4.73 *	4.52
Gl.1	5.18	5.87	5.62
LCB 1320	4.79	5.32	5.12

* Difference significant

the value obtained in November (Table 5.15). This trend was however not evident in other clones as the variations were not significant.

No significant variation in the potassium content was also evident in any of the clones studied (Table 5.16). An increase in magnesium content in clone BD 10 before defoliation and a general decreasing trend 3 weeks after defoliation (except in LCB 1320) were evident from the data (Table 5.17).

An increase in the calcium content of latex was found in clones PB 86 and Tjir 1 while the variations in other clones were not significant (Table 5.18). The values again reduced 3 weeks after defoliation in all clones except in LCB 1320. There was no statistical significance between the values in November and that obtained 3 weeks after defoliation.

Dry rubber content

There was no significant variations between the dry rubber content of latex recorded in November and February in the clones studied, the only exception being Tjir 1. The dry rubber content in this clone was higher during February as compared to November (Table 5.19).

Bursting index

The bursting index was significantly high during the period of summer defoliation (February) as compared to that recorded in during the normal period (November) in all clones except in Gl 1 (Table 5.20).

Table 5.15

Phosphorus content of latex in November and during defoliation and refoliation.

Clone	Phosphorus content (mg/g total solids)		
	November	Before defoliation	3 weeks after defoliation
PB 86	1.99	2.00	1.40 *
Tjir 1	2.18	2.30	1.86
BD 10	1.67	1.93 *	1.51
Gl. 1	1.08	1.21	0.99
LCB 1320	1.16	1.41 *	1.19

* Difference Significant

Table 5.16

Potassium content of latex in November and during defoliation and refoliation.

Clone	Potassium content (mg/g total solids)		
	November	Before defoliation	3 weeks after defoliation
PB 86	6.23	6.41	6.11
Tjir 1	4.37	5.00	4.07
BD 10	4.33	4.39	4.92
Gl. 1	4.87	4.39	5.53
LCB 1320	4.15	4.86	4.53

Table 5.17

Magnesium content of latex in November and during defoliation and refoliation.

Clone	Magnesium content (mg/g total solids)		
	November	Before defoliation	3 weeks after defoliation
PB 86	1.70	1.78	0.92 *
Tjir 1	0.67	0.81	0.47 *
BD 10	0.31	0.53 *	0.28 *
Gl.1	1.30	1.28	0.78 *
LCB 1320	0.71	0.82	0.62

* Difference significant

Table 5.18

Calcium content of latex in November and during defoliation and refoliation

Clone	Calcium content (mg/g total solids)		
	November	Before defoliation	3 weeks after defoliation
PB 86	55	78 *	60
Tjir 1	56	71 *	63
BD 10	56	62	57
Gl. 1	54	62	60
LCB 1320	43	52	58

* Difference Significant

Table 5.19

Changes in the dry rubber content of latex during summer defoliation period (February) as compared to period of normal yield (November)

(Average of two recordings per period.)

Clone (Av. of 4 trees)	Dry rubber content (%) November	 February
PB 86	35.02	35.51
Tjir 1	42.05	43.12 *
BD 10	44.35	43.83
Gl.1	43.70	43.12
LCB 1320	40.80	41.36

* Difference Significant

Table 5.20

Changes in the bursting index of latex during summer defoliation period (February) as compared to period of normal yield (November)

(Average of two recordings per period)

Clone		Bursting index	
		November	February
PB 86	..	29.6	40.0 *
Tjir 1	..	37.0	54.5 *
BD 10	..	36.6	52.6 *
Gl.1	..	38.0	43.5
LCB 1320	..	31.1	45.6 *

* Difference Significant

Dilution reaction

It was observed that the dilution reaction during the period of summer defoliation was significantly lower compared to that during November in all clones except in Gl 1 (Table 5.21).

Effect of Ethrel on yield depression during summer defoliation

Table 5.22 summarises the effect of Ethrel application in counteracting the yield depression during the period of summer defoliation. The data also give the variations in plugging index and initial flow rate during the period and the modifying effect of Ethrel on these characters. The depression in yield during the period of summer defoliation amounted to 42 and 45% in the first and second years of study. There was marked increase in the plugging as well as a slight decrease in the initial flow rate. Application of Ethrel brought down the plugging index resulting in enhanced yield. From the data it would appear that the depression in yield was mainly mediated through alterations in the plugging index and that Ethrel, acting on plugging index, could counteract the depressing effect of summer defoliation on yield. The trees stimulated had also slightly higher initial flow rate compared to unstimulated trees during the period of summer defoliation.

Table 5.21

Changes in the 'dilution reaction' during summer defoliation period (February) as compared to the period of normal yield (November)

(Average of two recordings per period.)

Clone	% dilution on tapping November	 February
PB 86	9.45	6.88 *
Tjir 1	8.93	5.66 *
BD 10	8.95	6.10 *
Gl.1	9.21	8.68
LCB 1320	8.51	6.00 *

* Variation significant at 5% level

Table 5.22

Effect of ethrel application on the yield depression during summer defoliation period

Treatments	Latex yield (ml)		Plugging index		Initial flow rate	
	During November	During summer defoliation (Feb-March)	During November	During summer defoliation (Feb-March)	During November	During summe defoliation (Feb-March)
1974-75						
Unstimulated trees	92.5	53.5 (-42.17%)	5.4	9.07 (+67.96%)	25.0	24.25 (-3.0%)
Stimulated trees	76.7	118.2 (+54.1%)	6.7	4.45 (-33.6%)	25.8	26.9 (+4.3%)
1975-76						
Unstimulated trees	86.5	44.8 (-48.2%)	5.6	10.45 (+86.6%)	23.5	21.0 (-10.7%)
Stimulated trees	79.3	115.5 (+45.6%)	6.0	4.80 (-20.0%)	22.8	23.0 (+0.8%)

Effect of watering during the period of summer defoliation on yield depression

The data on the effect of watering in counteracting the yield depression during summer defoliation during the two years of study are summarised in Table 5.23. The results indicated that while there was more than 58% reduction in yield in control plants it was only 21% in plants which were irrigated. The increase in plugging index during summer defoliation was 136% as compared to the value during November in the control. In the irrigated plants however the increase was only 21% indicating reduction in plugging index as influenced by watering. As compared to November, the initial flow rate in the unirrigated plants was slightly less in February. On the contrary, irrigated plants recorded a higher value of initial flow rate during February.

Effect of foliar spray of anti-transpirant (PMA) on yield during the period of summer defoliation

As indicated in the data (Table 5.24) the foliar spray of 10^{-3} M phenyl mercuric acetate resulted in an increase in yield. The foliar spray had caused stomatal closure(Table 5.2 resulting in increased stomatal resistance (Table 5.26).

DISCUSSION

Clonal variation in relation to yield depression

Results from the studies on clonal variation in the yield pattern during the period of summer defoliation indicate that Gl 1 was the least affected, while the worst affected was RRIM 623. Other clones were affected to varying extent in

Table 5.23

Effect of watering on yield depression during summer defoliation period (Average of two years data)

Parameters	Unirrigated		Irrigated (from January.)	
	Period of Normal yield (November)	During summer defoliation (February)	Period of Normal yield (November)	During summer defoliation (February)
Volume yield(ml)	105.75	43.50 (-58.87%)	77.50	61.25 (-21.0%)
Plugging index	2.38	7.05 (+196%)	4.13	5.00 (+21%)
Initial flow rate	13.0	12.75 (-1.92%)	14.37	15.25 (+6.12%)

Table 5.24

Effect of foliar spray of phenyl mercuric acetate on yield during summer defoliation.

Treatment	Yield (g/tree/tap)		
	Pre treatment	Post treatment	% difference
Unsprayed control	17.33	18.58	+ 7.16
PMA sprayed	16.00	21.75 *	+ 41.42

* Difference Significant

Table 5.25

Effect of foliar spray of phenyl mercuric acetate on stomatal opening

Treatment	Stomatal measurements (U)	
	Pore Width	Pore Length
Control	1.56	11.00
PMA : 10^{-4}M	1.26	11.20
PMA : 10^{-3}M	0.92	11.40
PMA : 10^{-2}M	0.82	10.90

Table 5.26

Effect of foliar spray of phenyl mercuric acetate on stomatal resistence.

Treatment	Stomatal resistance (Sec cm^{-1})
Control	10.0
PMA : 10^{-4}M	14.8
PMA : 10^{-3}M	17.8
PMA : 10^{-2}M	25.5

between. Gl 1 was a clone in which there was complete defoliation while LCB 1320 showed a gradual and phased defoliation that at no time the trees remained completely leaf lees. In spite of this Gl 1 had the least drop in yield. In another location (Kinalur), where also Gl 1 exhibited complete defoliation and remained leafless for about ten days, there was practically no depression in yield. It would thus appear that no relation exists between the extent of defoliation and the degree to which the yield drops. Wimalaratna and Pathiratna (1974) also could not find any relation between the leaf fall pattern and the fluctuations in yield in different clones. The pattern of results thus prompts one to assume that the soil moisture stress which prevails during the period of summer defoliation might also be an important factor in depressing yield. The clonal variations with regard to the extent of yield depression might represent the varying tolerance of clones to drought conditions. The present results confirm Gl 1 as a drought tolerant clone. This observation might look contradictory to the generally accepted notion that Gl 1 is suitable for water logged conditions. But it could be assumed that truly water logged conditions might subject the trees to a condition of physiological drought. The drought tolerant character of Gl 1 has already been identified (Saraswathy Amma and Sethuraj, 1975). Another observation of interest is that the clone RRIM 605 appears to be drought susceptible. The present findings thus contradicts the assumption of Jacob and Pillai (1968) that this clone might be suitable for drought affected regions.

Yield fluctuations in relation to different stages of defoliation and refoliation

From the studies on the yield fluctuations in relation to stages of defoliation and refoliation, it became evident that yield may be increased slightly during the period of 50% defoliation. The yield is affected after the emergence of new leaves. Wimalaratna and Pathiratna (1974) also have observed that the lowest yield is synchronised with the stage of leaf emergence or later but not at the stage of defoliation. In the case of chemical defoliation in the off-season also, a higher yield was observed immediately after defoliation. While the effect of defoliation might have had a direct effect on yield by reducing the transpiration, possible direct effect of 2,4-D on yield increase cannot also be ruled out. Harmful effects of artificial defoliation at different times of the year have been reported by Schweizer (1936). In the present study, refoliation did not however occur for a period of more than four months and as such the gradual decline in yield in these plants should be considered to be the consequence of a leafless condition for a prolonged period. The fact that the duration of leaf-less condition during summer defoliation is very short, makes a comparison difficult. The finding reported in Section II that the age of leaf maturity alone could not influence the increase in yield after annual tapping rest and that the rainfall or soil moisture *per se* might play a role in the pattern of yield increase, is thus relevent.

Effect of tapping rest during summer defoliation period on the pattern of subsequent yield

The results, though obtained from small scale experiments give an indication that atleast in the case of three of the four clones studied, tapping rest has resulted only in reduced yield during the period following the rest period as compared to the trees which were tapped continuously. No previous work on these aspects seems to have been made and it would be rewarding if the necessity for giving tapping rest during the period of summer defoliation in different clones is investigated in detail.

Changes in the physiological factors during summer defoliation period

The major change during summer defoliation was observed in latex flow. The reduction in yield could be accounted by a rise in the plugging index. This finding is in agreement with the earlier observation of Sethuraj (1968) that the fall in yield during the period of wintering is the result of a short duration of flow. Paardekooper and Samosorn (1969) also could relate fluctuations in yield at different periods of the year with changes in the plugging index. The clonal variations in yield depression could also be explained by similar variations in the plugging index. Saraswathy Amma and Sethuraj (1975) reported differential reaction of clones to soil drought and in their results a relationship between variations in plugging index and yield was also evident. Gl 1 was the least affected by the summer defoliation (or the soil drought) and this character of this clone reflected in lesser modulations in plugging index due to such seasonal variations.

No significant variation in reducing or non-reducing sugars to account for any decrease in yield was obtained. As the decrease in yield was the result of lesser volume of latex and not of a lower rubber content, the lack of any relationship between variations in carbohydrates and yield depression is conceivable. Nor any variations in the protein level to account for the yield drop could be observed. Mineral elements in latex showed a trend of slight increase before defoliation in some of the clones. Higher cation level may induce a higher plugging and lower yield (Pushparajah et al, 1975). But the lowest yield is often encountered during the expansion stage of new leaves, a period at which the cation concentrations actually recorded a fall. The general trend of seasonal fluctuations in the mineral composition of latex, ie. an increase before defoliation followed by a fall in the concentration during the emergence and expansion of new leaves, has a similarity with the seasonal changes in mineral composition in the bark reported by Tan (1975). The assumption that the yield depression during summer defoliation is a function of latex flow only is strengthened by the finding that there is no fall in the dry rubber content of latex. On the other hand there was an increase in d.r.c. in the case of Tjir 1. The increase in the dry rubber content could be the result of lesser extraction of latex during this period.

The high plugging index during this period can be considered to be the direct result of changes in the lutoid stability as was evident from the results on the bursting index. The variation in bursting index in clone Gl 1 was not significant and this result corroborates the tolerant character of this clone. As can be expected with high plugging and shorter flow, the clones affected recorded only a lower dilution reacion . Understandably Gl 1 remained an exception.

Effect of Ethrel application on yield depression during summer defoliation period

The foregoing discussions have revealed that the depression in yield during summer defoliation is mainly a result of higher plugging index. It is well established that yield stimulants act as antiplugging agents (Boatman, 1966). It is therefore not surprising that ethephon could counteract the

the yield depression during summer defoliation period. A higher response to stimulation during the period of wintering as compared to other seasons has already been reported (Abraham and Tayler, 1967; Sethuraj and George, 1975).

Effect of watering during summer defoliation period on yield

Watering has considerably reduced the extent of yield depression during summer defoliation period. This effect of watering on yield also has mediated through lowering of plugging index. Effect of soil moisture on plugging index is already known (Saraswathy Amma and Sethuraj, 1975; Sethuraj and George, 1976). The results point out the possibility of irrigation during drought periods to counteract yield depression although the economic feasibility should be carefully considered.

Effect of foliar spray of anti-transpirants on yield during summer defoliation period

The use of anti-transpirants to reduce water loss from plants is well documented (Zelitch, 1971). Phenyl mercuric acetate is considered to be an effective anti-transpirant. The finding that foliar spray of 10^{-3}M PMA increas d the yield during summer defoliation supports the contention that the yield depression during this period is related to the water relations of the plant. While further studies are necessary for assessing the feasibility of the use of anti-transpirants in plantations, the results do indicate that by reducing the transpiration rate during periods of drought, the yield depression can be arrested to some extent. It may also be stressed that as its use would be confined to a short period of yield depression, the possible harmful effects of such chemicals on photosynthesis do not assume much importance.

SUMMARY

Clonal variation in the degree of yield depression during the period of summer defoliation was observed. While RRIM 623 appeared to be drastically affected, the yield depression was minimal in Gl 1. The drop in yield as well as the clonal differences in this regard could be explained by the modulations in the plugging index. The lowest yield was found to be associated not with leafless stage but with the formation and expansion of new leaves. At the stage of 50% defoliation, there was slight increase in yield. An increase in yield along with defoliation was evident even when defoliation at off-season was achieved by chemical defoliant. A leafless condition for a prolonged period may affect yield, as in the case of chemically defoliated plants. A similar condition does not occur in the case of summer defoliation as the new leaves emerge within 7-10 days. There was also some indications that atleast in the case of certain clones tapping rest during summer defoliation did not result in any higher subsequent yield. Investigations on the changes in the physiological factors relating to yield during summer defoliation period revealed that the character which was most affected was plugging index. Studies on bursting index indicated that the lutoid stability was also affected during summer defoliation periods in the case of all the affected clones. In Gl 1, wherin the yield depression was not significant, the changes in bursting index were not very pronounced. Fluctuations in the concentrations of mineral elements were not however related to increase in plugging index. The yield depression also could not be accounted by any change in the level of sugars of protein in latex. The important role of plugging process in the yield depression during summer defoliation period was evident from the finding that application of Ethrel could completely prevent yield depression. The possibility that the moisture status of the tree during this period has an overriding effect on yield depression emerged from the results of experiments on watering and foliar spray of an anti-transpirant. Watering as well as foliar spray could reduce the degree of yield depression during summer defoliation.

GENERAL DISCUSSION AND CONCLUSION

The present investigations embrace studies on the effect of environmental and internal factors on yield, factors influencing the effectiveness of exploitation methods and the physiological basis of yield depression during the period of summer defoliation (wintering) in para rubber (*Hevea brasiliensis* Muell. Arg.)

Direct and indirect effects of environmental factors on yield as well as their interactions were assessed by path coefficient analysis. It was concluded that soil temperature and relative humidity were important parameters influencing yield. Importance of soil moisture, especially when it becomes a limiting factor, was evident from the studies. Relationship between yield and water status of the tree has already been stressed by Ninane (1967 b). The present studies provided evidence that there is clonal variations in the reaction to moisture stress. It was also demonstrated that variations in yield at different periods of the year, as influenced by environmental fluctuations, could be accounted by the changes in the latex flow pattern. In clones which were not significantly influenced by seasonal variations, the fluctuations in the plugging index were also negligible. Gl 1 was identified as a clone most tolerant to environmental fluctuations. Saraswathy Amma and Sethuraj (1975) had already reported that among the nine clones they studied, the effect of soil moisture on plugging index was least evident in Gl 1. The adaptivity of this clone can profitably be utilised in breeding programmes for evolving drought tolerant clones.

Studies on the internal factors influencing yield have revealed that differences in latex flow pattern were mainly responsible for clonal variations in yield. Both initial flow rate and plugging index were found to be important determinants of yield. While Milford et al (1969) considered plugging index to be a clonal character, studies of Sethuraj et al (1974) indicated that initial flow rate also might be a heritable clonal character. The negative correlation between initial flow rate and plugging index necessitates an assumption that a high flow rate might delay plugging by sweeping out the flocs inside latex vessels and that an efficient plugging process which starts operating within minutes of tapping may by itself affect the initial flow rate in turn. The internal factors which affect the initial flow rate and plugging index also were examined. It was demonstrated that anatomical characteristics of the bark and turgor pressure might influence the initial flow rate. On the other hand, plugging index was influenced by the lutoid stability and drainage area. Sethuraj et al (1974) and Sethuraj and George (1976) first indicated the influence of drainage area on plugging index.

The present study confirmed this and has further shown that the nature of development of drainage area as a result of tapping, may exhibit clonal differences. The results also indicated that the clonal variation in yield may be governed by the mineral composition of latex as well. In budded plants this aspect is complicated by the fact that the root system necessarily belongs to any of the seedling materials.

The yield of rubber from the tree is a function of both the volume of latex and its rubber content. The results of the present investigations however indicate that dry rubber content of latex is not related to the clonal variations in yield. This confirms the assumption that yield is determined predominantly by the latex flow pattern. Once this assumption is accepted it is comprehensible why the carbohydrate level in latex did not show any correlation with yield. Contention of Tupy and Primot (1974) that yield potential of the tree is related to the carbohydrate level has been derived from indirect evidences and need further evaluations in the light of the present results. The present studies also stressed the necessity to distinguish between cause and consequence of yield when attempts are made to relate biochemical composition of latex with yield; the present results indicated that a higher RNA content associated with high yield was assumably the consequence of greater extraction of latex.

Investigations on the factors influencing the effectiveness of tapping systems and stimulants elucidated the physiological basis of the differential effects of tapping systems and methods of stimulation. Effectiveness of tapping systems is largely dependant on their capacity to enlarge the drainage area. It would therefore appear that when the environmental factors favour an extension of drainage area for a given length of cut, lengthening of the cut would have lesser effect. Similarly clones in which the drainage area for a given length of cut is assumably larger, lengthening of the cut or opening of more cuts would have lesser effects. Even some of the comprehensive tapping experiments conducted earlier (Paardekooper *et al.* 1975) did not have the objective of any physiological analysis of the effectiveness of different systems of tapping. It was also demonstrated that the harmful effects of daily tapping can be alleviated by opening two cuts and alternating the tapping. Once the basis of clonal variations in the response to different systems is identified, a more judicious selection of tapping systems would become possible.

Another aspect which became clear from the studies was the influence of various factors on the effectiveness of stimulation. It was demonstrated that concentration of the chemical used and the period, the duration and the mode of application were important factors influencing the response to stimulation. The response was found to be highest during period of low yield. A new information of interest was that the generally recognised declining trend in response with prolonged stimulation was less pronounced with lower concentrations. The component of yield which was affected by prolonged application of stimulant was found to be the initial flow rate. Intensive tapping also was reported to have affected the initial flow rate (Sethuraj et al, 1976). It can be assumed that prolonged application of stimulants may also lead to physiological changes in the latex vessels similar to those resulting from intensive tapping. The high incidence of brown bast following stimulation of clone Gl 1 is indicative of such physiological changes.

The contention of Sethuraj et al (1975) that the methods of stimulant application designed to extend the drainage area would result in better response was further confirmed in the present investigations. The results with the multiple band application of Ethrel also indicate the possibility of commercial adoption of this method.

The conclusion which can be drawn from the studies on the physiological changes during the period of summer defoliation is that the yield depression during this period is more a consequence of the prevailing moisture stress than any direct effect of defoliation or refoliation.

The fall in yield is accountable by an increase in the plugging index. In clones which were least affected during this period, the changes in latex flow pattern was also not very pronounced. The present study has confirmed the earlier finding of Sethuraj (1968) that the reduction in yield during wintering is caused by a shorter duration of flow. In the present enquiry,no evidence was also obtained for the need for tapping rest during summer defoliation. On the other hand the results revealed that the application of any anti-plugging agent like ethephon can counteract the process of yield depression. This could also be achieved by enhancing the moisture status of the tree through irrigation or by limiting water loss by foliar spray of anti-transpirants.

In summary, the results offer certain general conclusions: Yield is a function of the factors influencing latex flow. Latex flow is influenced by environmental factors and the internal factors such as lutoid stability and drainage area. While lutoid stability cannot be subjected to physiological manipulations, drainage area can be altered by tapping systems and stimulation methods. Enhancement of drainage area results in lower plugging index and hence higher yield. As latex flow is influenced by the water status of the tree as well, operations designed to raise the water status of the tree also would naturally increase yield.

Seasonal fluctuations in yield as well as clonal variations in yield can be traced to factors influencing latex flow. It should however be stressed that the partioning ratio, ie. the ratio of yield of rubber to total biological yield, will certainly exert its influence on the growth rate of the tree. In the case of rubber, the method of exploitation has an overriding effect on the partitioning ratio. A rational balancing between yield and tree's vigour is imperative. The knowledge derived from the present studies might help to regulate yield more judiciously.

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