SOIL MOISTURE AND NUTRIENT INFLUENCE ON GROWTH AND YIELD OF *HEVEA BRASILIENSIS* IN TRIPURA

VARGHESE PHILIP

CERTIFICATE

This is to certify that the thesis entitled *Soil moisture and nutrient influence on growth and yield of Hevea brasiliensis in Tripura* submitted by Mr Varghese Philip to the Indian Institute of Technology, Kharagpur, for the award of the degree of Doctor of Philosophy in Science is a record of bonafide research carried out by him during the period from 1990 to 1997 under our joint supervision. The thesis, in our opinion, is worthy of consideration for the award of the degree of Doctor of Philosophy in accordance with the regulation of the Institute. The results embodied in this thesis have not been submitted to any other University or Institute for the award of any degree or diploma.

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LIST OF ABBREVIATIONS

g_s - Stomatal conductance
MAP - Months after planting
T.max - Maximum temperature
T.min - Minimum temperature
RH - Relative humidity
SSD - Sunshine duration
WS - Wind speed
Evapo - Evaporation
PI - Plugging index
DRC - Dry rubber content
Pi - Inorganic phosphorus
RGR -Relative growth rate
MPa - Mega pascal
LSD - Least significant difference
°C - Degree Celsius
RRII - Rubber Research Institute of India
RRS - Regional Research Station

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ABSTRACT

Hevea brasiliensis, a native of the Amazon basin, has been planted commercially in India since the early 1900's. To meet the ever increasing demand of natural rubber, plantations are being raised in non-traditional regions. Tripura in the N.E. India is in the forefront. Specific agromanagement practices is needed to raise this crop in this environment which is different from that in the traditional rubber growing region. Keeping this in view, the present investigation was undertaken at RRS, Tripura to gather precise information on the growth of young *Hevea* as influenced by soil moisture and nutrients during different seasons. The various growth parameters studied showed that higher growth was obtained when soil moisture availability was high (-0.03 MPa), the influence being more pronounced during winter period. Different levels and combination of nutrients also influenced the growth. Higher levels of phosphorus in particular was observed to maintain a higher growth rate during winter. In general, NPK application at 40 kg ha^{-1} with irrigation to provide a soil moisture tension of -0.03 MPa, was optimum for the growth of young rubber plants.

An experiment was taken up in the mature phase in a nine year old planting at RRS, Tripura to monitor the influence of irrigation and selected nutrient doses on the yield and yield components. Results of the study showed that irrigation at fortnightly interval maintaining a soil moisture tension in the range of -0.03 to -0.10 MPa along with NPK

application of 40 kg ha^{-1} has significantly increased the yield of latex. The influence of irrigation on yield of latex was more pronounced during the winter period (Oct-Jan).

Interrelationship of yield, yield components and meteorological parameters was worked out. It was observed that yield of latex is related to the yield components and weather. To understand the direct and indirect effects of yield components and meteorological parameters on yield a path analysis was performed. Correlation analysis pointed out that PI, latex sugar concentration, T.max, RH, WS, SSD and rain are the primary factors affecting yield. Path analysis however showed that PI, SSD and evaporation are the primary factors directly affecting yield. Fifty six per cent variability in yield was explained by factors considered in the study.

CHAPTER I

INTRODUCTION

The para rubber tree (*Hevea brasiliensis* MUELL-ARG.) is a native of the Amazon river basin in South America. This tree was introduced to tropical Asia in 1876 through the Kew gardens in UK with the seeds brought from Brazil by Sir Henry Wickham. The tree is now grown in the tropical regions of Asia, Africa and America. Natural rubber a raw material having multifarious uses is obtained from the latex of *Hevea brasiliensis,* the species which accounts for 99 percent of the world's natural rubber (Webster and Baulkwill, 1989).

The *Hevea* planting material was first introduced to India in 1878 from Ceylon and the commercial plantation started in the early 1900's. The rapid strides made in the wake of the industrial revolution fostered a demand for natural rubber which was met by the plantation industry despite setbacks of price fluctuation, threat of devastating diseases and challenges of synthetic substitutes. Commercial cultivation of rubber in general has been limited to the humid tropics, where the climate closely resembles that of its centre of origin. In India, the development of the rubber plantation industry was confined to a narrow tract in the western side of the western ghats in the state of Kerala and adjoining districts of the neighboring states, which accounts for 90 percent of the area. The rubber tree is adaptable to a wide range of climatic conditions as evidenced by the growth of rubber in China under very low temperature conditions. *Hevea* is also reported to thrive in a wide range of soils.

The natural rubber production in India has not been able to keep up with the demand in consumption. The production / consumption gap during the year 1996-97 was around 13,000 t (Rubber Board, 1997), this gap is projected to widen further by the turn of the century. By 2000 A.D the shortfall is expected to grow to 50, 000 tones and by 2011 to 3.5 lakh tones. Large scale expansion of area is required to increase production and to reduce the production/consumption gap to the extent possible. As the area available in traditional region is limited, area expansion has to be taken up in the non traditional regions.

The North Eastern region of India (22°N to 29.5°N), though outside the traditionally recognized Northern limit, has been planted with rubber since 1950. Though this region is suitable for the growth of *Hevea brasiliensis*, there are environmental stresses of various kinds influencing growth and yield of the tree unlike in the traditional regions. The major environmental stress in North East India is the prolonged low temperature of less than 20°c for nearly five months coupled with low soil moisture during this period. Only China cultivates rubber around this latitude. Limited information only is available on the cultural practices to be adopted under low temperature (Jiang, 1988) and prolonged drought conditions (Pushparajah, 1983 a ; Sethuraj *et al*, 1989) in the non-traditional regions.

Appropriate management practices are needed for this region to foster good growth during the immature period and in realizing the production potential in the mature stage of growth. Irrigation to ameliorate drought effect is being pursued in the western and eastern region of India where rubber is being cultivated on a trial basis (Mohankrishna *et al*, 1991; Chandrashekar *et al* 1994). In Tripura the period from October to February is characterized by low mean minimum temperature and soil moisture deficit condition. Growth performance of young rubber plants in different moisture regimes during this period is lacking. Nutrient management has been found to influence growth and yield of *Hevea* as is evident by the literature reviewed. Though a preliminary study on the nutrient requirement of *Hevea* in the young stage is reported (Krishnakumar and Potty, 1989), detailed information on the impact of nutrients during the early growth period from this region is also lacking.

In the mature phase, the yield of rubber is related to flow characteristics of latex. Latex is held under high hydrostatic pressure in latex vessels in the phloem region. Controlled wounding of the bark of the tree by tapping results in expulsion of latex held in the laticiferous vessels. Latex vessel turgor is maintained by the entry of water from the surrounding tissues which maintains latex flow until the vessels are plugged. Since this process involves water, the availability of this component from soil assumes importance. Plugging of laticiferous vessels is governed by the ionic balance, particularly potassium and magnesium in latex. During winter a reduction in dry rubber content followed by a prolonged latex flow is encountered as a result of winter stress. Rubber plants experiences two types of stresses during winter in Tripura viz. low temperature and inadequate soil moisture levels. Precise information on factors leading to the situation mentioned above is not available. Reduction in dry rubber content can be attributed to slow rubber biosynthesis. Nutrients and water play major role in the biosynthesis of latex. Similarly two distinct growth pattern is also noticed. Growth during period from November to April is slow and during May to October higher compared to growth in the traditional region. Nutrients and soil moisture could influence growth in the early growing phase also. No systematic study has been taken up to study the influence of nutrients and soil moisture on growth and yield of *Hevea*. The present study was therefore taken with the following objectives.

1. To study the role of soil moisture and major nutrients viz. N, P and K and their interaction on the growth during early immaturity period of *Hevea*.

2. To study the influence of irrigation and selected nutrient doses on yield and yield components in mature *Hevea*.

3. To study the interrelationships of meteorological parameters on growth, yield and yield components of *Hevea*.

CHAPTER II

REVIEW OF LITERATURE

The early commercial rubber plantations in India were started in the 1900's. Since then management practices adopted bore a close relation to those practiced in other countries. Research efforts in evolving suitable management practices to suit local conditions started in the 1920's. The traditional rubber growing belt in India is confined to the West Coast region of the country extending from Kanyakumari district of Tamil Nadu in the South to Coorg district of Karnataka in the North (Pushpadas and Karthikakuttyama,1980). With over 5 lakh ha planted in this region additional area that could be brought under rubber from this region is negligible.

To keep up with the increase in demand of natural rubber, non-traditional areas had to be identified and planted (Sethuraj *et al*,1989). Expansion activities in the non-traditional tract gathered momentum in the 70's particularly in Tripura which now has the second largest area under rubber in India. The ecological conditions of this region being different , appropriate management practices have to be defined. Though an *ad hoc* recommendation on nutrient management of immature rubber has been made (Krishnakumar and Potty,1990), a detailed study on the nutrient and moisture parameters on growth and yield of rubber is lacking. In the following sections, literature on moisture , nutrients, temperature, seasons and their influence on growth and yield of rubber has been reviewed.

2.1. Soil moisture and nutrient supply.

Nutrient supply and uptake is influenced considerably by the soil moisture status. Mechanisms of uptake is either through mass flow, diffusion or root interception. Calcium and magnesium movement is through mass flow and that of phosphorus and potassium mostly through diffusion. When soil water potential is high, mass flow is unrestricted (Nye and Tinker,1977) and hence rainfall pattern in a region has a bearing on the nutrient movement.

The effect of moisture on N dynamics and mineralization has been investigated by many researchers (Bugakov, 1962; Miller and Johason, 1964; Stanford and Epstein, 1974; Cassman and Munns,1980) and optimum moisture has been reported to vary from 0.015 to 0.05 MPa. At low soil moisture levels the reduction of phosphorus and potassium uptake is greater than that of calcium and magnesium (Talha *et al*,1979). Soil moisture is therefore an important parameter with respect to nutrient availability to the plant. However in areas with long dry spells higher values of exchangeable potassium through addition of higher quantities of fertilizer is required to compensate for inadequate moisture to maintain a sufficiently high diffusive flux (Paauw,1978).

A low soil moisture level has been reported to reduce uptake of potassium and phosphorus and leads to absorption of more calcium and magnesium (Talha *et al*,1979). When plants were stressed, uptake of nutrients particularly phosphorus, potassium, calcium and magnesium decreased (Gardner and Tanner, 1976). Nutrient effects on stomatal function can be direct, through the K^+ balance in guard cells, or indirect, through nutritional effects on abscisic acid production. Potassium deficient plants have lower tolerance for water stress due to the role of K + in stomatal regulation (Marschner, 1986). Ionic balance especially of cations are reported to play a significant role in the growth and yield of *Hevea*. Studies conducted on the influence of soil moisture on cation uptake revealed that application of higher levels of potassium helps in maintaining higher exchangeable potassium and magnesium content in latex. During moisture stress period higher potassium application was found to maintain higher water potential, longer flow, thereby higher yield and in maintaining a better plant water status (Krishnakumar,1989).

2.2. Influence of temperature on growth and yield of rubber.

Temperature is a key environmental factor influencing plant growth. *Hevea* adapted to moderate temperatures are affected by extreme temperatures. In the traditional rubber growing regions temperature ranges from 20-34 ° C but in North East India ,a non traditional tract, the minimum temperature is less than 20° C for nearly 5 months and T.max less than 34° C (Rao and Vijayakumar, 1992). These areas normally pose stress conditions like drought, low temperature, high altitude and soil moisture deficit (Sethuraj and Raghavendra, 1984). Rao et (1993) has categorized the hydro thermal region of Agartala which has four months of dry period and varying temperature conditions as moderate.

The effect of temperature and altitude has been studied extensively by Zongdao and Yanging (1979) in China. Rubber growing areas in China lying between 18° and 24° N are affected by typhoons, cold climate and marginal rainfall. As distance from the equator increases, mean minimum and annual mean temperatures decreases. Away from the equator due to higher total annual input of radiation energy, there is a greater potential for photosynthesis and dry matter production (Oldeman and Frere, 1982).

At Cox's Bazzar in Bangladesh (23°N) with mean minimum temperatures of 18 ° C in Dec, Jan and Feb, Pushparajah (1983 a) reported that it might take 7 years or more to bring a young rubber plantation into tapping compared to 6 years or less in Malaysia.

Performance of clones vary in different climatic zones. In traditional rubber growing regions in India the immaturity period could be six to seven years and in the non-traditional regions it could be eight years or more (Sethuraj *et al,* 1989). In China growth of rubber is retarded during winter , the growing period limited to between June to October (Zongdao and Xuequin, 1983). The higher the temperature, higher is the growth rate and the threshold temperature for growth is found to be in the range of 20° C (Jiang,1988).

In the tropical low elevation regions like Kottayam (9° N latitude in Kerala, India) a monthly mean temperature of 26-28° C with adequate soil moisture and sunshine are associated with high latex production. It has been shown by Shangpu (1986) that the optimum temperature for latex production is 27-28°C, while an ambient temperature of 18-22° C is most ideal for latex flow. High temperature was found to retard latex flow and reduce yield (Lee and Tan, 1979).

2.3. Influence of moisture stress on water relations and latex flow.

Prolonged dry period has an adverse effect on the establishment of young plants and yield of mature rubber (Rao *et al*, 1990). Latex being predominantly watery, the plant water relations influences their flow (Buttery and Boatman, 1976). Soil moisture stress has significant effect on the yield components such as initial flow rate, PI and DRC. Besides the direct effect on turgor pressure, water deficit also triggers a series of biochemical changes in latex (Premakumari *et al*,1980). Clones of *Hevea* vary in their sensitivity to moisture stress (Saraswathi Amma and Sethuraj,1975) with duration of flow and amount of latex being reduced during water stress conditions (Sethuraj and Raghavendra,1984). This was attributed to enhanced plugging and restriction in the drainage area (Sethuraj and George,1976). Drought tolerant clones have been shown to maintain high solute potential in their C-serum even in summer months (Satheesan *et al*,1984). Raghavendra *et al* (1984) studying the pattern of latex flow reported that pattern of latex flow was altered by soil moisture. The duration of flow as well as the amounts of latex were reduced when trees were stressed. They monitored turgor pressure using mini manometers, and recorded turgor pressures of 0.75 to 1.2 MPa. Similar turgor pressure was also reported by Buttery and Boatman (1976). A high osmoticum content of sucrose, quebrachitol and mineral ions in latex and sufficient available water to approach maximum turgor pressure in the laticiferous tissue are the conditions required for good expulsion of latex (Pakianathan, 1989).

Conceicao *et al* (1985) studying the effect of soil water potential on clones found that lower soil water potential reduced clone leaf water potential linearly and led to a fast increase in stomatal resistance and a sharp reduction in transpiration. If a crop suffers from water stress in the early stages, it fails to develop a deep root system that would utilize water stored in deeper layers (Ritchie *et al*,1972).

Hevea latex contains 60-70 % water apart from the rubber fraction. Hence water availability form a potential limiting factor for production. *Hevea* is adapted to a wide range of ecological sites and so tolerates extreme conditions of soil moisture. A hydric deficit in *Hevea* causes a lowering in turgor pressure which affects latex flow at tapping (Pakianathan *et al,* 1989). The fact that PI displays very marked seasonal variation is probably connected with seasonal variation in rainfall i.e. availability of water to the tree (Paardekooper and Somosorn,1969). The increase in PI by moisture stress can be considerably reduced by irrigating the plants (Sethuraj and George,1976). The work of Haridas(1980) also indicate the influence of irrigation on PI and yield.

2.4. Seasonal variation and performance of rubber.

Introduction of rubber into regions of tropical wet dry climate has exposed the trees to dry seasons of upto 5 months. Effect of this on tree performance is confounded with that of temperature and other environmental factors (Webster,1989). Ideally *Hevea* performs best in climates of tropical lowland, evergreen rainforest regions with an annual rainfall of 2000-4000 mm at latitudes of 10° N and S of the equator. In the equatorial regions of rubber cultivation mean annual temperature is 28° C + or - 2° C and diurnal variation about 7° C (Barry and Chorley,1976). Diurnal variation and mean minimum temperature increases with distance from the equator. The flow of latex varies both in volume and in concentration according to the time of day and season of the year. The diurnal changes seem to be mainly due to changes in transpiration rate; seasonal effects can partly be attributed to variation in rainfall, partly to the physiological demands of wintering and refoliation (Buttery and Boatman, 1976). Ninane (1967) showed that transpiration of young rubber plants, being influenced both by temperature and RH of the surrounding air, was highly correlated with saturation deficit of the air.

Rainfall pattern in the rubber growing countries show wide variations. Southern Malaysia has no severe dry period compared to the north of the country (Webster,1989). In Thailand at latitudes 6-12 ° N rainfall is around 2000 mm and at latitudes of around 18 ° N it falls to 1200-1500 mm falling over 120 days (Saengruksowong *et al* 1983). In India the traditional rubber growing belt enjoys both South West and North East monsoons with an annual range of 2000-4000 mm per year. However in the North Eastern regions, the North East monsoon is scanty (Pushpadas and Karthikakuttyamma, 1980) and the region experiences nearly 4-5 months of moisture deficit in the winter months. Thus away from the equator, most regions in the N.E.India, China, Bangladesh and Vietnam experiences severe cold and dry conditions (Rao and Vijayakumar,1992).

A uniform annual distribution of rainfall is regarded as favorable for the growth of *Hevea* (Polhamus,1962). Moisture stress of different magnitude is reported to adversely affect growth of young rubber (Sivanadyan *et al*, 1973; Sivanadyan *et al*, 1975; Pushparajah and Haridas, 1977). Growth in the immature stages require sufficient moisture particularly during shoot flush to maintain height increment (Haridas, 1980). Trials at Ivory Coast revealed reductions in growth in areas with longer dry spells than the wetter areas (Omont, 1982). Though rarely practical, irrigation has been shown to increase yields (Haridas, 1984) and alleviate adverse effects of water stress (Sethuraj, 1986).

Yield and yield components are influenced by different environmental parameters. Seasonal variation in yield has been ascribed to variation in both initial flow rate and PI (Milford *et al*, 1969;

Saraswathiamma and Sethuraj, 1975). The increase in PI caused by drought was thought to be connected with a fall in the lipid compound content (Premakumari *et al*, 1980). In the Ivory Coast, latex production reaches a peak in August and a secondary peak of production occur in November to early December after the minor rainy season (Ribaillier, 1971). In the wet districts of Ceylon, PI reaches a maximum after winter defoliation and declines gradually until the onset of the next wintering period (Waidyanatha and Pathiratne, 1971).

2.5. Applied nutrients and its influence on plant growth.

As early as in the 1900's response of *Hevea* to fertilizer addition was demonstrated in Vietnam, Cambodia, Malaysia, Indonesia and Sri Lanka (Compagnon, 1962). The importance of fertilizers on tree performance was noted by Bolton (1960) and Ti *et al* (1972). Fertilizer application right from the time of planting is aimed at bringing the plants ready for early tapping. Schedules of fertilizer application rate used in many rubber growing countries are based on local trials (Guha, 1975; Hardjono and Angkapradipta, 1976; Punnoose *et al*, 1976; Kalam *et al*, 1980; Omont, 1981; Yogaratnam and Veerasuriya, 1984) and are similar to those used in Malaysia. There are many reports on the influence of major nutrients on plant growth. Results of multi-locational trials in the pre-tapping stage indicated that response to applied fertilizers were dependent on initial soil fertility status (Ananth *et al*, 1966). In North Eastern India a slash and burn type of cultivation is prevalent. This rapidly mineralizes organic matter reserves with levels of upto 100 ppm of nitrate N in the top soil , as was seen in Malaysia(Watson *et al*, 1964). Even after ten years of planting there was continued mineralisation accompanied by a downward movement of NO3-N, fall in pH and in levels of organic matter and exchangeable bases. This confirmed the existence of a leaching process set about by jungle clearing and soil exposure (Pushparajah and Chellapiah, 1969; Soong and Yap, 1976; Pushparajah, 1984).

2.5.1. Nitrogen.

Owen *et al* (1957) reported that the influence of nitrogen on girth of plants became apparent with time. Girth increment with the application of nitrogen was also reported by Bolton (1960), Kalam *et al* (1980) and Pushparajah *et al* (1983 b). Yogaratnam and Weerasurya (1984) reported a positive response in girth to application of nitrogen. Potty *et al* (1980) reported that increasing the level of nitrogen from 30 to 60 kg ha^{-1} improved girth and girth increment of rubber trees.

2.5.2. Phosphorus.

Pushparajah *et al* (1977) observed that phosphorus fertilizers were required for maximum growth of *Hevea* trees. Rubber Research Institute of Malaysia (1978) also reported significant response to phosphorus application on girth. In the highly depleted soils of North East India, Krishnakumar and Potty (1989) observed a marked increase in the girth of plants at higher levels of nitrogen, phosphorus and potassium. Reis *et al*

(1984) also reported girth increase with phosphorus application in the immature phase.

2.5.3. Potassium.

Importance of potassium in the nutrition of *Hevea* is fairly well established and considerable research has been carried out in the various rubber producing countries. Potassium plays a vital role in the growth and development of plants (Von Uexkull, 1985). Reports of the Rubber Research Institute of Malaya (1971 a) indicated that lack of potassium resulted in poor girth. Pushparajah *et al* (1974) reported good bark renewal with potassium application. Response of plants to potassium nutrition has however been varied. Owen *et al* (1957) reported lack of response in growth to potassium in most trials and negative effects from some. Growth responses to potassium nutrition from the traditional rubber growing region as reported by Punnoose *et al* (1976) highlighted depressed growth of rubber plants with higher potassium levels.

Die back symptoms of branch have been noticed in extremely potassium deficient soils of Indonesia and application of potassium fertilizers was observed to restore the crown of trees (Dijkman,1951). Increased application of potassium and lowering the quantity of nitrogen before winter increased cold hardness of rubber in China (Zongdao and Xuequin, 1983).

2.5.4. Calcium.

Calcium application in rubber plantations comes mainly through the rock phosphates applied. The role of calcium in the mineral nutrition of *Hevea* is important. It has been noticed that the tree is adaptable to survive in a low calcium environment (Bolton, 1960). Considering the fact that genetically the tree being adaptable to the depleted Amazon tropical forest condition, this argument holds good (Krishnakumar and Potty, 1992). Calcium/total cation ratio is reported to be important for root growth. In acid mineral soils a ratio lower than 0.15 may inhibit root growth. This is particularly important for sub soil penetration by roots (Howard and Adam, 1965).

2.5.5. Magnesium.

Rubber Research Institute of Malaya (1969a and 1969b) reported that magnesium incorporation in fertilizer mixtures greatly improved growth and that the rate of girth increment was found to be higher in magnesium applied areas which had magnesium deficiency. Reports of Rubber Research Institute of Sri Lanka (1987) and Yogaratnam and Weerasuriya (1984) also have indicated increased girth with moderate magnesium application. In the traditional rubber growing regions in India, magnesium application is recommended only in regions where it is deficient

2.6. Nutrient interactions on growth of rubber.

Nutrient interactions were seen to influence growth of young rubber. Owen *et al* (1957) obtained both positive and negative NP interaction on growth. NK, PK and NPK were also highlighted by them. George (1963) also reported positive NK interaction on plant girth. Bolton and Shorrocks (1961) showed positive NP interaction helped in growth. With various nutrient interactions influencing plant growth a balanced manuring regime is of vital importance in bringing the trees to tappable girth early.

2.7. Applied nutrients and its influence on yield and yield components.

Major nutrients viz. nitrogen, phosphorus and potassium exert a positive influence on the yield of rubber. This could be due to a direct effect or mediated through their effect on growth of bark, bark renewal etc. (Samsidar *et al*, 1976). Constable (1953) reporting on the Ceylonees long term fertilizer trial using clonal material, showed that use of NPK fertilizers during the immature phase and in the early tapping years resulted in a 27% yield increase. Guha and Pushparajah (1966) obtained 22 per cent increase in yield from combined application of N, P and K in Malaysia. Beneficial effects of manuring on yield were also reported by Potty *et al* (1980), Rubber Research Institute of Sri Lanka (1988 and 1989) and Mathew *et al* (1989).

2.7.1. Nitrogen

Owen *et al* (1957) did not find significant influence of applied nitrogen on yield during the first four years. George (1963), Guha (1975), Punnoose *et al* (1976), Potty *et al* (1976) and Angkapradipta *et al* (1986) on the other hand obtained yield response to nitrogen application. Yogaratnam and Weerasurya (1984) obtained response to higher levels of N application and the response was reported to be more pronounced with time. The general nitrogen recommendation of RRII for mature rubber is 30 kg ha^{-1}.

2.7.2. Phosphorus

Owen *et al* (1957) observed response in yield to phosphorus application during the first four years. When soil phosphorus was low response in yield to added P was obtained (Punnoose *et al*, 1976). Similar results were obtained by Potty *et al* (1976) and Pushparajah *et al* (1976 a). Haines and Crother (1940) reported that the effect of phosphorus applied during immature phase continued to early years of tapping.

2.7.3. Potassium.

Reports from Malaysia and Sri Lanka indicate varying responses to applied potassium during the mature phase of rubber (Yogaratnam and Weerasuriya,1984; Rubber Research Institute of Malaya, 1971 b. Punnoose *et al* (1976) found significant yield increase with K application during the initial four years of tapping. The residual effect of K in the subsequent years also produced significant yield increase with 100 kg K_2O ha^{-1}, when soil Mg was also very high. Application of K fertilizers has been shown to be particularly important in sustaining yield (Sivanadyan *et al*,1972). Potassium is reported to increase the potassium and phosphorus level in the latex and at the same time suppressing the levels of magnesium and calcium (Pushparajah, 1969; Pushparajah *et al*, 1976 b). Philpot and Westgarth (1953) working with centrifuged latex reported that latex with high phosphorus/potassium appeared to have high mechanical stability while those with high magnesium had low stability. An increased addition of potassium in Vietnam terrarosa soil has increased the yield by increasing the P/Mg ratio in the clone, GL 1 which is high in latex Mg (Beaufils,1954). Pushparajah *et al* (1976 b) showed that application of K increased flow rate and yield. The beneficial effect of K possibly through the lowering of Mg and increase in P content or due to K increasing the stability of latex. Yip and Gomez (1984) showed that K has a direct or indirect role in reducing pre-coagulation and thus increasing flow giving higher yields which can be expected to be more stable.

2.8. Soil and leaf nutrient status.

Critical levels of nutrients have been fixed by the Rubber Research Institute of India (Pushpadas and Ahmed, 1980) for discriminatory approach in fertilizer application for rubber. Organic carbon is taken as the index of available nitrogen. A value of less than 0.75 per cent is considered low and more than 1.5 per cent as high. The available phosphorus (extracted by Bray II reagent) content ranging from 1 to 2.5 mg/100 gm soil is considered to be medium in relation to rubber nutrition. For available potassium the medium range is 5 to 12.5 mg/100 gm soil and for available magnesium the medium range is 1 to 2.5 mg/100 gm soil.

In Tripura (NE, India) application of fertilizers increased the available nutrient status of the soil which was also reflected in the leaf nutrient content (Krishnakumar and Potty, 1989).

CHAPTER III

Materials and Methods.

Agromanagement practices can regulate plant growth during various seasons. The agroclimatic condition prevailing in Tripura is not typically tropical. Rubber is known to thrive best in a tropical environment within 10° North and South of the equator. Though the climatic condition prevailing in Tripura is different from the recorded agroclimatic requirement of *Hevea*, this tree has been thriving reasonably well in Tripura during the last four decades. However analysis of the growth pattern of *Hevea* has revealed distinct growth patterns during different seasons. The present study was therefore undertaken to monitor the influence of three major nutrients on the growth of young *Hevea* plants at different growing seasons and under different moisture regimes in the agroclimatic condition of Tripura.

3.1. Site Details.

The Regional Research Station, Agartala is situated at 23° 53' North and 91 ° 15' East latitude at an altitude of 16.6 m above MSL. Experiment in the immature phase was laid out in a flat open area in the research farm of RRS. The soil in the experimental area is fine loamy, mixed hyperthermic Typic Dystrochrept (Bhattacharya *et al*, 1996) with a pH of 4.45. Initial available nutrient status of the soil showed an organic carbon content of 0.71 per cent, available content of 0.24 P, 7.13 K, 14.04 Ca and

7.24 mg^{-1} 100 gm soil. Top soil from the surface 15 cm was taken for filling the polybags. Stones and debris were removed before filling. The micrometeorological parameters observed during the period of study is shown in appendix.1.

3.2. Immature phase.

To study the influence of irrigation and nutrients on the growth of young rubber plants, an experiment was started in August 1991. Polythene bags of size 60 cm width and 90 cm length of 1000 gauge thickness was filled with soil and arranged in trenches of size 60 cm during August 1991. The soil in these bags was allowed to settle and budded stumps of rubber clone RRIM 600 were planted in these bags during October 1991.

3.2.1. Design and layout.

The experiment was laid out in a split plot factorial design with three replications. Irrigation treatment to maintain three moisture regimes was allotted to the whole plot treatment and a 3^3 NPK factorial combination of nutrient application constituted the sub-plot treatment (Fig 1). This experimental design was chosen to get information on the influence of soil moisture regime alone and also on applied nutrients and their interaction on the growth parameters of young rubber.

Fig 1. Layout of the experiment in the immature phase

(One replication)

Whole plots	(M_1)	(M_2)	(M_3)
Sub plots :	N P K	N P K	N P K
	0 0 0	0 0 0	0 0 0
	0 0 1	0 0 1	0 0 1
	0 0 2	0 0 2	0 0 2
	0 1 0	0 1 0	0 1 0
	0 1 1	0 1 1	0 1 1
	0 1 2	0 1 2	0 1 2
	0 2 0	0 2 0	0 2 0
	0 2 1	0 2 1	0 2 1
	0 2 2	0 2 2	0 2 2
	1 0 0	1 0 0	1 0 0
	1 0 1	1 0 1	1 0 1
	1 0 2	1 0 2	1 0 2
	1 1 0	1 1 0	1 1 0
	1 1 1	1 1 1	1 1 1
	1 1 2	1 1 2	1 1 2
	1 2 0	1 2 0	1 2 0
	1 2 1	1 2 1	1 2 1
	1 2 1	1 2 1	1 2 1
	2 0 0	2 0 0	2 0 0
	2 0 1	2 0 1	2 0 1
	2 0 2	2 0 2	2 0 2
	2 1 0	2 1 0	2 1 0
	2 1 1	2 1 1	2 1 1
	2 1 2	2 1 2	2 1 2
	2 2 0	2 2 0	2 2 0
	2 2 1	2 2 1	2 2 1
	2 2 2	2 2 2	2 2 2

0 - No fertilizers 1- 40 kg ha^{-1} 2- 80 kg ha^{-1}

M_1 - Moisture regime of -0.03 MPa

M_2 - Moisture regime of -0.10 MPa

M_3 - Moisture regime of -0.50 Mpa

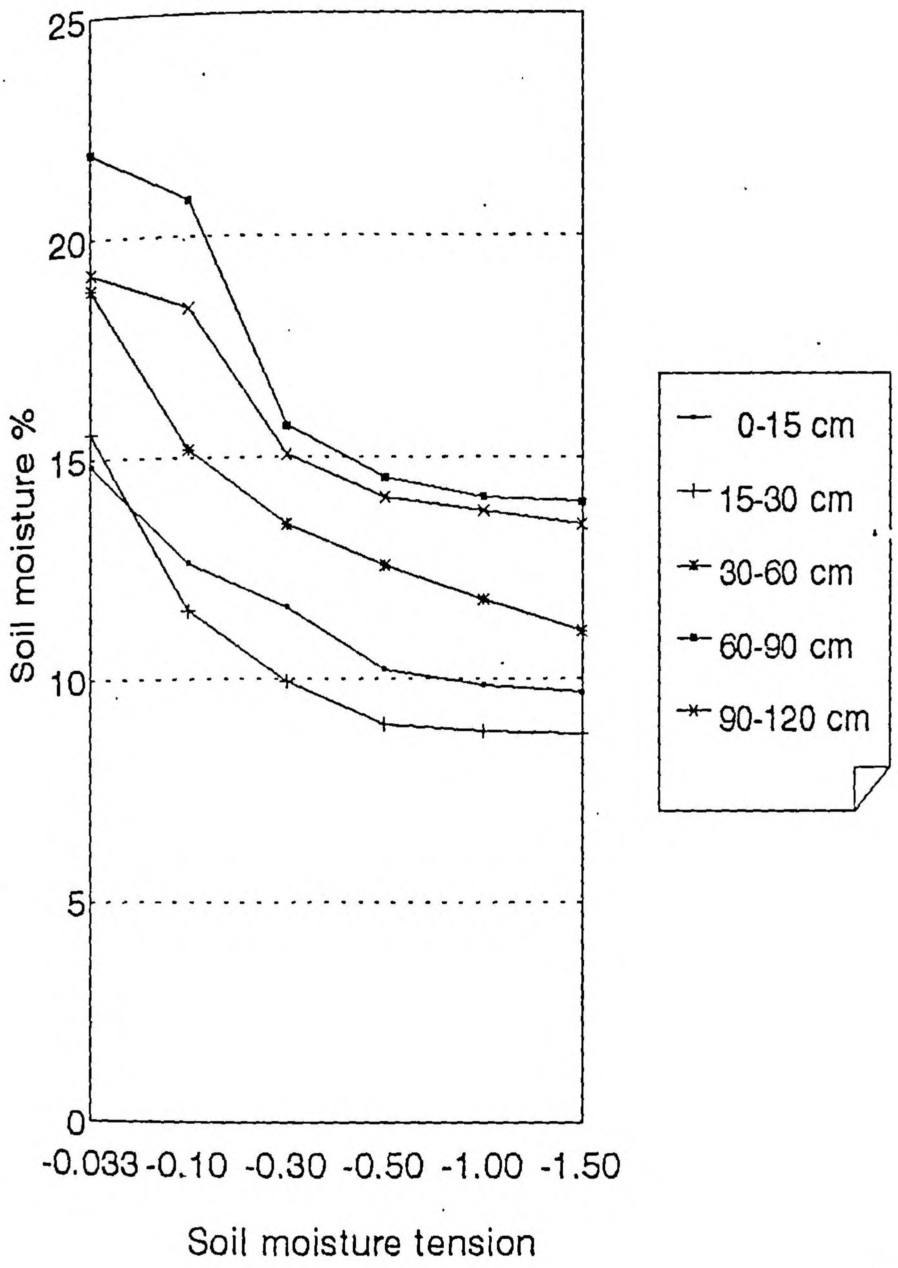


Fig 2. Soil moisture characteristic curve

3.2.2. Moisture regimes.

The three moisture regime treatments were upto -0.033, -0.033 to -0.10 and -0.033 to -0.50 MPa. A soil moisture characteristic curve was prepared using the disturbed soil (Fig. 2) and the quantum of water required to charge the polybag plants corresponding to -0.033 MPa (the field capacity) was calibrated. For maintaining the other two moisture regimes between -0.033 to -0.10 and -0.033 to -0.50 MPa the plots were allowed to deplete to -0.10 and -0.50 MPa respectively and irrigated back to -0.033 MPa . The soil moisture percentage in the treatments were monitored employing the technique of Time Domain Reflectometry (TDR) using a TRASE SYSTEM (Soil Moisture Corp. Inc. USA). Plants in the whole plots were thus subjected to alternate wetting and drying cycles.The three moisture regimes is designated as -0.033 (M_1), -0.10 (M_2) and -0.50 (M_3) MPa henceforth. Irrigation imposition in all treatments was done only during the period from October - April in 1991-92 and in the same period during 1992-93. The objective of imposing these moisture regimes were to study the influence of irrigation during the early growth phase of plants which coincides with the dry and winter period in this region.

3.2.3. Schedule of fertilizer application.

A general fertilizer recommendation has been adopted for young rubber in Tripura. This recommendation has been evolved on an adhoc basis based on early results of some nutritional trials (Krishnakumar and

Potty, 1989). In Tripura there are two distinct growth phases, one during the period from April - November which corresponds to summer and from November to April corresponding to winter. Growth of plants are reported to be influenced by the quantity of various nutrients, during various seasons. The present study envisages to monitor the influence of 3 major nutrients viz. N P and K on the growth of *Hevea* plants during the above two seasons in the three moisture regimes.

Nitrogen was supplied through urea (46 per cent N), 50 per cent of phosphorus was supplied in water soluble form (single super phosphate, 18 per cent P_2O_5) and the remaining in water insoluble form (Mussourie rock phosphate, 18 per cent P_2O_5). Potassium was supplied as muriate of potash (60 per cent K_20). The area available in polybags for applying these fertilizers was also taken into consideration while calculating the quantity of fertilizers. This aspect was considered because a larger application area is available for rubber plants grown in the field. The first application of nutrients for immature rubber is given two to three months after planting. In this experiment the first dose of fertilizers was given in November, 1 month after planting. In the 2nd year during 1992, the fertilizers were applied in 2 splits, during April and September. Fertilizer application in polybags was done in a band around the plant base and gently forked in.

3.2.4. Observations recorded.

3.2.4.1. Plant height.

Height of plants from the bud union was measured using a tape till the plants were 6 months old. Subsequent plant heights were not recorded. Height is reported in centimeter (cm).

3.2.4.2. Plant girth.

Diameter of plants from all the treatments were taken using a vernier caliper, at a height of 10 cm from the bud union. Diameter readings were then converted and reported as girth (circumference) in cm.

3.2.4.3. Whorl number.

The number of whorls which developed upto the 10th month after planting was recorded during the 6th and 10th month respectively.

3.2.4.4. Transpiration and stomatal conductance.

Recording of transpiration and stomatal conductance (g_s) was limited to nine nutrient combinations in all the three moisture regimes using a portable steady state porometer (LI COR Inc. USA) and reported in mmol m^{-2} s^{-1} . Recording time was from 8.30 am to 10.30 am, during

December and April. The period of December represents winter and April the post winter period.

3.2.4.5. Biomass estimation.

The method of Shorrocks *et al* (1965) was used in the estimation of biomass

$W = 0.002604\ G^{2.7826}$ where W= shoot weight and G= girth in cm.

3.2.4.6. Relative growth rate (RGR)

RGR was worked out using the natural logarithm of biomass values. Ln biomass 2 - Ln biomass 1 (kg $season^{-1}$)

3.2.4.7. Root biomass.

To study the influence of different moisture and nutrient treatments on the root biomass, plants from 18 nutrient combinations and 2 moisture regimes were taken for sampling. After the above ground portion of the selected plants were cut back, the bags containing the roots were dug out from the trenches and apportioned into 3 equal parts to study the root biomass. Roots from each of these soil strata was carefully extracted by wet sieving. These were then owen dried and the dry weight (g) recorded.

3.2.5. Analysis of soil and plant.

3.2.5.1. Soil.

Soil taken for filling the polybags were subjected to chemical analysis to determine the initial soil fertility status. Organic carbon was determined by the wet digestion method of Walkley and Black (Jackson,1973). Available phosphorus in soils was determined colorimetrically using Bray II reagent (Bray and Kurtz,1945). The available potassium, calcium and magnesium was determined after extraction with Morgans reagent, and read in a zeeman polaroid atomic absorption spectrophotometer (Hitachi), the procedure used by Rubber Research Institute of India (Karthikakuttyamma , 1989).

3.2.5.2. Leaf and bark.

To study the uptake of nutrients at various moisture and nutrient regimes, foliar analysis was carried out for major nutrients *viz.* N, P, K, Ca and Mg. The assessment of nutrient requirement through leaf analysis was reported by Chapman (1941), Beaufils (1955) and Shorrocks (1961). Basal leaves from the terminal whorl were selected for analysis. Bark samples taken from selected treatments were also taken and processed as per standard procedure (Karthikakuttyamma, 1989). Nitrogen was estimated by the Microkjeldhal method. Phosphorus, potassium, calcium and magnesium by method adopted by RRII as described by Karthikakuttyamma(1989).

3.2.6. Statistical analysis

The data collected from the immature phase on plant height, girth, biomass, RGR and leaf nutrients were analyzed statistically using the analysis of variance for 3^3 factorial split plot and the significance tested by the F-test (Cochran and Cox, 1965). The Least Significant Difference (LSD) was worked out for mean separation at the appropriate level of probability where F-test was significant. LSD values was not worked out in cases where the F test was not significant. Data on transpiration, stomatal conductance (g_s), root biomass and bark nutrients were done on selected treatment combinations taken in a split plot design. The analysis of variance was done for split plot and mean separation carried out using LSD when the F-test was significant. Growth and meteorological parameters were subjected to correlation analysis. The statistical analysis was done on a PC (Pentium, Acer) using the MSTAT package (Michigan State University, USA).

3.3. Mature phase

Yielding pattern of *Hevea* has been observed to be closely associated with agroclimatic conditions. During winter when the temperature drops, it has been observed that the dry rubber content (DRC) decreases and that there is a prolonged flow. This is a result of various stress factors acting on the trees. Latex flow is governed by soil moisture and nutrients, particularly phosphorus, potassium and magnesium along with other factors. The present study was therefore taken up with a view to monitor the influence of irrigation and fertilizer doses on yield and yield components of rubber. A field experiment was laid out in an existing nine year planting at the Regional Research Station , Agartala of the RRII.

3.3.1. Experimental details

Though rainfall in Tripura is adequate to meet the water requirement of *Hevea* on an annual basis, the distribution pattern leaves a period of around five months of dry period from November - April. This coincides with the winter period when trees are under cold as well as water stress. Occurrence of water deficit in N.E. India has already been reported (Saseendran *et al*, 1993). During cold stress, the trees respond by dilution of DRC during tapping and latex continues to flow even after the usual plugging period. Plugging is related to the ionic balance and nutrient concentrations.

An experiment was therefore started during October 1991 to study the role of irrigation in conjunction with nutrients to mitigate soil moisture and winter stress. The experiment was laid out in a nine year old rubber planting having clone RRIM 600 in a split plot design. The whole plot consisted of eight treatments involving two irrigation regimes viz.,

I_1- With irrigation and

I_0- Without irrigation

and four nutrient combinations viz.

NPK_0 - No fertilizer application

NPK_1- NPK at 30 kg ha^{-1}

NPK_2- NPK at 40 kg ha^{-1}

NPK_3- NPK at 80 kg ha^{-1}

The treatment combination were as detailed below.

(1) I_1 N_0 (2) I_1 NPK_1 (3) I_1 NPK_2 (4) I_1 NPK_3

(5) I_0 N_0 (6) I_0 NPK_1 (7) I_0 NPK_2 (8) I_0 NPK_3

The sub plot treatments were ten months starting from January 1992. viz.,

(1) Jan '92	(2) Feb '92	(3) Mar'92	(4) Sep'92
(5) Oct '92	(6) Nov '92	(7) Dec'92	(8) Jan'93
(9) Feb '93	(10)Mar '93		

Months were taken as the sub plot treatment to study the influence of irrigation and nutrients during different months. Each plot consisted of 20 trees with 6 net trees on which yield recordings were made. The experiment was replicated twice.

In the irrigation treatment plots, irrigation was given to charge the root zone depth of 15 cm to -0.033 MPa moisture potential. 240 l water per tree was found adequate to meet the field capacity requirement of the soil. Soil moisture at the end of the fortnight was found to be depleted to -0.10 MPa before the next irrigation. In the irrigated plots the soil moisture was was thus in the range of -0.03 to -0.10 MPa. Water was applied in the inter-row spaces.

The general fertilizer recommendation for mature rubber in Tripura is 35 kg NPK ha^{-1}. Nutrient doses higher than the general

Fig 1a LAYOUT OF EXPERIMENT IN MATURE PHASE

WHOLE PLOTS

R I	I_1NPK_1	I_1NPK_0	I_0NPK_0	I_1NPK_2	I_0NPK_3	I_1NPK_3	I_0NPK_1	I_0NPK_2
R II	I_0NPK_0	I_1NPK_2	I_0NPK_1	I_1NPK_2	I_1NPK_0	I_0NPK_1	I_1NPK_3	I_0NPK_3

SUB PLOTS ; MONTHS

JAN	NOV
FEB	DEC
APR	JAN
SEP	FEB
OCT	MAR

DESIGN : SPLIT PLOT

recommendation was considered in this experiment to know if higher nutrition under irrigated and unirrigated condition has a regulatory influence on latex flow during winter. The first nutrient imposition was in October 1991 when the total annual application was given in a single dose. During 1992 the nutrients as per treatment was given in 2 split doses, the first in April and the second in August 1992. The experiment was continued upto March 1993. Layout of the experiment is given in fig 1(b).

3.3.2. Observations.

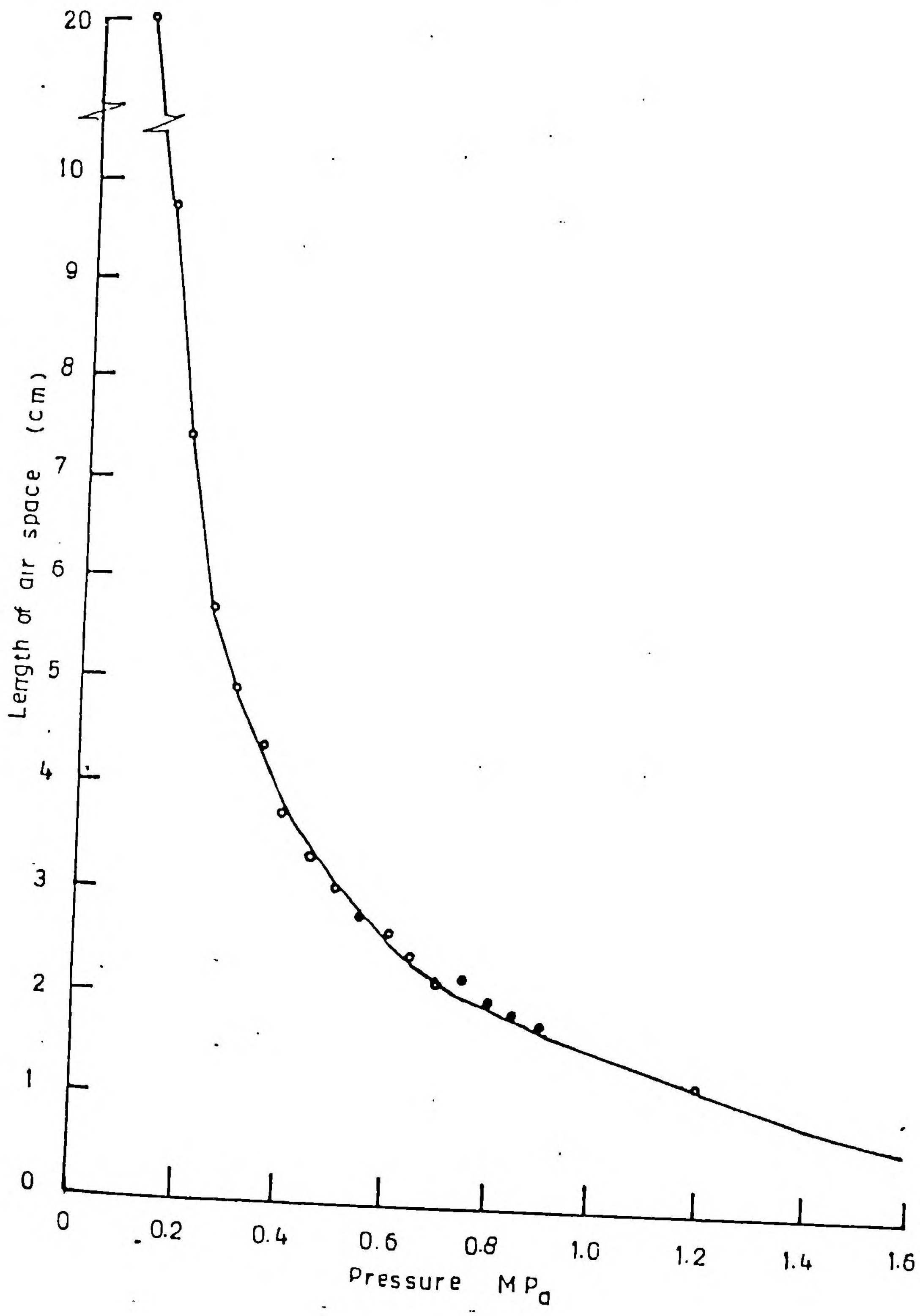
3.3.2.1. Soil available nutrients.

Available nutrients in the soil both in the pre and post treatment period was sampled and analyzed. Analysis of organic carbon, phosphorus, potassium, calcium and magnesium was done using the methods described earlier (Jackson,1973).

3.3.2.2. Tree Girth and length of tapping cut.

Tree girth (circumference) was measured periodically at a height of 150 cm above the bud union using a tape. The length of tapping panel was also measured for assessing the mean flow per unit length of cut.

Fig. 3 Minimanometer callibration curve



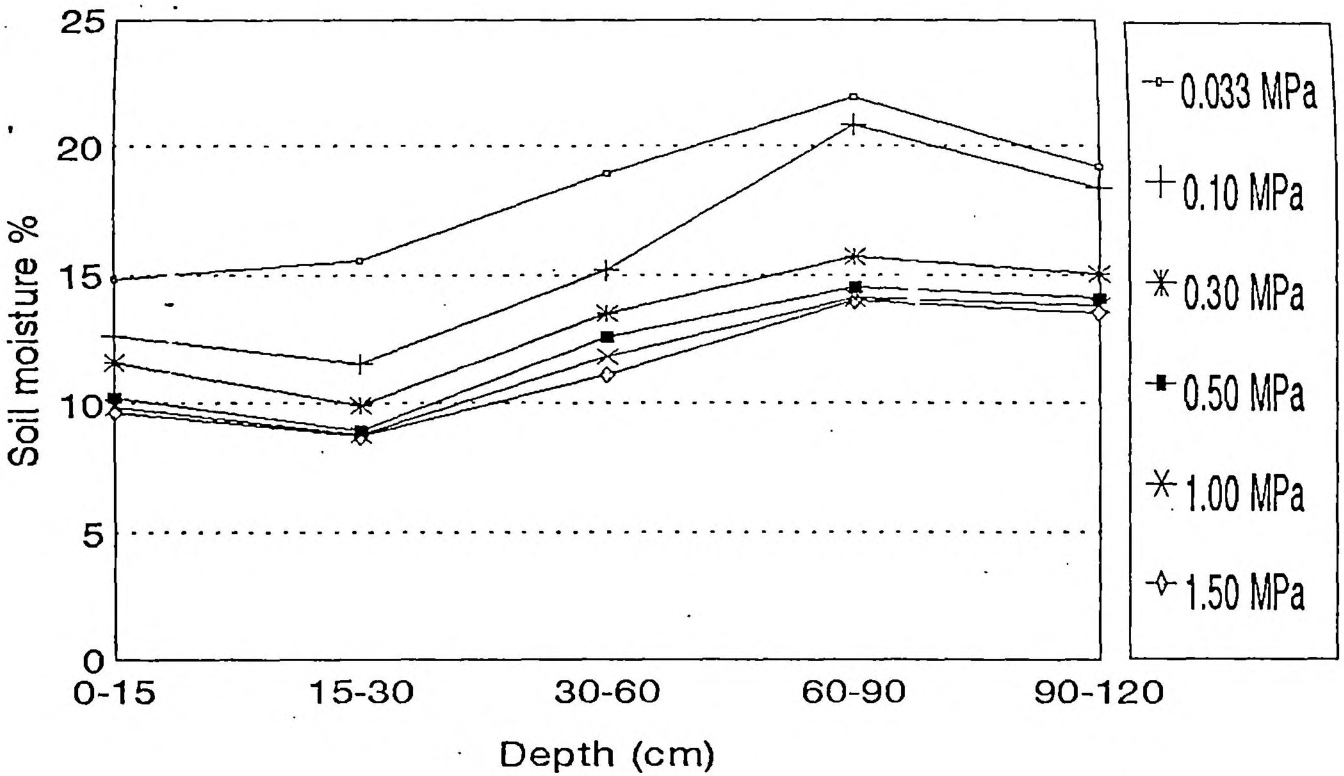


Fig 4.Soil moisture distribution pattern depth wise

3.3.2.3. Soil moisture status.

Soil moisture was estimated by the gravimetric method. Soil moisture tension was estimated from a characteristic curve prepared using pressure plate apparatus (Richards, 1949) and soil moisture distribution pattern at various depths was ascertained (Fig. 4). Soil moisture tension in the unirrigated plots was in the range of 0.09 to 0.87 MPa and in the irrigated in the range of 0.03 to 0.10 MPa during Oct-Apr.

3.3.2.4. Meteorological parameters.

Daily recordings of the meteorological parameters viz. Temperature (max. and min.), relative humidity, sunshine duration, pan evaporation and rainfall was obtained from the agrometeorology station of RRS, Agartala. The mean monthly and weekly data was calculated.

3.3.2.5. Yield and yield components.

Yield and yield components were recorded on the 6 net trees from each plot at fortnightly intervals. Total latex volume, the dry rubber content and plugging index were recorded from January 1991 to March 1992. Dry rubber content was determined by taking a small quantity of fresh latex, weighing it and then coagulating it with 1 % formic acid. The coagulum was then squeezed to separate the rubber which was dried at 70° c. The DRC is then expressed in percentage (w/w). Plugging index was calculated as per the formula of Milford *et al* (1969).

$$PI = \frac{\text{Mean flow within the first 5 minute (ml min}^{-1})}{\text{Total latex yield (ml)}} \times 100$$

The turgor pressure of latex vessels was monitored following the method outlined by Raghavendra *et al* (1984). Disposable mini manometers made of 21 gauge syringe needles ground at the tip attached to no 48 surgical poythene tubing which were sealed (the total length of the manometer was 20 cm) were used. The length of air space trapped was calibrated against known pressures (Fig 3). By measuring the air space the turgor was determined.

The latex potassium, calcium and magnesium were determined as follows. To 5 gm total solid (dried latex) HNO_3 was added to wet the sample and ashed at 555° C for 3 hours. The ash was digested in a waterbath with 1 ml HNO_3 and 5 ml distilled water for 30 min. and the contents transferred to a 100 ml volumetric flask and the volume made up. Calcium and magnesium in the extract was determined by Atomic Absorption Spectrophotometer and potassium by flamephotometer by ISI method for test of NR (ISI, 1966).

Total soluble sugars was estimated by the method of Scott and Melvin (1953). About 1 gm of latex was extracted with 2.5 per cent TCA and made upto a known volume. Aliquots were used for the estimation of sugar. 2 gm anthrone was dissolved in a litre of concentrated H_2SO_4. 1ml of the TCA extract was evaporated to dryness in a water bath. 1 ml of water was added and the tubes were kept in an ice bath. 4 ml of anthrone reagent was added and the tubes were kept in an ice bath. 4 ml of anthrone reagent was added and the tubes were kept in an ice bath for 10 min. The tubes were shaken well, heated in boiling water for 10 min. and cooled. The optical density was measured at 620 nm.

Inorganic phosphorus was determined by the method of Taussky and Shorr (1953). Reagents - Sulpho-molybdenum solution- 10 per cent. At the time of analysis, 5 gm of ferrous sulphate and 10 ml of sulphomolybdic solution were mixed in a 100 ml volumetric flask and the volume made upto 100 ml with distilled water. 0.2 ml of the latex extract prepared was pipetted and the volume made upto 2 ml with 2.5 per cent TCA. 2 ml of sulphomolybdic acid reagent was then added and the absorbance measured at 740 nm using potassium dihydrogen orthophosphate as standard.

To closely monitor the yield during winter, weekly yield was collected during Jan, Feb. and Mar '93. The weekly yield represents mean yield obtained from 2 tappings in a week.

3.4. Statistical analysis.

The data on yield and yield components were analyzed using the analysis of variance for the split plot design (Snedecor and Cochran, 1968). Mean separation when F-test was significant was done using LSD. The statistical analysis was done on a PC (Pentium, Acer) using the MSTAT package (Michigan State University, USA). To study the interrelationship of yield, its components and meteorological parameters, a path coefficient analysis was performed (Singh and Choudhury, 1985).

CHAPTER IV

RESULTS AND DISCUSSION

4.1. Effect of moisture regimes on plant parameters and physiological functions: Immature phase.

4.1.1. Plant height.

The height of plants under various moisture regimes is given in Table 1. There was significant difference in the height of plants with moisture regimes, both at 3 and 6 months after planting corresponding to winter and post winter period. During the winter period from Oct-Jan, plants growing in moisture regime of -0.033 MPa (M1) recorded a significantly higher plant height than those growing in the lower moisture regimes. The plants growing in M_1 moisture had 13.81 % and 18.76 per cent more height than the plants growing respectively in -0.10 MPa (M_2) moisture regime -0.50 MPa (M_3) moisture regime. The relative increase in plant height was observed to be greater during the winter period than during post-winter period. During winter the plant height at M_3 moisture regime was 18.76 % more as compared to 12.75 % during the post-winter period in M_1. Plant height in moisture regimes of M_2 and M_3 were on par, 3 and 6 months after planting . The impact of irrigation on plant height was conspicuous in the 10 th month after planting. Irrigation treatment was discontinued in April'92 and the plots started receiving monsoon rain thereafter. This may be the reason why plant height was on par in the three moisture regimes.

Table 1. Effect of moisture regimes on plant height (cm)

Moisture regime (MPa)	January 3	April 6	August 10
	(Months after planting)		
- 0.033 (M1)	54.52	78.38	183.76
- 0.10 (M2)	46.99	72.94	176.96
- 0.50 (M3)	44.29	68.39	166.61
LSD(P=0.01)	4.75	5.92	ns

Table 2. Influence of moisture regimes on plant girth (cm)

Moisture regimes (MPa)	Jan 3	Apr 6	Aug 10	Oct 12	Dec 14	Apr 18
			(Months after planting)			
-0.03 (M1)	2.21	2.74	4.95	6.96	8.35	10.15
-0.10 (M2)	1.99	2.58	4.87	6.85	7.94	8.54
-0.50 (M3)	1.83	2.42	4.46	6.37	7.31	7.80
LSD(P=0.05)	0.22	0.17	ns	ns	0.56	0.16

There was an overall advantage in plant height in the high soil moisture regime (M_1). The height increment was more during April to August than during January to April in all the three moisture regimes, with the highest increment in M_1 plots. It is possible that during its early growth stages, *Hevea* plants follow a rhythmic growth pattern whereby rapid shoot elongation periods are separated by rest or stagnant periods. This may be the reason for a decreased growth rate during the period from winter to post winter. Though moisture status may not be the only limiting factor for plant growth in this region, adequate soil moisture during low growth period is important. The result obtained in the study are in conformity with the findings of Haridas (1980) on the height increase of young *Hevea* plants in Malaysia.

4.1.2. Plant Girth.

The influence of irrigation on plant girth was evident three months after planting when the plants grown in moisture regime of M_1 registered nearly 18 per cent higher girth compared to those grown in M_3 (Table 2). The girth of plants continued to be significantly higher in the higher moisture plots 6 months after planting. The impact of irrigation in terms of girth increment during the early growth phase is observed to be more prominent during the winter period than in the post winter period in the first year. Growth of plants in the wet season (Aug - Oct) that followed, was non significant. When the moisture regime was re-imposed from October in the second year of planting, plants grown in M_1 moisture registered a 10 per cent increase in girth than those in M_3 moisture. Plants in the M_1 moisture regime 18 months after planting showed 23 per cent increase in girth over the plants grown in M_3 as recorded in April'93. Results clearly show that irrigation during winter and post winter period i.e. Jan to April was beneficial to plants by resulting in higher girth.

The early growth phase of plantations in Tripura coincides with the onset of winter and there is a lag phase in growth during this period. Irrigation overcomes the stress experienced during the winter period which coincides with low soil moisture and helps the plants to maintain a steady growth rate during this period. Results indicate that irrigation during winter helps to mitigate stress factors to a certain extent during the early immature phase of Hevea. This could help in achieving a uniform growth rate besides maintaining a higher growth rate, which would help in attaining tappable girth early. In areas where rubber is grown and where moisture deficit exists in summer months, irrigation has been reported to help the plants attain a faster growth rate. (Jessy *et al*.1994; Chandrashekar *et al*,1994)

4.1.3. Number of Whorls.

The influence of irrigation during the early growth period of six months after planting, though not significant, provided the plants with a higher number of whorls in the M_1 moisture plots (Table3). In the wet season following it, the plants, ten months after planting, growing in M_1 have maintained a higher growth rate as evidenced by a higher number of whorls. A higher number of whorls in the pre winter season would ensure that these plants by virtue of having higher total leaf area will have a better photosynthetic activity which could promote a better growth rate

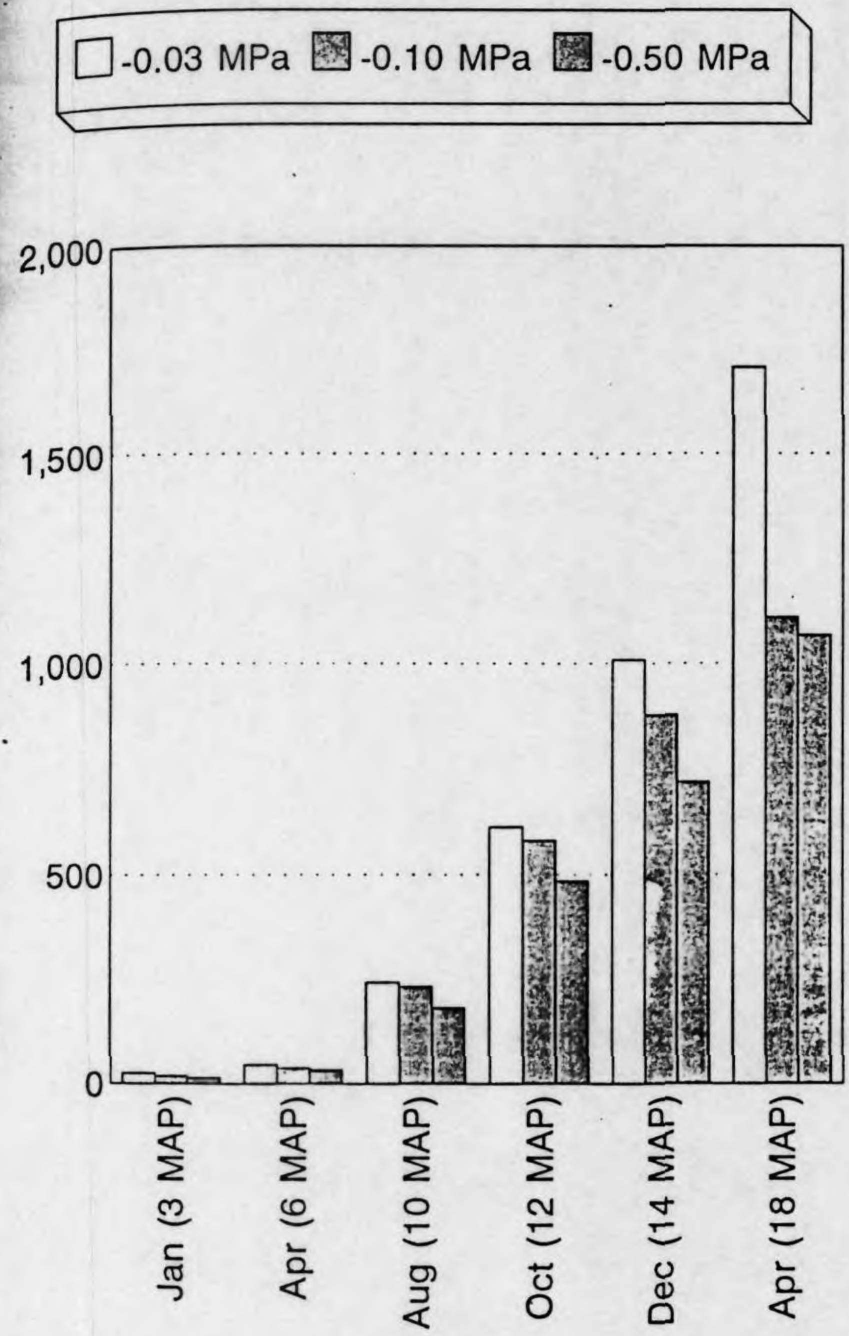


Fig.5. Influence of moisture regimes on biomass of plants (g/plant)

during winter that could follow. Increase in the number of whorls with irrigation was reported from Kerala. (Jessy *et al*,1996).

4.1.4. Biomass.

Biomass data showed that during the early months, after the planting in winter, higher moisture regimes significantly enhanced biomass production (Fig. 5). The trend continued up to April, the post winter period. This is in conformity with the findings of Madeira and Pereira (1990/91) and Gupta *et al* (1996) who showed that irrigation during dry season increased biomass production in the early growth stages. No significant difference in biomass was observed in the rainy season (Aug-Oct) between the moisture regimes. During December, in the winter phase again, higher moisture regimes helped in higher biomass accumulation. The production of biomass at the end of April, 18 months after planting also showed a significant increase. Biomass increment during different seasons is shown in Fig. 6. Though biomass increment was observed to be higher in M_1 plots, the influence of soil moisture in consolidating the biomass of plants was significant during the period from Nov-Dec'92 and Jan-Apr'93. The information that plants growing in M_3 produced a comparable biomass as that of plants in M_2 by the end of the year, could be usefully exploited under field conditions during dry spells when water supply is limited.

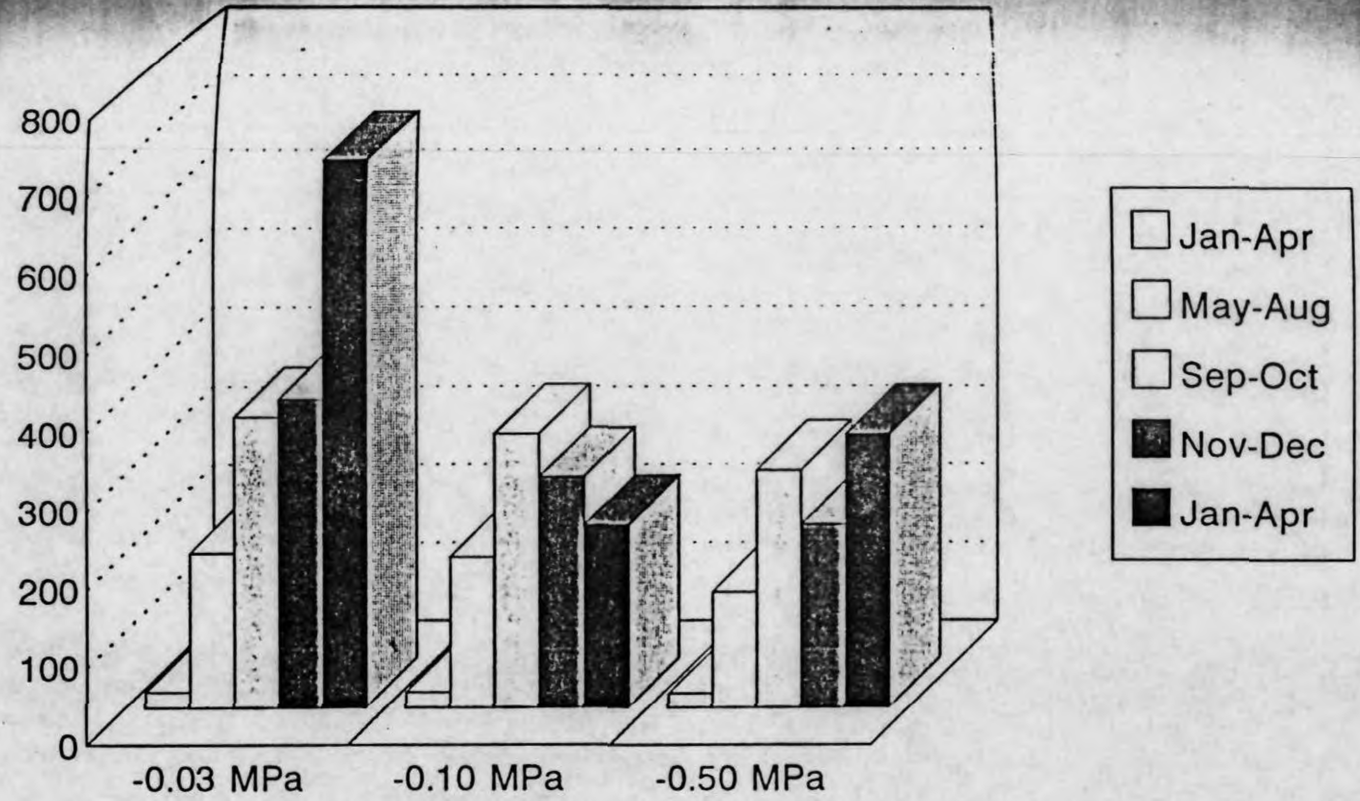


Fig.6. Influence of moisture regimes on biomass increment of young rubber

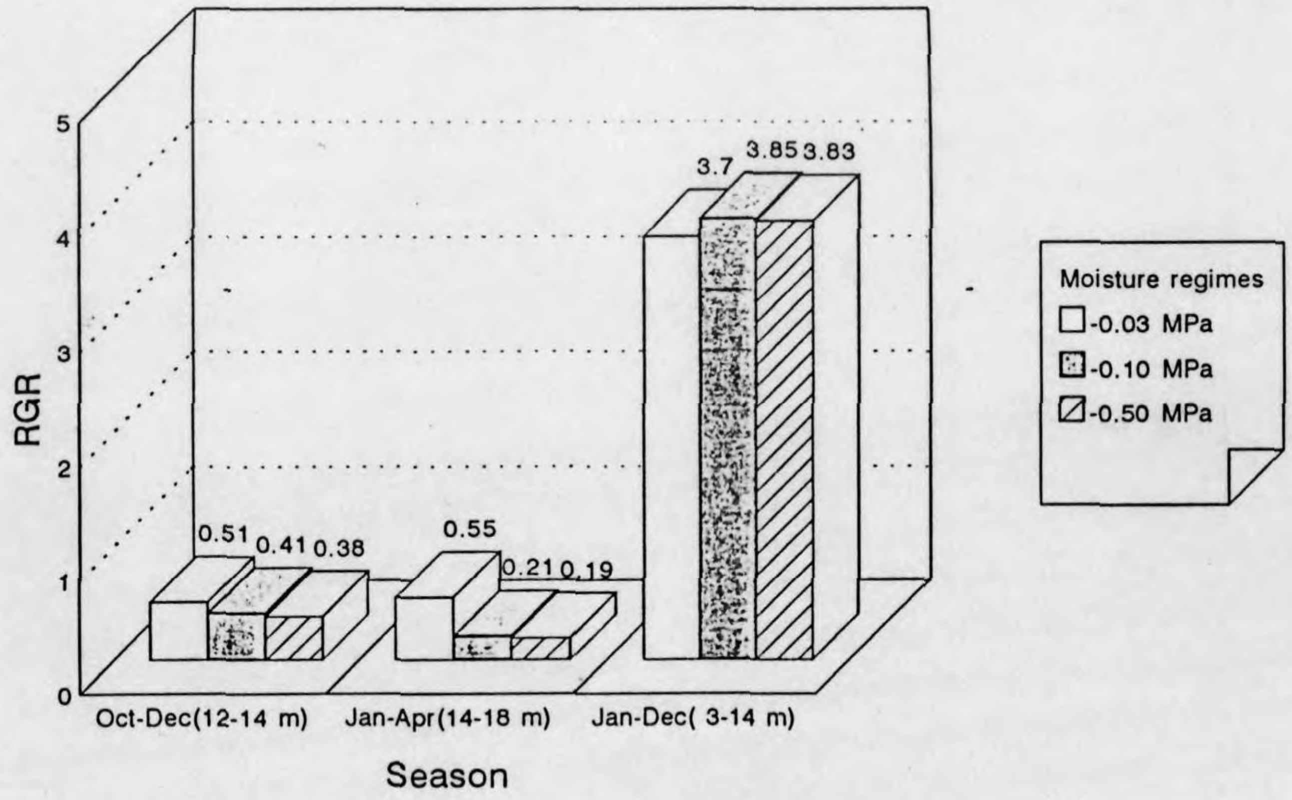


Fig.7.Influence of moisture regimes on RGR (kg/season)

4.1.5. Relative Growth Rate (RGR)

During the early phase of growth i.e. 3 to 6 months after planting, the moisture regimes could not influence the RGR (Fig. 7). However, after 12 months the RGR was higher for the plants maintained at M_1. A significant impact of irrigation was seen only during December to April, the period when there is a soil moisture deficit. This period encounters stresses of two kinds, namely, low temperature and soil moisture deficit resulting in the lowest growth rate of plants. Irrigation provided prior to the onset of this stress period has been observed to help the plants in mitigating the stress as manifested by a higher biomass content. Though the influence of moisture was not significant on the RGR taking the growth rate on an annual basis, a higher RGR was observed at M_1 moisture regime during October to April. This period could be critically important to young rubber grown in Tripura and could be exploited under field conditions by irrigating only during this period to ensure a modest growth rate.

There are reports of reduced growth of young rubber under soil moisture deficit conditions from many rubber growing countries (Omont, 1982 ; Saengruksowong *et al*, 1983; Pushparajah and Haridas, 1977; Chandrashekar *et al*, 1994). Increasing the moisture availability to plants by irrigation and other conservation techniques have shown that problems of initial establishment, growth retardation and low yield can be controlled to some extent (Pushparajah and Haridas, 1977; Vijayakumar *et al*, 1988). Maintaining a higher RGR during the winter when rate of growth is minimum is important as this would help the plants in

Table 3. Effect of moisture regimes on whorl number

Moisture regimes (MPa)	April 6	August 10
	(Months after planting)	
-0.03 (M1)	3.01	5.88
-0.10 (M2)	2.74	5.25
-0.50 (M3)	2.31	5.20
LSD(P=0.01)	ns	0.36

Table 4. Effect of moisture regimes on transpiration and stomatal conductance (mmol m^{-2} sec^{-1}) .

Moisture regime (MPa)	December (14 MAP)		April (18 MAP)	
	TR	g_s	TR	g_s
-0.03 (M1)	2.00	99.58	3.28	190.29
-0.10 (M2)	1.48	79.34	2.89	162.08
-0.50 (M3)	0.96	71.73	2.58	117.63
LSD(P=0.05)	0.73	14.58	0.68	29.92

MAP - Months after planting. TR- Transpiration
g_s - Stomatal conductance

maintaining a higher growth rate during the subsequent seasons thereby helping in achieving an overall higher growth rate. Such a growth pattern has been reported by Chandrashekar *et al* (1994) during dry and wet seasons in the non traditional rubber region viz., Konkan in Western India.

4.1.6. Transpiration.

Transpiration was recorded during the dry months (Table 4). During December '92 , 14 months after planting a significantly higher rate of transpiration was noticed in M_1 compared to M_3 moisture regime. Transpiration in the M_2 regime was also high. Soil moisture has a definite influence on transpiration during winter as could be seen from the higher transpiration of plants maintained at high soil moisture regime. While transpiration was on par in M_1 and M_2 moisture regimes, it dropped significantly in the M_3 moisture regime. This suggests that M_2 and M_3 moisture regime is of significance to plant growth.

Transpiration was 26 per cent less in soil moisture tension of M_2 than in M_1 during winter, while the reduction was only 11.89 per cent at the same soil moisture tension in the post winter period. A 108 per cent reduction in transpiration was observed in M_3 during the winter period compared to M_1, the corresponding percentage reduction in transpiration in this moisture regime during the post winter period was only 21 per cent. Transpiration in winter phase was about half that in post winter phase for both M_1 and M_2 moisture regime, the reduction, however was not statistically significant. The reduction in transpiration during winter and post winter period in the M_3 moisture regime compared to M_1 was significant. The data suggest that transpiration is regulated by soil moisture deficit during winter and post winter periods. The extent of reduction in transpiration is also influenced by the soil moisture tensions. It can be inferred that the plants suffer a greater degree of stress at M_3 during winter period than in the post winter period. The effect of water availability on growth when investigated showed that leaf water potential, relative water content and canopy transpiration were reduced with increasing soil water stress (Ismail *et al*, 1994).

4.1.7. Stomatal conductance (g_s).

Data on the influence of moisture regimes on stomatal conductance is given in Table 4. In M_1 the g_s during winter was significantly higher than that in M_2 moisture regime. During December i.e. peak winter period, there was no significant difference in g_s between M_2 and M_3. During April i.e. the recording after winter period, a comparison of g_s between three moisture regimes showed that g_s is highest in M_1 followed by M_2 and M_3 and the variation was significant. Stomatal conductance in M_1 was significantly higher than that in M_2 and that in M_2 was higher than that in M_3; while g_s in M_1 and M_2 varied significantly in December, the variation was not significant in April. At higher moisture tension during winter, the g_s presumably got adjusted by stomatal regulation. The decrease in g_s from M_2 to a higher soil moisture tension level of M_3 was not significant during December but when the moisture level dropped from M_1 to M_2 the g_s decreased significantly. Stomatal conductance is a physiological parameter which indicates the plant water status in relation to its growing environment. Non significant variation of

g_s between M_2 and M_3 range suggest that plants can tide over winter period even at a higher soil moisture tension. Maintenance of a higher soil moisture tension of M_3 would be adequate to meet the water requirement. Unlike in annual crops boundary layer conditions change frequently in tree crops due to canopy movement brought about by change in wind speed. Therefore g_s to a great extent in tree crops like rubber will be influenced by the atmospheric conditions also. During winter the air turbulence can be expected to be lower than that during the post winter period and a relatively low g_s obtained during winter in the present study can be attributed to this.

The g_s during April in the three soil moisture regimes revealed that there was a significant reduction in the g_s as the soil moisture tension increased from M_1 to M_3 and from M_2 to M_3. It can be said that in the post winter period a moisture range of M_2 appears to be of significance. Stomata play a significant role in water conservation, and soil moisture deficit can influence stomatal closure even though leaf water potential do not change significantly. (Mansfield *et al*, 1990). There are reports which consider the deleterious effect of water stress on photosynthesis to be indirect, the primary effect being stomatal closure (Jones, 1985 ; Cornice *et al*, 1987). Stomatal conductance is a phenomenon directly related to the opening of stomatal aperture. This indirectly has a bearing on growth as it results in an intake of carbon dioxide. Maintenance of higher moisture level during post winter period therefore is expected to maintain a higher g_s and consequently a better photosynthetic activity. Photosynthetic inhibition during water stress has been reported (Kaiser, 1984 ; Leegood *et al*, 1985).

4.1.8. Effect of moisture regimes on plants in the immature phase.

Irrigation provided to maintain higher soil moisture availability has been observed to influence all the growth parameters as well as the physiological parameters namely, transpiration and g_s recorded during the study in the immature period of *Hevea*. The observation on biomass has revealed that the moisture regime of M_1 has helped in a significantly higher biomass build up than at M_2 and M_3 but there was no significant difference in biomass increment between M_2 and M_3 moisture regimes. This trend was observed in the second year post winter season also. In the case of g_s also a similar trend was observed. The data on all the parameters studied indicated that M_1 provided the best growing environment with respect to moisture for *Hevea* irrespective of the season. However, a distinct difference in growth pattern at higher soil moisture tensions of M_2 and M_3 in the two seasons was noticed. Moisture management practices, distinctly different, may therefore be necessary during winter and pre / post winter period. Cost benefit and critical moisture levels need to be looked into for which further studies are necessary.

Table 5. Effect of applied nutrients on plant height (cm)

Treatments (nutrients kg ha^{-1})	(Jan'92) 3 MAP	(Apr'92) 6MAP	(Aug'92) 10MAP
N_0	47.88	71.97	179.81
N_1	48.40	74.57	192.35
N_2	49.52	73.17	155.18
F ratio	ns	ns	**
P_0	49.74	73.71	164.78
P_1	47.03	73.01	176.97
P_2	49.03	72.99	185.58
F ratio	ns	ns	**
K_0	49.50	72.12	178.27
K_1	47.46	73.15	186.59
K_2	48.84	74.44	162.47
F ratio	ns	ns	**
LSD (N,P,K)	-	-	17.06

MAP- Months after planting

** - Significant at 1 % level

N, P, K: 0- No fertilizer, 1- 40 kg ha^{-1}, 2- 80 kg ha^{-1}

Table 6.
Effect of applied nutrients on periodic girth of plants (cm)

Treatments (nutrients kg ha^{-1})	(Jan'92) 3	(Apr'92) 6	(Aug'92) 10	(Oct'92) 12	(Dec'92) 14	(Apr'93) 18
	(Months after planting)					
N_0	1.99	2.54	4.86	6.86	7.90	8.82
N_1	2.05	2.62	5.06	7.07	8.29	9.29
N_2	2.06	2.58	4.36	6.26	7.42	8.38
F ratio	ns	ns	**	**	**	**
P_0	1.99	2.56	4.44	6.47	7.54	8.54
P_1	2.01	2.59	4.81	6.72	7.89	8.93
P_2	2.03	2.58	5.03	7.01	8.17	9.03
F ratio	ns	ns	**	**	**	*
K_0	2.02	2.57	4.69	6.07	7.59	8.52
K_1	1.96	2.54	4.93	7.03	8.23	9.17
K_2	2.07	2.63	4.65	6.46	7.78	8.80
F ratio	ns	ns	*	**	**	**
LSD (N,P,K)						
(P=0.01)	-	-	0.32	0.40	0.47	0.47
(P=0.05)	-	-	0.24	-	-	0.36

* - Significant at 5 % level.
**- Significant at 1 % level.
N, P, K: 0- No fertilizer, 1- 40 kg ha^{-1}, 2- 80 kg ha^{-1}

4.2. Influence of nutrients on plant growth and physiological functions :Immature phase.

4.2.1. Plant height.

Nitrogen, phosphorus and potassium application did not influence the plant height up to 6 months after planting (Table 5). However nitrogen and potassium at higher levels increased the plant height, though the increase was non significant. Height of plants was significantly influenced by N, P and K addition, 10 months after planting. Plots with N at 40 kg ha^{-1} (N_1) recorded the highest plant height. This was however on par with plots where nitrogen fertilizer was not applied (N_0) . The 80 kg N plots (N_2) showed lower height than N_0. Higher dose appeared to have inhibited the growth. The height recorded in K applied plots also showed a similar trend, with height retardation observed in high K applied plot of 80 kg ha^{-1} . Plant height gained significantly with phosphorus application. Both 40 and 80 kg ha^{-1} P (P_1 and P_2) gave better height than plots without P (P_0). Phosphorus at P_1 and P_2 was on par. However the P_1 level can be considered as the optimum.

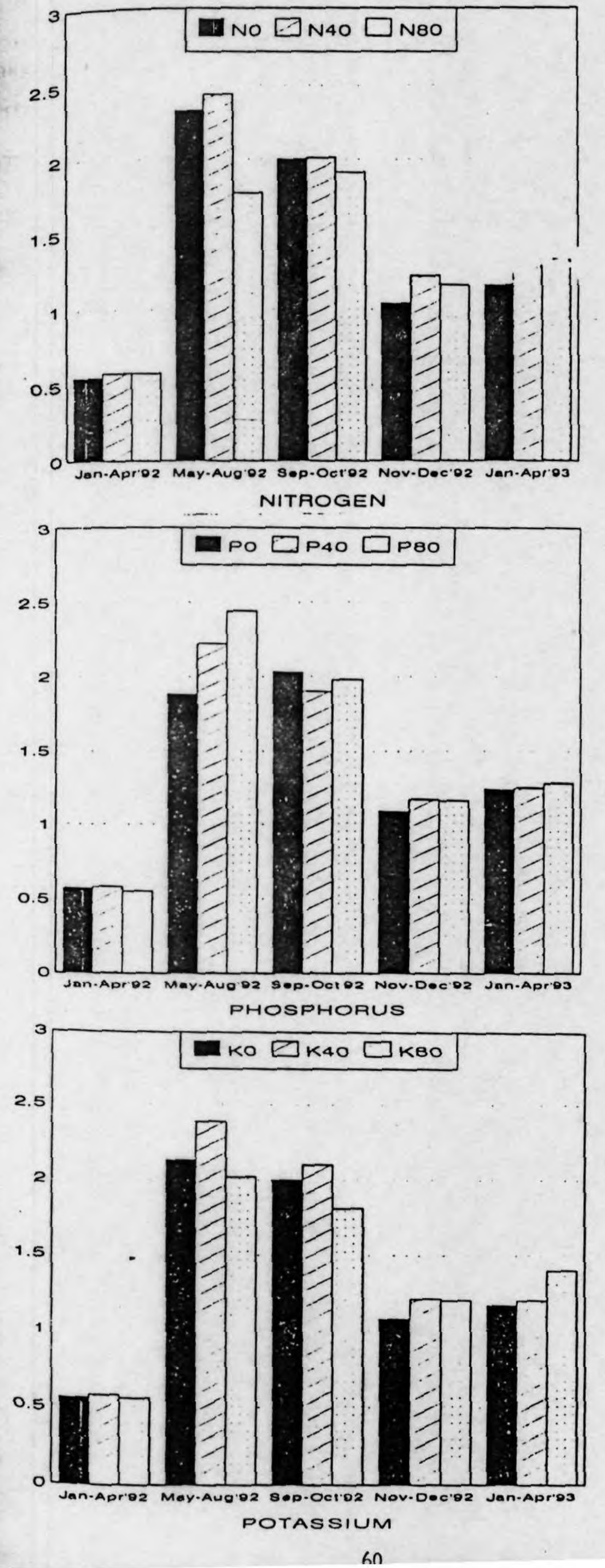
4.2.2. Plant Girth.

4.2.2.1. Nitrogen.

Plant girth recorded from 3 to 18 months after planting at different nutrient levels are given in Table 6. The intervals represent winter period (Jan and Dec), post winter period (Apr and Aug) and pre-winter (Oct). It can be seen that levels of nutrients did not have any significant effect on girth of plants during January and April i.e. up to 6 months after planting. An increase in girth in general is however seen. Lack of significant difference at higher level of N could be attributed to the early stage of plants when their root spread is not adequate for extraction of nutrients. However N addition 10 months after planting significantly influenced plant girth. N_1 gave higher girth compared to N_2. Girth in the N_1 and N_0 plots were on par. However, the increase in average girth in the N_1 plots was nearly 5 per cent over the N_0 plots during August to December. Nitrogen application of 40 kg ha^{-1} has distinctly influenced the plant girth by April'93, which was significantly different from the N_0 and N_2 plots. Nitrogen at 40 kg ha^{-1} was observed to be adequate for young rubber plants up to 18 months after planting. The independent influence of N has been observed to be the highest for N_1 level. Growth depression at N_2 irrespective of the seasons has also been observed. Growth reduction at N_2 has been significant in 10, 12, 14 and 18 months after planting. Influence of N on girth increment also showed a similar trend (Fig. 8) except during Jan-Apr'93 when girth increment was high in N_2 plots.

Influence of N on girth increment is shown in fig. 8. Nitrogen did not significantly influence girth increment from Jan'92 to Apr'92. During May'92-Aug'92, N_1 gave higher girth increment compared to N_0. A lesser girth increment in N_2 plots compared to N_0 plots was also observed. Period from Nov-Dec also showed a similar trend, though the effect of N on girth increment was non significant. However during Nov-Dec'92 both N_1 and N_2 recorded higher girth increment than N_0 plots. Highest girth increment during Jan-Apr'93 was observed in plots with N_2, though girth *per se* was lower in N_2 compared to N_1. Increase in girth

Fig.8. Effect of applied nutrients on girth increment



through addition of nitrogen has been reported by many workers (Owen *et al*, 1957 ; Kalam *et al*, 1980; Potty *et al* 1980). Pushparajah and Haridas (1977) observed depressed growth in N applied plots without K application. Improved nitrogen nutrition is reported to lower water stress in trees and increase growth (Fife and Nambiar,1995).

4.2.2.2 Phosphorus.

Phosphorus at higher levels has been observed to increase the girth in general (Table 6). Increase has been found significant at P_2 level compared to P0 plots. It has also been observed that girth increase from 10 to 18 months after planting particularly after 12 and 14 months, has been highest at P_1 level. Phosphorus is involved in various metabolic activities and also in root development. Higher levels of P would influence root proliferation and consequently a higher uptake of nutrients. Girth increment was observed to be more in P_1 and P_2 level of phosphorus application compared to P_0 except during Sept-Oct period (Fig. 8). During the post winter period of May-Aug'92 when maximum growth was observed, girth increment was significantly higher in P_1 and P_2 plots. Young *Hevea* plants have been reported to respond to phosphatic fertilizer application (George, 1963). Phosphorus requirement in the traditional region during the first year is only 10 kg and during the second year at the rate of 40 kg ha^{-1} and in N.E.India the present application rate is 40 kg ha^{-1}. The soils of Tripura are deficient in P. Need for a higher level of P is therefore evident in Tripura as shown by the response data.

4.2.2.3 Potassium.

Response of plants to added potassium started becoming significant by the tenth month after planting (Table 6). Potassium applied at 40 kg ha^{-1} (K_1), increased the girth significantly compared to 80 kg K application (K_2). By December, 14 months after planting, the K_1 and K_2 applied plots recorded significantly higher girth than K_0 plots. Potassium at K_2 level was observed to inhibit the girth.

Soils of Tripura is predominantly illitic and the available K status of these soils are not satisfactory, may be due to fixation. Krishnakumar and Potty (1989) recommended a potassium dose of 14, 25, 35 and 25 kg from the first to the fourth year. Krishnakumar *et al* (1993) suggested further work on K, taking into consideration the physico-chemical aspects and stress conditions prevailing. A high native magnesium present in the soil is known to depress the available potassium content and hence a high level of K application is necessary to maintain a satisfactory level of available K. Increase in girth has been observed in K_1 plots. Girth increment was higher in K_1 plots from Jan-Dec,92 (Fig. 8). Period from Jan'93 -Apr'93 showed higher girth increment in K_2. This period encounters low temperature during Jan and Feb and a higher girth increment observed in K_2 plots during this low growth period suggests a possible influence of K in offsetting winter effect to promote growth. Reviewing the work done in the traditional region on potassium, Punnoose and Mathew (1993) concluded that in immature rubber, benefits from K application was observed only when the soil available K was poor and that

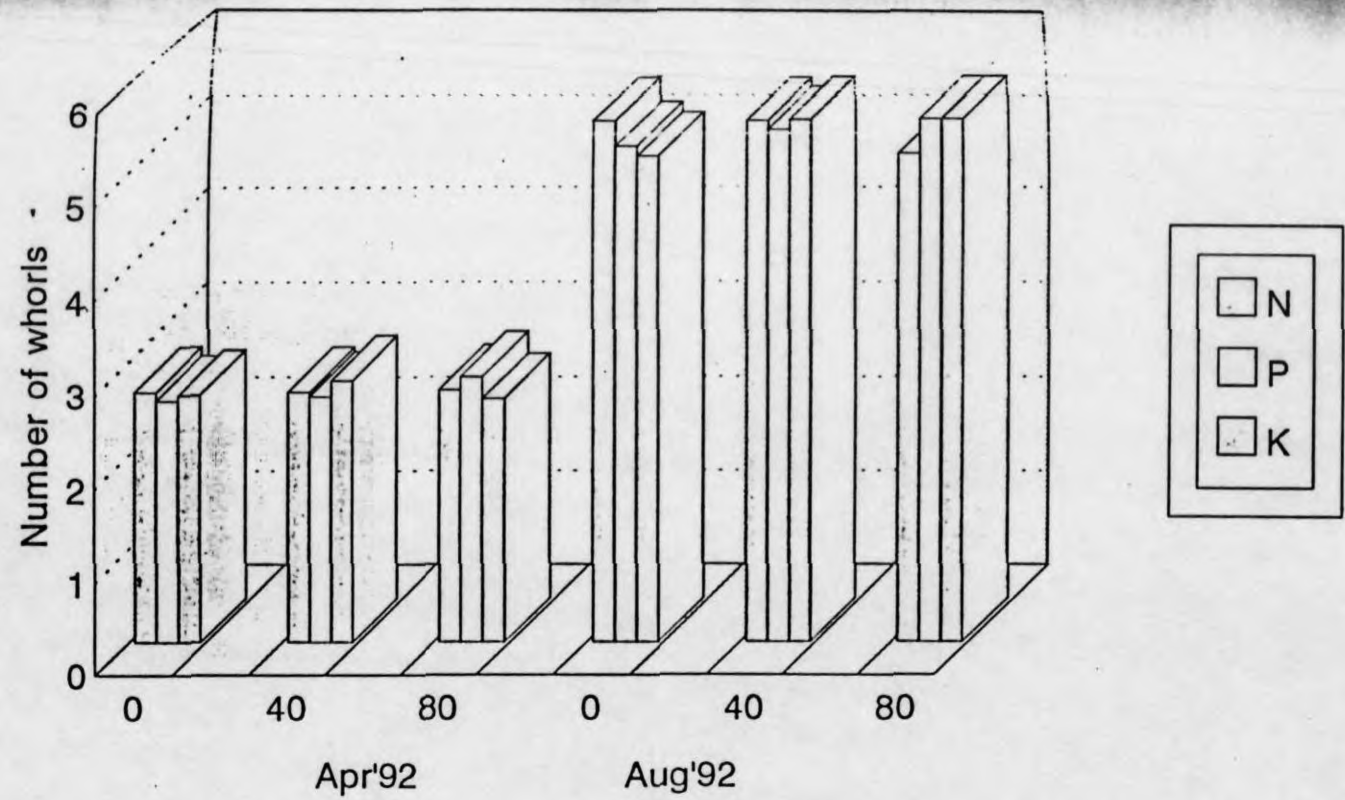


Fig.9. Effect of applied nutrients on number of whorls

indiscriminate application of K depresses growth. A similar trend as reported above was also indicated in the present study.

4.2.3. Number of whorls.

The three levels of N and K were on par but at higher levels (80 kg) there was a decline in the number of whorls. Phosphorus was found to have contributed significantly to the increase in the number of whorls (Fig. 9). At 10 months after planting N at higher levels did not increase number of whorls but a reduction was observed, the extent of reduction being significant. Regarding K there was a significant increase from K_0 to K_1 level but there was no increase in the number of whorls when K level was increased to the next higher level (K_2). The only nutrient which showed a consistent trend in influencing number of whorls with increasing dose was phosphorus. In other growth parameters also P has shown a similar trend in this study. Six months after planting, which is an initial establishment stage, is too early a stage to show a clear response. However at 10 months after planting all the three nutrients showed a clear response. Benecke and Gobl (1974) attributed increased needle length in *Pinus* to improved P availability.

4.2.4. Biomass.

There was a marked effect of nutrients on biomass production. The influence of added nitrogen on biomass was not observed till the 10 th month after planting (Table 7). Biomass in the N_1 plots though on par with N_0 plots, was higher. Biomass of plants supplied with

Table 7. Influence of added nutrients on plant biomass (g $plant^{-1}$)

Treatments (Nutrients kg ha^{-1})	(Jan'92)	(Apr'92)	(Aug'92)	(Oct'92)	(Dec'92)	(Apr'93)
	3	6	10	12	14	18
	(Months after planting)					
N_0	19.05	37.42	229.19	579.32	862.76	1199.47
N_1	20.60	40.27	253.11	635.79	993.93	1376.35
N_2	19.27	38.15	171.34	465.17	749.06	1051.45
F ratio	ns	ns	**	**	**	**
P_0	19.05	37.57	180.88	505.06	774.06	1087.72
P_1	19.54	39.71	224.72	558.08	882.27	1254.97
P_2	20.33	38.56	248.05	617.14	949.42	1284.58
F ratio	ns	ns	**	**	**	**
K_0	19.50	38.21	206.06	550.60	833.77	1090.20
K_1	18.01	36.74	236.19	623.12	975.73	1339.40
K_2	21.41	40.89	211.40	506.56	796.26	1197.67
F ratio	ns	ns	ns	**	**	**
LSD (N,P,K)	2.50	-	38.89	87.75	135.45	
163.45						

* - Significant at 5 % level.

** - Significant at 1 % level.

N, P, K: 0- No fertilizer, 1- 40 kg ha^{-1}, 2- 80 kg ha^{-1}

80 kg N was low. This trend continued during October and December. This pattern had changed 18 month after planting when 40 kg N applied plots registered significantly higher biomass than N_0 and N_2 plots. Significant retardation of biomass in the N_2 plots was seen. Phosphorus on the other hand had significantly increased the biomass of plants from the 10 th month after planting. Phosphorus at P_1 and P_2 level helped in higher biomass production than P_0. Potassium at K_1 level significantly improved biomass of plants from the 10th month after planting compared to K_0 and K_2 levels. As in the case of nitrogen, potassium at 80 kg was seen to retard biomass production. A higher level of K suppresses the effect of N, leading to a lower biomass production. Moisture stress adversely affects dry matter accumulation and yield, though this could be overcome to some extent by application of potassium. Umar *et al* (1993) found plant growth to be significantly better with K under all moisture regimes.

4.2.5. Root biomass

The production of root biomass is dependent to a large extent on soil temperature, soil water and nutrition factors (Bowen, 1980). The effect of added nutrients on the feeder root biomass in three depths irrespective of the moisture regime is shown in table 8. A higher root biomass was observed in the uppermost layer of 0-23 cm when the mean of all treatments were considered together. A mean root biomass of 12.34 g was seen in this layer, compared to 11.18 and 9.76 g respectively in the 23-46 cm and lowest layer of 46-70 cm. Reporting on the spatial distribution of roots, Philip *et al* (1997) reported a higher root length density in the top layer of 0-18 cm in a mature rubber plantation. Soong

Table 8. Effect of nutrients on biomass of feeder roots (g).

Nutrient levels N	P	K	0 - 23 cm		23 - 46 cm		46 -69 cm	
0	0	0	5.41	f	6.91	ef	7.72	d
0	0	1	12.45	bcde	8.54	def	12.15	abcd
0	0	2	9.52	cdef	10.67	cdef	15.45	ab
0	1	0	9.79	cdef	7.44	ef	6.15	d
0	1	1	11.97	bcdef	10.34	cdef	9.78	bcd
0	2	0	12.02	bcdef	5.84	f	7.07	d
0	2	1	12.68	bcd	8.18	ef	9.57	bcd
0	2	2	8.02	cdef	8.18	ef	6.71	d
1	0	0	5.72	ef	10.72	cdef	7.34	d
1	0	1	8.07	cdef	12.63	bcde	16.67	a
1	1	0	16.62	b	16.05	abc	10.57	abcd
1	1	1	28.68	a	19.27	a	9.27	bcd
1	2	0	16.93	b	12.50	bcdef	8.55	cd
1	2	1	24.02	a	18.54	ab	14.87	abc
2	0	0	7.11	def	8.37	def	7.77	d
2	2	0	11.54	bcdef	11.17	cdef	6.35	d
2	2	1	14.75	bc	14.90	abcd	7.95	d
2	2	2	6.93	def	11.09	cdef	11.69	abcd
Mean			12.34		11.18		9.76	
SE (d)			2.86		2.76		2.76	

Means followed by a common alphabet are not significantly different at the 5% level using DMRT.
N, P, K: .0- No fertilizer, 1- 40 kg ha^{-1}, 2- 80 kg ha^{-1}

Table 9.
Percent roots in moisture regime of -0.03 MPa (M_1) at depth intervals of 23, 46 and 69 cm given different nutrient doses.

NPK	Total roots (g)	Per cent roots in 0-23	23-46	46-69
000	23.85	21.4	39.2	39.4
001	47.11	36.4	26	37.6
002	38.52	26.9	37.6	35.4
010	21.50	34.0	29.7	36.3
011	27.80	30.7	40.6	28.6
020	17.65	43.6	23.5	32.9
021	31.40	30.7	28.3	40.9
022	20.65	16.0	44.3	39.7
100	25.5	14.9	51.6	33.5
101	40.66	24.0	36.1	39.9
110	47.43	41.3	32.6	26.1
111	61.48	55.0	32.4	12.6
120	47.35	47.4	25.3	27.2
121	61.80	46.2	36.8	17.0
200	25.45	33.4	38.3	28.3
220	29.21	37.9	44.7	14.4
221	42.85	40.9	42.0	17.1
222	38.27	23.1	34.6	42.3
Mean	36.03	33.5	35.9	30.5
SD	13.43	11.2	7.5	9.7

N, P, K: 0- No fertilizer, 1- 40 kg ha^{-1}, 2- 80 kg ha^{-1}

Table 10
Percent roots in moisture regime of -0.50 MPa (M_3) at depth intervals of 23, 46 and 69 cm given different nutrient doses.

NPK	Total roots (g)	Per cent roots in 0-23	23-46	46-69
000	16.24	35.2	27.6	37.2
001	19.17	40.5	25.2	34.3
002	32.74	26.5	20.9	52.6
010	25.27	48.6	33.6	17.8
011	36.37	42.3	25.8	31.9
020	32.22	50.7	23.3	26.5
021	29.47	53.3	25.3	21.4
022	25.19	50.6	28.7	20.7
100	22.09	34.6	37.6	27.8
101	34.08	18.7	31.1	50.2
110	39.07	35.2	42.5	22.3
111	52.96	44.5	35.1	20.4
120	28.63	39.9	45.4	14.7
121	53.05	36.7	27.0	36.3
200	21.07	27.1	33.2	39.6
220	28.90	41.6	29.0	29.4
221	32.35	36.9	36.6	26.4
222	21.15	23.6	42.3	34.0
Mean	30.56	38.1	31.7	30.2
SD	10.25	9.7	7.1	10.5

N, P, K: 0- No fertilizer, 1- 40 kg ha^{-1}, 2- 80 kg ha^{-1}

(1976) also reported a higher concentration of feeder root in the top 7.5 cm depth.

In the treatment receiving no fertilizer (N_0 P_0 K_0), in -0.03 MPa moisture regime (M1), the top 0-23 cm layer soil had only 21.4 per cent feeder roots compared to the deeper two layers of 23-46 and 46-69 cm which had 39.2 and 39.4 per cent feeder roots, respectively (Table 9). In the N_1 P_1 K_1 treatment per cent roots were highest in the top surface layer followed by the lower two layers. In the treatment receiving N alone it was observed that the surface layer had the least per cent roots. In the treatment with P_0 and K_0 the roots have been observed to move to deeper layers for extraction of nutrients. Maximum root biomass was observed in N_1 P_2 K_1. Distribution of root biomass in plots receiving optimum fertilization has helped in a buildup of higher root biomass in the surface layer. At very high concentration of nutrients (N_2 P_2 K_1 and N_2 P_2 K_2) root biomass was observed to be lower compared to N_1 P_1 K_1 or N_1 P_2 K_1. Lower root biomass observed in high NPK plots can be attributed to inhibition of root growth in the limited soil volume of the polybag. At lower soil moisture regime of -0.50 MPa (M_3) the trend in root biomass buildup (Table 10) is similar to that of M_1 as described earlier. However as regards the distribution of roots in various depth zones in the two moisture regimes, it is seen that at M_1 level the highest percentage of roots was in the middle layer (23-46 cm) followed by the top layer. Lowest percentage was observed in the lowest depth (46-69 cm). However in M_3 the percentage of roots was found the highest in the top layer which declined progressively as the depth increased.

4.2.6. Transpiration.

A few selected nutrient combinations were taken up for the study of their role in influencing the transpiration of plants (Table 11). No definite interrelationship could be obtained during winter and post winter; however it can be seen that transpiration increased in April compared to December, and the extent of increase was maximum for the treatment $N_2\,P_2\,K_2$. In the winter the plot which received the highest dose of N and K ($N_2\,P_0\,K_2$) registered the lowest transpiration suggesting that it had prevented water loss and helped in maintaining a higher plant water status. During post winter period, the lowest transpiration was again recorded with the highest level of K ($N_0\,P_2\,K_2$). High levels of K in soil tends to promote potassium status of leaf and high foliar K has been found to be associated with reduced transpiration in several tree species. The rapid reduction in transpiration resulting from K fertilizer application suggests that K acts physiologically. (Bradbury and Malcolm,1977). As K plays a dominant role in stomatal opening, the nutritional status of the plant affects water loss by transpiration. The beneficial effects of K preventing water loss has been reported by Brag (1972). The observations obtained in this study are in conformity with the above findings. These observations point to the fact that a closer attention to the K nutrition is required particularly for mitigating the various stress factors in Tripura condition.

Table 11.
Effect of nutrients on transpiration and stomatal conductance (mmol m^{-2} sec^{-1}) .

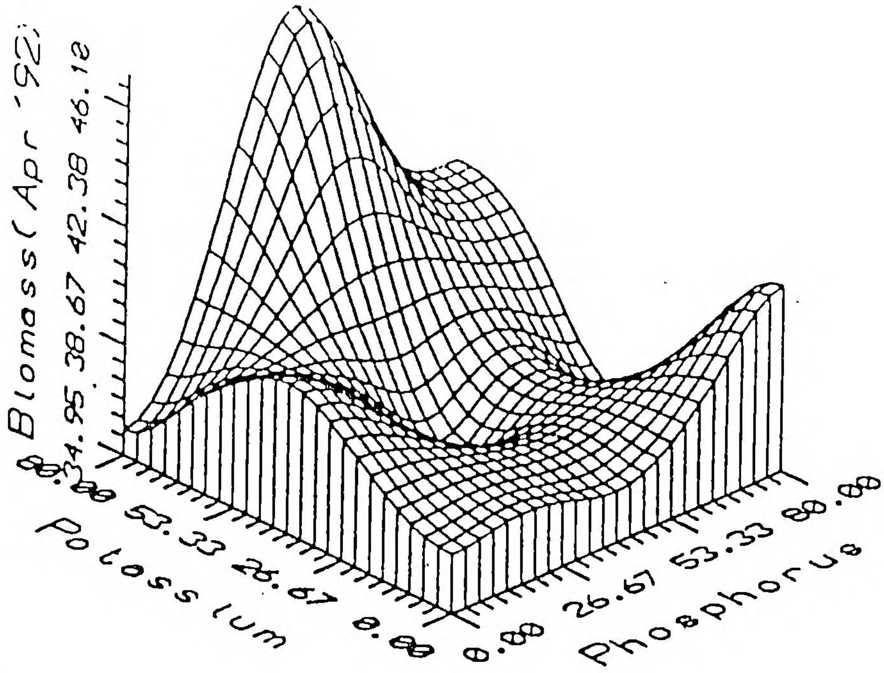
Nutrient levels N P K	Dec(14 MAP) TR	Dec(14 MAP) SC	April(18 MAP) TR	April(18 MAP) SC
N_0 P_0 K_0	1.65	109.54	3.48	179.68
N_0 P_0 K_2	1.72	108.80	4.04	166.03
N_0 P_2 K_1	1.56	86.88	3.59	166.90
N_0 P_2 K_2	1.23	57.85	2.76	144.09
N_1 P_2 K_0	1.66	98.05	2.95	144.68
N_1 P_2 K_1	1.39	71.71	2.93	143.82
N_2 P_0 K_2	1.04	66.68	3.32	130.29
N_2 P_2 K_1	1.74	78.54	3.34	155.36
N_2 P_2 K_2	1.35	73.91	4.01	179.19
LSD(P=0.05)	ns	21.78	0.71	30.26

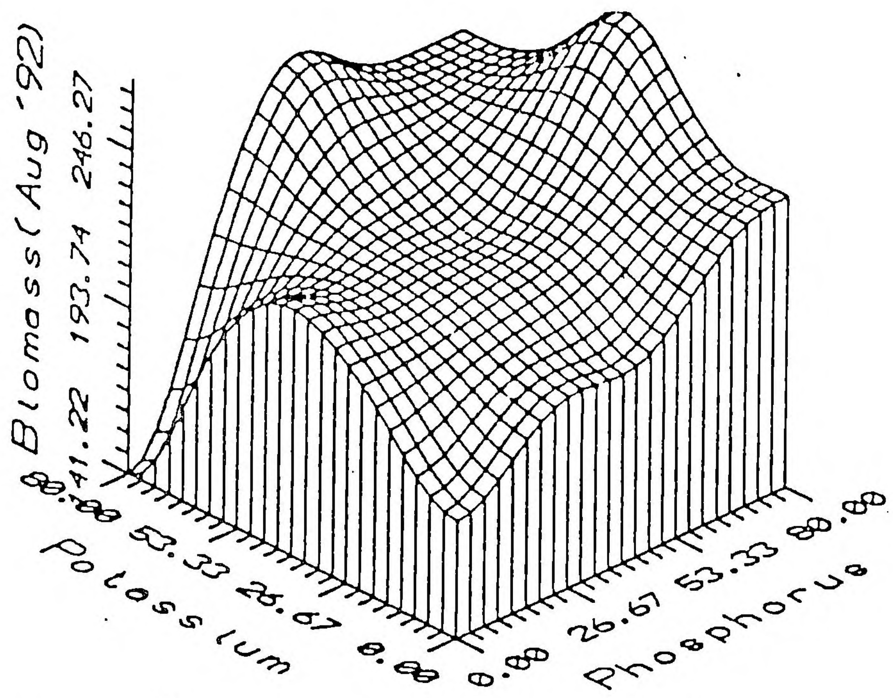
MAP - Months after planting
N, P, K: 0- No fertilizer, 1- 40 kg ha^{-1}, 2- 80 kg ha^{-1}
TR - Traanspiration g_s - stomatal conductance

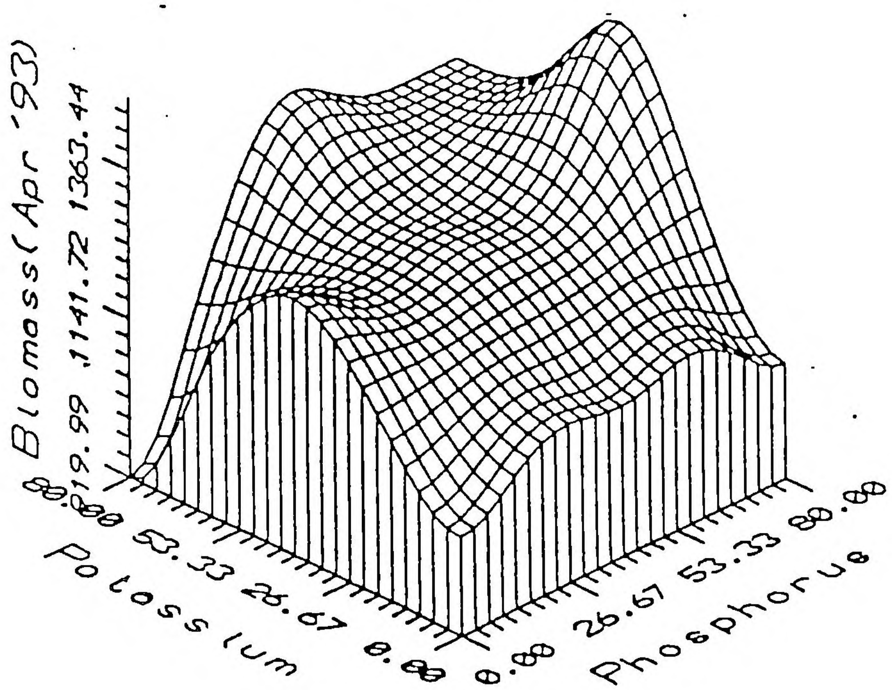
4.2.7. Stomatal Conductance.

Stomatal conductance has been the highest in plots receiving no fertilizer in December as well as in April (Table 11). A marginal reduction (non significant) was noticed when K alone was added at 80 kg ha^{-1}. When K was applied along with P and N there was a significant reduction in g_s during winter and post winter period. Lowest g_s was obtained for the treatment receiving 80 kg P and K (N_0 P_2 K_2) during winter. The treatment receiving 80 kg N and K without P (N_2 P_0 K_2) has also significantly reduced the g_s during winter. During April also the treatment with the highest dose of N and K without P recorded the lowest g_s. Addition of K alone was not found to significantly influence the g_s probably because K absorption had not taken place to the level desired. This could be due to the fact that in the absence of the other two nutrients, root development and other physiological parameters may not have been active to ensure proper uptake of K. Potassium in the plant system plays a key role in the osmoregulation helping to check water loss. This is already observed from the data on transpiration. Stomatal conductance increased when N and P was applied without K. Transpiration has also shown a similar trend. However, the effect of K on g_s has been different in winter and post winter period. At the highest dose of P and K the per cent reduction in g_s when compared to no fertilizer plots was 50 per cent in winter and was only 20 per cent, during post winter. This indicates that the influence of P and K was more pronounced in winter than during post winter. At the highest level of N, P and K (N_2 P_2 K_2) the g_s was significantly lower than that in the plots receiving N_0 P_0 K_0, N_0 P_0 K_2 and N_1 P_2 K_0 plots during winter. The nutrients appeared to have played a role in regulating transpiration and g_s. During April, the treatment of N_0 P_2 K_2 did not significantly reduce the g_s when compared to the plots receiving the highest level of K alone (N_0 P_0 K_2) as was observed in December, suggesting that influence of P and K in regulating g_s is lesser in post winter than during winter. The lowest g_s was recorded in April for the treatment N_2 P_0 K_2.

Stomatal conductance has been reported to be regulated by potassium. Nitrogen has also been reported to influence g_s through their role in regulating the stomata (Pleasants, 1930). Stomatal conductance and transpiration rate of K-sufficient rubber plants decreased with increase in soil moisture stress (Samarapulli *et al*, 1993). Nitrogen deficiency can lead to root resistance which causes leaf water stress. In the highest level of nutrients (N_2 P_2 K_2) the g_s was significantly lower than that in no fertilizer plot during winter. However during April this treatment resulted in almost similar g_s as that in no fertilizer plot. The difference in the response pattern under the two situations indicates that at higher nutrient levels in winter, g_s was reduced as a result of osmoregulation. During April at higher levels of all three nutrients, metabolic activity including the influence of N on cytokinin in increasing the root volume may have accelerated the g_s. Comparing the data of December and April it is observed that maximum g_s was seen in the treatment receiving highest level of N, P and K and the lowest in the treatment without K (N_1 P_2 K_0). During summer as a result of possible faster metabolic activity maintenance of turgor in the guard cells as influenced by K would be more efficient, leading to higher stomatal conductance.


Biomass(Apr '92)
34.95 38.67 42.38 46.10
80.00 53.33 26.67 0.00
Potassium
0.00 26.67 53.33 80.00
Phosphorus


Biomass(Aug '92)
141.22 193.74 246.27
80.00 53.33 26.67 0.00
Potassium
0.00 26.67 53.33 80.00
Phosphorus


Biomass(Apr '93)
919.99 1141.72 1363.44
80.00 53.33 26.67 0.00
Potassium
0.00 26.67 53.33 80.00
Phosphorus

4.3. Effect of nutrient interaction on plant biomass.

Phosphorus and potassium interaction has been found to influence biomass of plants at various stages of growth (Fig. 10). While the straight effects of phosphorus and potassium were significant at the 80 and 40 kg ha-1 levels, their interaction effects showed higher biomass at P_{40} and K_{80} levels during April'93. The increase was however on par with the other P and K combinations except P_0 K_0 and P_0 K_{80}. The highest biomass was obtained at $P_{80}K_{40}$ level during the 10th and 18th month after planting. Significantly lower biomass during the 10th month was seen in P_0 K_0, P_0 K_{80} and $P_{40}K_0$ compared to other PK combinations. In the 18th month however higher levels of PK combinations were seen to be significantly superior in terms of biomass production, with the highest biomass in $P_{80}K_{40}$. This is in agreement with the straight effects of nutrients. Phosphate absorbed by plant cells rapidly becomes involved in metabolic processes, while potassium is involved in meristematic growth. In the low K treatment, reduction in biomass may have been due to a reduction in cell size and growth rate.

4.4. Effect of moisture and nutrient interaction on plant growth and physiological functions: Immature phase.

4.4.1. Plant girth.

It is seen from Fig. 11 that at any level of moisture regime, the interaction with N at 3 levels does not significantly influence the girth. Phosphorus has been observed to significantly interact with moisture regimes from 12 months after planting (Table 12). At M_2, girth has

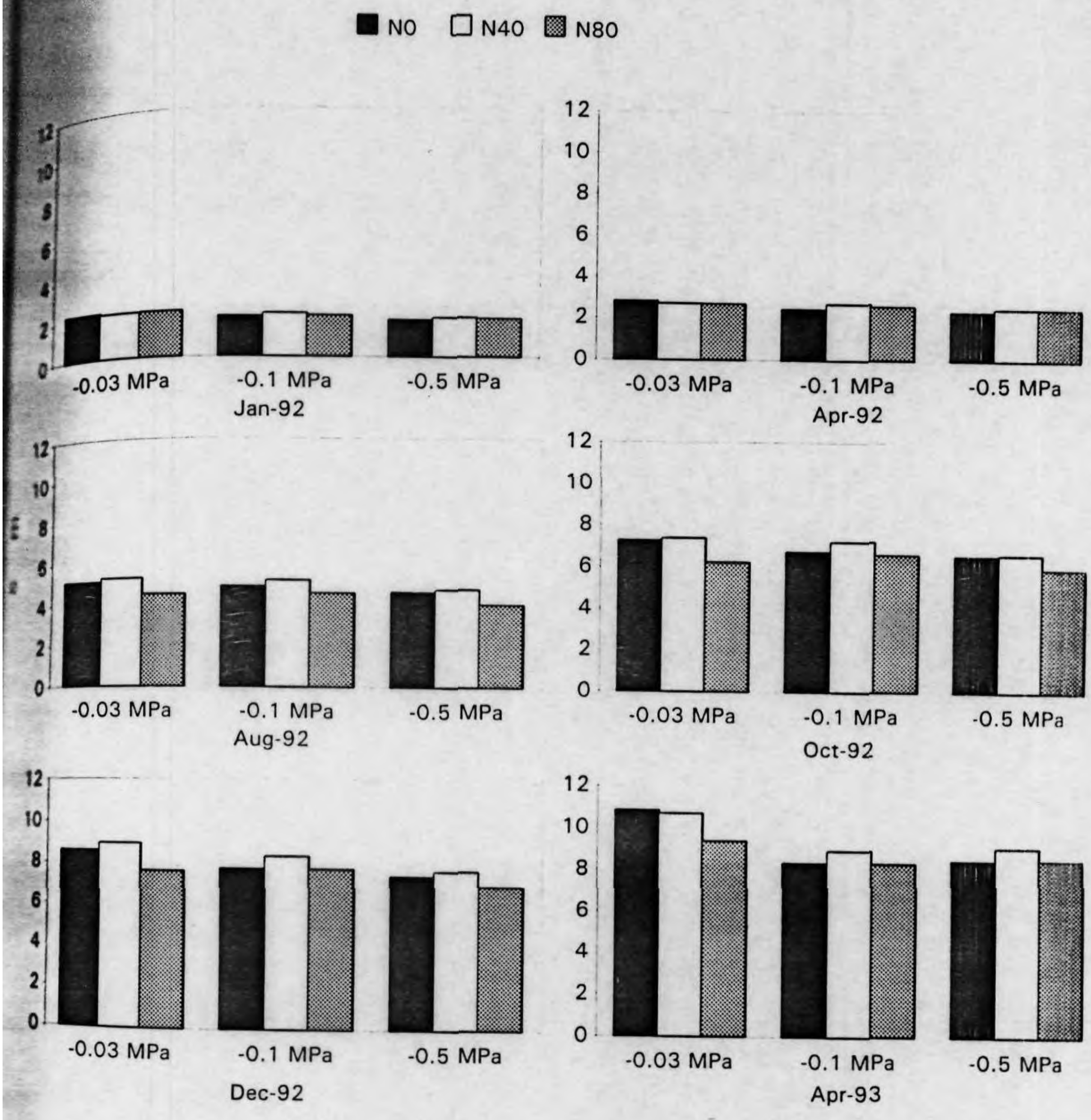


Fig. 11. Moisture and nitrogen interaction on girth of plants

Table 12. Moisture and Phosphorus interaction on girth of plants (cm).

MAP	Moisture regime(MPa)	Phosphorus levels 0	1	2	LSD(P=0.05)
3 (Jan)	0.033	2.17	2.22	2.24	ns
	0.10	1.97	1.95	2.06	
	0.50	1.85	1.86	1.79	
6 (Apr)	0.033	2.69	2.81	2.72	ns
	0.10	2.56	2.55	2.63	
	0.50	2.45	2.41	2.40	
10 (Aug)	0.033	4.44	5.15	5.25	ns
	0.10	4.56	5.02	5.04	
	0.50	4.32	4.26	4.78	
12 (Oct)	0.033	6.46	7.20	7.23	0.52
	0.10	6.74	6.94	6.90	
	0.50	6.20	6.00	6.90	
14 (Dec)	0.033	7.74	8.70	8.62	0.62
	0.10	7.76	8.06	8.01	
	0.50	7.17	6.90	7.87	
18 (Apr)	0.033	9.53	10.50	10.42	0.57
	0.10	8.37	8.66	8.61	
	0.50	7.71	7.63	8.05	

MAP- Months after planting

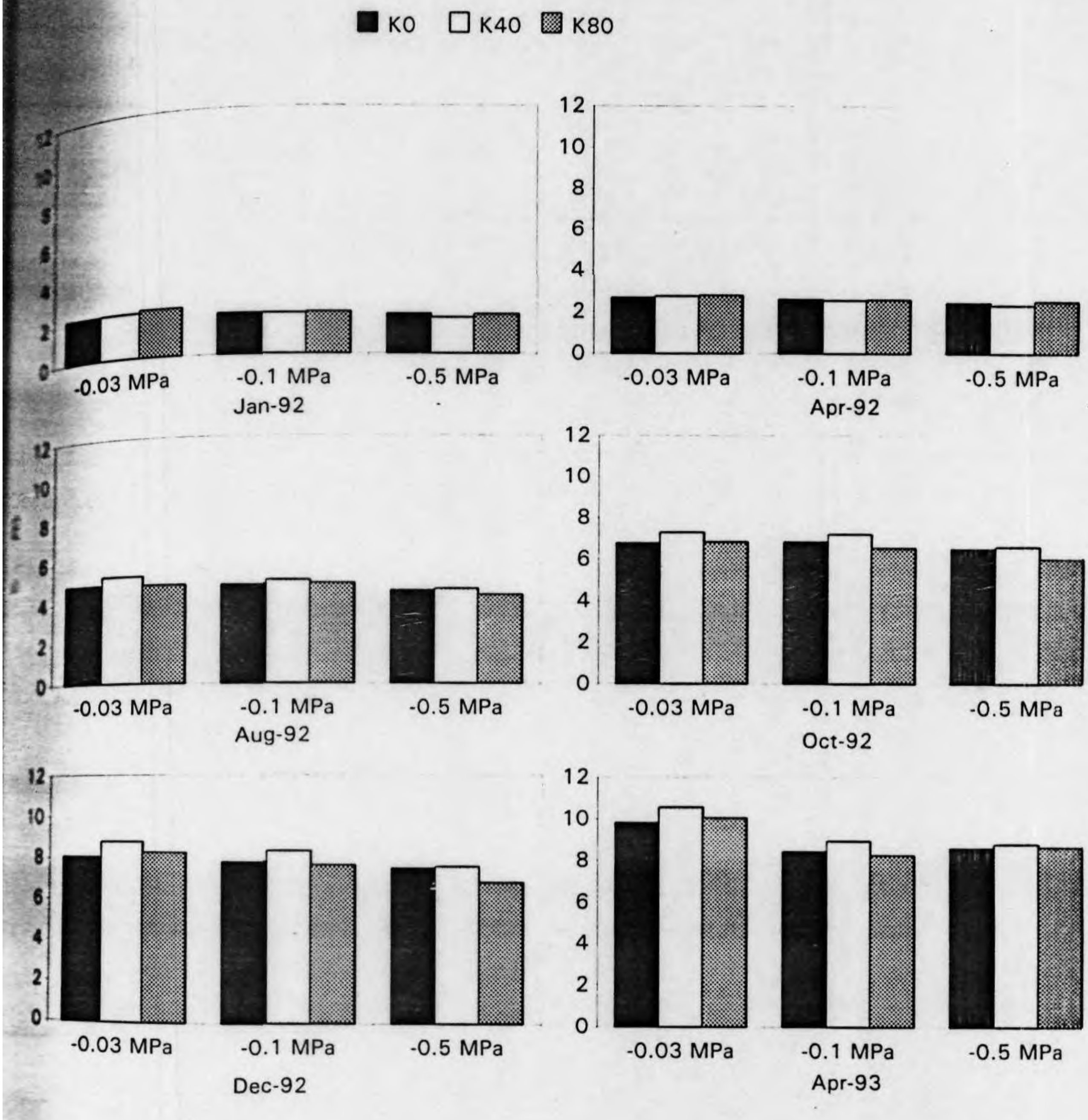


Fig 12. Moisture and potassium interaction on girth of plants

increased at P_0 level. This was however not significant. At the same P level at M_3 moisture regime, girth was observed to be significantly lower suggesting the direct influence of moisture regimes. At P_1 level of phosphorus application the highest girth was observed in the M_1 plot. As the moisture stress increased a gradual decline in girth was observed and the extent of decrease in girth from M_2 to M_3 moisture regime was significant. At P_2 level of phosphorus application, moisture regime did not significantly influence girth of plants up to 14 months after planting. This indicates that at higher P level plants could maintain uptake of P even under moisture stress. At lower P level (P_1), a significant reduction in girth observed in M_3 moisture regime plots compared to M_1 moisture regime plots suggests that at this level of P, its availability to the extent required for the growth could not be ensured at low soil moisture level. The data reveal that the influence of P on plant girth is dependent more on moisture levels and levels of P than on the growing season. Availability of P has been reported to be reduced in drier soils and under such situations P uptake has been higher under higher concentrations of P (Viets, 1972). Higher uptake of P in higher moisture regime has also been reported by Viets (1972). While a 11 per cent increase in girth was seen in 40 kg P applied plots in the M_1 moisture regime compared to No- phosphorus application during December, the per cent increase in the same plots during April was only 9 per cent. This underscores the importance of adequate nutrition and maintenance of higher soil moisture status during the winter season, to tide over stress conditions prevailing at this time. Moisture in conjunction with phosphorus at moderate level (P_1) is able to improve girth of young rubber plants at higher soil moisture level but a higher rate of P is required for attaining comparable girth in low soil moisture regimes to compensate for lower soil moisture. Increasing the dosage of fertilizers especially under stress conditions is known to decrease the quantity of water required to produce dry matter. In a nursery trial Leite *et al* (1985) obtained better girth when young *Hevea* plants were irrigated and fertilized compared to unirrigated and unfertilized plants. Irrigation during the dry season increased the above ground biomass production more than what was obtained with nutrient supply without irrigation in the early growth stages.(Madeira and Pereira,1990/91).

The data on interaction of K and moisture regime is presented in fig. 12. Moisture levels did not influence the uptake of K as evidenced by the girth of plants. The different levels of K also did not interact with soil moisture in influencing the girth of rubber plants in the different growth seasons considered in this study.

4.4.2. Root biomass.

Data on the influence of moisture and nutrients on root biomass is given in Table 13. Overall mean of all treatments indicate that root biomass was significantly higher at M_1 moisture regime than at M_3 moisture regime. Root biomass in M_1 N_0 P_0 K_1 was 145 per cent higher than at M_3 N_0 P_0 K_1 when roots in the three depth was considered together. The effect of P under M_3 moisture regime is more pronounced than that of P at M_1. Root biomass was 82.5 per cent more in M_3 N_0 P_2 K_0 than in M_1 N_0 P_2 K_0 moisture regime. Phosphorus is reported to play a significant role in root proliferation in rubber (Philip *et al*, 1997). In

Table 13. Effect of moisture and nutrients on root biomass (g).

Nutrient levels N	P	K	0-23 cm		23-46 cm		46.69 cm	
			Moisture regime (MPa)					
			-0.033 (M_1)	-0.50 (M_3)	-0.033 (M_1) (M_3)	-0.50 (M_1)	-0.033 (M_1)	-0.50
0	0	0	5.10 kl	5.71 jkl	9.35	4.48	9.40	6.05
0	0	1	17.14 cdefgh	7.76 ghijkl	12.25	4.83	17.72	6.58
0	0	2	10.37 efghijkl	8.66 ghijkl	14.50	6.83	13.65	17.25
0	1	0	7.32 hijkl	12.27 efghijkl	6.38	8.50	7.80	4.50
0	1	1	8.55 ghijkl	15.39 cdefghij	11.30	9.38	7.95	11.60
0	2	0	7.70 ghijkl	16.35 cdefgh	4.15	7.52	5.80	8.35
0	2	1	9.65 fghijkl	15.71 cdefghi	8.90	7.46	12.85	6.30
0	2	2	3.30 l	12.75 efghijkl	9.15	7.22	8.20	5.22
1	0	0	3.80 kl	7.65 ghijkl	13.15	8.30	8.55	6.14
1	0	1	9.76 efghijkl	6.38 ijkl	14.66	10.60	16.24	17.10
1	1	0	19.57 cde	13.75 defghijk	15.44	16.60	12.42	8.72
1	1	1	33.79 a	23.57 bc	19.94	18.59	7.75	10.80
1	2	0	22.45 bcd	11.42 efghijkl	12.00	13.01	12.90	4.20
1	2	1	28.55 ab	19.49 bcdef	22.75	14.32	10.50	19.24
2	0	0	8.50 ghijkl	5.72 jkl	9.75	7.00	4.20	8.35
2	2	0	11.07 efghijkl	12.01 efghijkl	13.94	8.40	4.20	8.50
2	2	1	17.55 cdefg	11.95 efghijkl	17.95	11.85	7.35	8.55
2	2	2	8.85 ghijkl	5.00 kl	13.23	8.95	16.19	7.20
Mean			11.97	11.75	12.71	9.66	10.20	9.15
SE (d)			4.04		ns		ns	

N, P, K: 0- No fertilizer, 1- 40 kg ha^{-1}, 2- 80 kg ha^{-1}

Means followed by a common alphabet are not significantly different at the 5 % level using DMRT higher soil moisture tension a higher concentration of P would be required to maintain a higher uptake of P and consequently a higher root biomass buildup. Phosphorus when applied with K also showed a positive interaction with moisture regime. The treatment $M_3 N_0 P_1 K_1$ recorded a 24 per cent increase in root biomass compared to $M_1 N_0 P_1 K_1$. Though the extent of increase in root biomass was less, the treatment $N_0 P_2 K_2$ also recorded higher root biomass in M_3 moisture regime.

The above trend was observed to change when N was applied. In all treatments at the 1st level of N (N_1), root biomass was higher in M_1 moisture regime. In treatments $N_1 P_0 K_2$ and $N_2 P_0 K_0$, root biomass was higher in M_1 pointing to the fact that N uptake is greatly influenced by moisture regime and applied N is better utilized in root biomass buildup at higher moisture than at lower moisture availability in soils. Application of N and K at 40 kg each ($N_1 P_0 K_1$) gave 19.3 per cent higher root biomass in M_1 over M_3 moisture regime. The treatment $N_1 P_0 K_1$ has also increased the root biomass by 59.45 at M_1 and 54.3 per cent in M_3 moisture regime over the treatment $N_1 P_0 K_0$ at corresponding moisture regime. The root biomass study suggests that the uptake of N and K and their role in root biomass buildup has been superior when applied together. Growth of rubber roots was reported to have improved with K nutrition (Samarapulli *et al*,1993).

Treatment $N_1 P_1 K_0$ registered 21.4 per cent increase in total root biomass, values being 47.43 g per plant in M_1 (Table 9) as against 39.07 g in M_3 (Table 10). The reduction of total root biomass was negligibly small in moisture nutrient combination of $M_1 N_1 P_2 K_0$ as against $M_1 N_1 P_1 K_0$, but the reduction was sizeable at the lower moisture potential of M_3. A negative interaction of high level of P when applied with N is seen at M_3.

Of the various nutrient combinations studied $N_1 P_2 K_1$ recorded the highest root biomass in both moisture regimes (Tables 9 and 10). There was an increase in root biomass by 13.86 per cent in M_1 compared to M_3 , suggesting that a better utilization of NPK occurred at higher moisture regime. At higher levels of N a reduction of root biomass was seen when $N_1 P_2 K_1$ was compared with $N_2 P_2 K_1$ in M_1 and M_3 moisture regimes(Table 13). Higher levels of nutrients was not observed to offset the deleterious effect of moisture stress when N was raised to 80 kg level. The behavior of P and K provides scope for considering the increase in dose of these two nutrients from the 40 kg level, which is the current recommendation. The present fertilizer recommendation for rubber in N.E.India is 40:40:20 kg NPK ha^{-1}. The present study has indicated a much higher root biomass buildup at 40 and 80 kg K and that 80 kg K has helped in better utilization during moisture stress as evidenced by a buildup in root biomass.

Root biomass in M_3 moisture regime showed a decline with depth (Table 10). In the M_1 moisture regime higher root biomass was observed in the 23-46 cm depth followed by the top layer (0-23 cm) and lowest depth (46-69 cm). Highest root biomass was observed in $N_1 P_2 K_1$. Percentage of roots in this treatment at M_1 moisture was the highest in 0-23 cm depth (47.4 per cent) and the lowest layer having only 17 per cent. But under moisture regime of M_3 the per cent roots in the lower layer was

7.8 per cent more than that in M_1 moisture. In treatments without P it was seen that root biomass in surface layer (0-23 cm) was less than that of lower layers in M_1 moisture. In the absence of P, roots might have gone to deeper layers. This was the case with M_3 moisture regime also. Need for a proper placement of fertilizer can also be deduced from this observation.

4.4.3. Transpiration.

Transpiration during winter (December), 14 months after planting, was not significantly influenced by moisture and nutrient interaction (Table 14). Higher transpiration was noticed in the higher moisture plots. Nutrient combinations of N_1 P_2 K_1 and N_2 P_0 K_2 recorded low transpiration rates during winter. During post winter period of April, 18 months after planting, moisture nutrient interactions significantly reduced the transpiration rates. Xu *et al* (1995) reported decrease in stomatal transpiration under high EC and or low soil water content. During April (Post winter) high dose of K applied plots in low moisture regimes has shown lower transpiration rates than other nutrient treatments. A lower transpiration rate recorded in plants well supplied with K may be due to the ability of K in osmoregulation during stress periods. Plants well supplied with K transpired less water per unit weight of dry matter than deficient plants. (Blanchet *et al*, 1969).

4.4.4. Stomatal conductance.

Stomatal conductance was significantly influenced by moisture and nutrient interaction during the winter period (Table 15). In

Table 14. Moisture and nutrient interaction on transpiration (mmol m^{-2} sec^{-1}) .

Nutrient levels			December(3 MAP)			April (6 MAP)		
			Moisture regimes					
N	P	K	-0.033 (M_1)	-0.10 (M_2)	-0.50 (M_3)	-0.033 (M_1)	-0.10 (M_2)	-0.50 (M_3)
N_0	P_0	K_0	2.26	1.43	1.25	3.74	4.12	2.57
N_0	P_0	K_2	2.70	1.52	0.94	4.59	3.49	4.05
N_0	P_2	K_1	1.96	1.79	0.94	3.87	3.50	3.41
N_0	P_2	K_2	1.67	1.22	0.78	3.47	3.15	1.66
N_1	P_2	K_0	1.86	2.21	0.91	3.65	2.23	2.98
N_1	P_2	K_1	1.65	1.57	0.95	3.17	2.85	2.77
N_2	P_0	K_2	1.21	0.99	0.93	5.01	2.51	2.44
N_2	P_2	K_1	2.25	2.02	0.95	4.27	2.53	3.23
N_2	P_2	K_2	2.48	0.55	1.03	4.46	3.19	4.38
LSD(P=0.05)				ns		1.22		

MAP - Months after planting

N, P, K: 0- No fertilizer, 1- 40 kg ha^{-1}, 2- 80 kg ha^{-1}

Table 15 Moisture and nutrient interaction on stomatal conductance (mmol m^{-2} sec^{-1})

Nutrient levels			December (3 MAP)			April(3 MAP)		
			Moisture regimes					
N	P	K	-0.033 (M_1)	-0.10 (M_3)	-0.50 (M_1)	-0.033 (M_3)	-0.10 (M_1)	-0.50 (M_3)
N_0	P_0	K_0	157.23	78.82	92.58	215.83	173.67	149.53
N_0	P_0	K_2	128.90	106.33	91.17	207.66	168.83	121.60
N_0	P_2	K_1	129.67	68.37	62.60	186.17	188.17	126.37
N_0	P_2	K_2	58.50	71.18	43.87	169.33	153.67	109.27
N_1	P_2	K_0	103.47	112.97	77.72	184.17	148.27	101.60
N_1	P_2	K_1	76.92	69.85	68.37	162.33	147.83	121.30
N_2	P_0	K_2	74.68	79.80	45.55	156.83	129.73	104.30
N_2	P_2	K_1	78.58	73.07	83.97	210.33	167.00	88.73
N_2	P_2	K_2	88.28	53.67	79.77	220.00	181.57	136.00
LSD(P=0.05)			36.67			ns		

MAP- Months after planting

N, P, K: 0- No fertilizer, 1- 40 kg ha^{-1}, 2- 80 kg ha^{-1}

M_1 and M_3 moisture regimes, plots receiving no fertilizer recorded the highest g_s. In general N_0 P_2 K_2 recorded significantly lower g_s than no fertilizer applied plots in M_1 and M_3 moisture regimes. Reduced g_s with increased P nutrition has been reported under well watered conditions (Ackerson,1985; Brandbury and Malcolm,1977 ; Dosskey *et al* 1993) and under drought conditions (Hak and Natr,1984). N_1 P_2 K_1 plots also gave low g_s in all the moisture regimes during pre and post winter periods. However significant influence of moisture and nutrients on g_s was not observed in April'93, the post winter period. Here too high g_s values were observed in no fertilizer plots. Reduced g_s could be interpreted as a mechanism which conserves plant water and enhances drought tolerance.

4.5. Effect of applied nutrients on nutrient content of plant parts.

4.5.1. Bark nutrient content.

Nutrients when taken up by plants are stored initially in plant tissues, which may be released as the tissues mature or senesce, the major storage sites being bark, roots, shoots and leaves (Driesche, 1984). The effect of applied nutrients on bark nutrient content is given in Table 16. There was an increase in bark nutrient content when K was applied at 40 kg (N_0 P_0 K_1) compared to treatment without K (N_0 P_0 K_1) plots. When K was applied at 80 kg alone (N_0 P_0 K_2), the bark N content was significantly higher compared to N_0 P_0 K_0 plots. Application of K at 40 and 80 kg did not influence the uptake of P. Application of K at 40 kg (N_0 P_0 K_1) however resulted in higher K in bark, the increase being significant when compared to treatment N_0 P_0 K_0. Bark K content was also significantly higher (45 per cent) in N_0 P_0 K_2 plots compared to N_0 P_0 K_0.

Table 16. Effect of applied nutrients on bark nutrient content (%)

Nutrient levels			Bark nutrient content (%)				
N	P	K	N	P	K	Ca	Mg
0	0	0	1.20 c	0.09	0.89 f	6.07 ab	0.38
0	0	1	1.29 bc	0.08	1.36 abcd	3.05 cd	0.13
0	0	2	1.32 abc	0.12	1.62 ab	4.08 abcd	0.21
0	1	0	1.25 bc	0.09	1.00 def	3.95 bcd	0.81
0	1	1	1.20 c	0.09	1.71 ab	6.09 a	0.21
0	2	0	1.29 bc	0.11	0.88 f	4.74 abcd	0.34
0	2	1	1.25 bc	0.08	1.56 abc	3.89 cd	0.24
0	2	2	1.26 abc	0.13	1.76 a	4.06 abcd	0.21
1	0	0	1.31 abc	0.11	0.91 ef	5.13 abc	0.26
1	0	1	1.31 abc	0.09	1.14 cdef	3.54 cd	0.20
1	1	0	1.38 ab	0.09	0.95 def	2.84 d	0.18
1	1	1	1.29 bc	0.08	1.45 abc	3.56 cd	0.16
1	2	0	1.30 bc	0.10	0.89 f	4.49 abcd	0.28
1	2	1	1.37 ab	0.11	1.28 bcdef	4.69 abcd	0.27
2	0	0	1.31 abc	0.08	0.85 f	4.84 abcd	0.28
2	2	0	1.28 bc	0.09	0.95 def	3.84 cd	0.19
2	2	1	1.35 ab	0.07	1.34 abcd	3.74 cd	0.24
2	2	2	1.44 a	0.11	1.46 abc	5.08 abc	0.27
SE (d)			0.06	ns	0.19	0.89	ns

N, P, K: 0- No fertilizer, 1- 40 kg ha^{-1}, 2- 80 kg ha^{-1}

Means followed by a common alphabet are not significantly different at the 5 % level using DMRT

An increase in bark K content by 16 per cent was noticed when K application was raised from 1st to 2nd level. The increase was however non significant.

Calcium content in no fertilizer plot (N_0 P_0 K_0) was high Application of K at 40 and 80 kg ha^{-1} level has significantly lowered the bark Ca content. This may have been due to the increased concentration of K affecting uptake of Ca. Influence of applied K on the uptake of Mg resulted in lowering of bark Mg content at both levels of K. In soils with appreciable quantities of illite, available K shows a negative correlation with available Mg. In soils with the above mineral composition applied K tends to get fixed. To maintain the availability of K, higher doses will have to be applied. Soils of Tripura has a preponderance of illite with medium level of available K. Uptake of higher K in plots receiving 80 kg ha^{-1} K and a consequent reduction in Mg in bark can be attributed to more of K becoming available resulting in lower uptake of Mg.

Treatment receiving phosphorus alone (N_0 P_1 K_0 and N_0 P_2 K_0) did not show significant changes in the bark N, P and K content. Calcium content in bark was however significantly lower than N_0 P_0 K_0. When P and K was added at 40 kg each (N_0 P_1 K_1), their effect on bark N and P was not significant but the K content increased significantly. However when P was applied at 80 kg alongwith K at 40 kg (N_0 P_2 K_1) the bark K showed a lower content than that recorded in N_0 P_1 K_1. Bark K content was high at P_2 level only when it was supplemented with K at 80 kg suggesting a positive PK interaction. Addition of N at 40 kg (N_1 P_0 K_0) increased N and Ca in bark, while it has resulted in reduction of K when compared to N_0 P_0 K_0. Phosphorus content in bark was not influenced by N when K was applied with N, each at 40 kg ha^{-1}(N_1 P_0 K_1). The bark N content remained same when compared to N_1 P_0 K_0 but bark K increased from 0.91 to 1.14 percent. The increase was not significant. Calcium content in bark was observed to be reduced significantly (Table 24).

Nitrogen at the first level (N_1 P_1 K_0 and N_1 P_2 K_1) recorded a significantly higher bark N compared to N_0 P_0 K_0 plots. Nitrogen at the second level with and without P and K did not show any specific trend in the bark N content. Nitrogen at the second level (N_2 P_0 K_0 and N_2 P_2 K_0) gave comparable bark N and K content compared to N_0 P_0 K_0. However, N and K in bark was significantly higher in N_2 P_2 K_1 and N_1 P_0 K_0 plots.

4.5.2. Leaf nutrient content.

Foliar nutrient status of a plant reflects the nutrient uptake from soils. The quantities of nutrients contained in foliage may amount to more than 30 % of the total nutrient in the tree (Driessche,1984). The effect of nutrients combined over the moisture regimes is given in table 17. Leaf nutrient content was seen to increase progressively with higher nutrient addition in soil. Leaf nitrogen in no N plots was 3.21 per cent. In the 40 kg N applied plots the leaf N value was 3.56, an increase in 10 per cent, and in 80 kg N applied plot, leaf N was 3.70 per cent, an increase of 13 per cent over no N control. Leaf nitrogen values considered to be in the critical range is between 3 to 3.5 per cent. Values below and above this is considered to be either low or high (Pushpadas and Ahmed, 1980). Leaf N values recorded in plots where N was not given was in the medium range.

Table 17. Effect of applied nutrients on leaf nutrient content (per cent).

Nutrient levels		Leaf nutrient content (%) N	P	K	Ca	Mg
	0	3.21	0.19	0.94	0.83	0.21
N	1	3.56	0.20	0.93	0.76	0.23
	2	3.70	0.19	0.89	0.68	0.22
F ratio		**	*	ns	**	ns
	0	3.47	0.18	0.90	0.68	0.21
P	1	3.47	0.20	0.94	0.80	0.23
	2	3.54	0.20	0.93	0.79	0.22
F ratio		ns	**	ns	**	ns
	0	3.46	0.19	0.78	0.80	0.23
K	1	3.54	0.20	0.99	0.73	0.22
	2	3.47	0.19	1.01	0.73	0.21
F ratio		ns	*	**	ns	ns
LSD						
(P=0.01)		0.08	0.01	0.06	0.80	-
(P=0.05)		-	0.009	-	-	-

N, P, K: 0- No fertilizer, 1- 40 kg ha^{-1}, 2- 80 kg ha^{-1}

Calcium and magnesium are important elements in the nutrition of *Hevea*. Calcium is not supplied directly. Calcium contained in the rock phosphate is the main source of supply of this element. Magnesium is applied as magnesium sulfate in areas of deficiency only in the immature stage. Leaf calcium content in the 40 and 80 kg phosphorus applied plots was significantly higher than in the no P control plots (Table 17). In the N and K applied plots leaf calcium did not show any specific trend. Leaf magnesium also did not show any particular trend. However leaf Mg was seen to be lower in, 40 and 80 kg potassium applied plots, suggesting a K, Mg interaction. Nutrient requirement based on leaf nutrient analysis was reported by Shorrocks (1961,62a and 62b) and the usefulness of leaf nutrient content as an indicator of fertilizer requirement for *Hevea* has been summarized by Watson (1989).

4.6. Effect of moisture and nutrient interaction on nutrient content of plant parts.

4.6.1. Bark nutrient content.

Nitrogen content of bark in plots where N was not added (N_0 P_0 K_0) showed that N was marginally higher in the M_3 moisture regime compared to M_1 (Table 18). When K was applied alone (N_0 P_0 K_1) the N in bark showed a significantly higher content in M3 moisture regime. Utilization of N seems to be better in the presence of K. Potassium may have favored a higher uptake of N made available from the native source. Treatments N_0 P_0 K_0 and N_0 P_0 K_1 had no influence on phosphorus level in bark. Treatment N_0 P_0 K_2 could not also influence bark the N, P and K

Table 18.
Moisture and nutrient interaction on nutrient content of bark (per cent).

Nutrient level N P K	Nitrogen -0.033 (M_1)	(in moisture regimes of) -0.50 (M_3)	Phosphorus -0.033 (M_1)	-0.50 (M_3)
0 0 0	1.17 h	1.23 fgh	0.09	0.09
0 0 1	1.24 efgh	1.34 bcdefgh	0.08	0.08
0 0 2	1.33 bcdefgh	1.32 bcdefgh	0.15	0.09
0 1 0	1.23 fgh	1.28 defgh	0.09	0.08
0 1 1	1.19 gh	1.21 fgh	0.08	0.10
0 2 0	1.41 bcdef	1.18 h	0.13	0.09
0 2 1	1.28 defgh	1.22 fgh	0.10	0.05
0 2 2	1.26defgh	1.27 defgh	0.17	0.09
1 0 0	1.49 bc	1.27 defgh	0.14	0.85
1 0 1	1.30 cdefgh	1.33 bcdefgh	0.09	0.08
1 1 0	1.33 bcdefgh	1.44 bcde	0.09	0.08
1 1 1	1.29 cdefgh	1.29 cdefgh	0.08	0.07
1 2 0	1.33 bcdefgh	1.27 defgh	0.09	0.11
1 2 1	1.35 bcdefgh	1.39 bcdefgh	0.12	0.10
2 0 0	1.44 bcde	1.80 a	0.09	0.06
2 2 0	1.34 bcdefgh	1.24 efgh	0.09	0.09
2 2 1	1.25 defgh	1.45 bcd	0.08	0.05
2 2 2	1.52 b	1.37 bcdefgh	0.16	0.06
SE(d)	0.08		ns	

Means followed by a common alphabet are not significantly different at the 5% level using DMRT.

cont......

Nutrient level			Potassium		Calcium		Magnesium	
			(in moisture regimes of)					
N	P	K	-0.033	-0.50	-0.033	-0.50	-0.033	-0.50
0	0	0	0.90	0.90	6.42	5.73	0.43	0.33
0	0	1	1.40	1.30	2.26	3.84	0.11	0.16
0	0	2	1.90	1.40	3.18	.4.99	0.17	0.25
0	1	0	1.30	0.70	3.68	4.23	0.13	0.23
0	1	1	1.80	1.60	7.05	5.13	0.23	0.19
0	2	0	0.80	0.90	5.50	3.99	0.45	0.24
0	2	1	1.80	1.30	4.50	3.27	0.31	0.18
0	2	2	1.90	1.96	3.08	5.05	0.17	0.25
1	0	0	0.90	0.90	5.41	4.85	0.36	0.17
1	0	1	1.00	1.30	4.09	3.00	0.24	0.17
1	1	0	1.00	0.90	3.16	2.52	0.19	0.18
1	1	1	1.30	1.60	4.05	3.08	0.19	0.13
1	2	0	1.10	0.70	5.60	3.38	0.34	0.23
1	2	1	1.60	1.00	3.66	5.72	0.25	0.29
2	0	0	0.80	0.90	4.48	5.21	0.29	0.27
2	2	0	1.00	0.80	4.43	3.25	0.19	0.19
2	2	1	1.30	1.30	4.10	3.39	0.26	0.23
2	2	2	1.60	1.30	6.01	4.15	0.30	0.24
F ratio			ns		ns			

N, P, K: 0- No fertilizer, 1- 40 kg ha^{-1}, 2- 80 kg ha^{-1}

content significantly. However the bark K content in M_1 moisture regime recorded 26.7 per cent increase over that recorded in M_3. There was a progressive increase in bark K content in the above treatments ($N_0 P_0 K_0$, $N_0 P_0 K_1$ and $N_0 P_0 K_2$) at M_1 and M_3 moisture regimes.

Bark P was not influenced significantly in treatments receiving P at 40 and 80 Kg ha^{-1}. Though no significant interaction of moisture regimes and nutrient level on bark K content was observed, wide variation in K content of bark was observed in the two moisture regimes (Table 18). An increase in 40 per cent bark K content was observed in M_1 over M_3 moisture regime. Application of P and K at 40 kg ($N_0 P_1 K_1$) did not significantly influence N, P and K level of bark. The bark K content was nevertheless high in both moisture regimes. Retention of high K in cells of plants grown in low soil moisture regime of M_3 may be a drought avoidance mechanism of plants in presence of adequate K. Bark N content was significantly higher in plots with 80 kg phosphorus ($N_0 P_2 K_0$) in M_1. Phosphorus and potassium content in bark was not influenced by the high dose of nitrogen. However when K was increased to 40 and to 80 kg level ($N_0 P_2 K_1$ and $N_0 P_2 K_2$), the bark K content recorded 125 and 126.5 per cent increase over $N_0 P_2 K_0$ plots in M_1 moisture regime. An increase in bark K content in M_3 was also observed in these treatments.

Nitrogen, phosphorus and potassium at 40 kg each ($N_1P_1K_1$) influenced K uptake in bark particularly in the M3 moisture regime. Nitrogen application at 80 kg alone and in combination with P and K helped in acquiring ignificantly higher bark N content. A higher bark N in

M_1 compared to M_3 moisture regime was obtained in treatments N_2 P_0 K_0 and N_2 P_2 K_2.

Moisture and nutrient interaction did not significantly influence calcium and magnesium uptake (Table 18). Calcium content in plots when fertilizers were not given was higher in both the moisture regimes than those in fertilizer applied plots. Maximum reduction in the uptake of calcium up to 101 % was noticed when the potassium level was 80 kg ha-1 . This amount of reduction was not found when potassium was in combination with the other nutrients. Magnesium content in bark also showed a similar trend, with higher magnesium in the bark in plots with no fertilizer. Potassium depressed the uptake of magnesium in bark. This was more pronounced in M_3 moisture regime.

4.6.2. Leaf nutrient content.

Influence of moisture regimes and NPK interaction on leaf nutrient content is given in Fig. 13. Leaf N content in plants with no fertilizers was higher in M_1 moisture regime, which declined progressively as the soil moisture tension increased. There was an increase in leaf N in M_1 moisture regime by 9.8 per cent when N was applied at 40 kg ha^{-1}. An increase in leaf N was observed in M_2 also. In the low soil moisture regime of M_3, leaf N content of plants recorded 12 per cent higher values than unfertilized plots, the increase being significant. Nitrogen at 40 kg in combination with P and K in all the three moisture helped the plants in acquiring leaf N content in the high range of critical level. Leaf N content

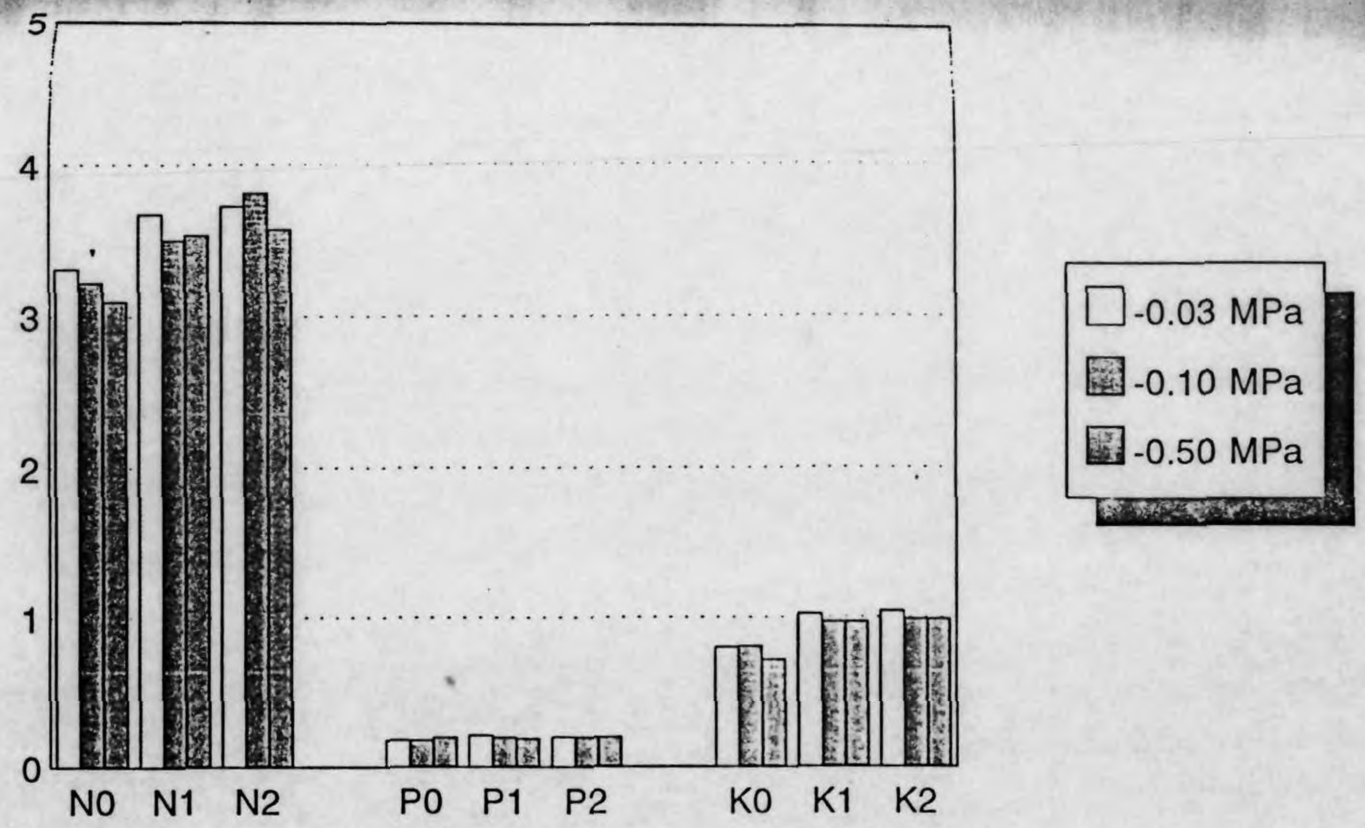


Fig.13.Moisture regimes and nutrient interaction on leaf nutrient content (%)

Table 19. Correlation of RGR vs meteorological parameters.

	T.max	T.min	SSD	Evaporation	Rainfall	RGR
	2	3	4	5	6	1
2	1.000					
3	0.984	1.000				
4	-0.644	-0.727	1.000			
5	0.312	0.201	-0.274	1.000		
6	0.985	0.976	-0.743	0.409	1.000	
1	0.354 *	0.374 *	-0.398 *	0.146	0.382 *	1.000

Significant at 5 % level

T.max - Maximum temperature
T.min - Minimum temperature
SSD - Sunshine duration

in the 80 kg N applied plots showed the highest value of N in M_2 moisture regime. Lower leaf N content observed in 80 kg N applied plots in M_1 compared to M_2 may be due to N being less available as a consequence of the downward movement of applied N in presence of higher soil moisture level. Haridas (1980) however reported increased nutrient uptake with increased water availability.

Leaf phosphorus and potassium did not show significant changes as a result of soil moisture and NPK interaction (Fig. 13). Leaf P content was found to be in the low to medium range while leaf K content was in the medium range of critical value in M_1 moisture regime.

4.7. Growth in relation to meteorological parameters

To understand the influence of weather on relative growth, correlation analysis was carried out and the results shown in Table 19. RGR was positively correlated with temperature, both maximum and minimum. There is a distinct period of reduction in growth during winter, which could be attributed to the low temperature prevailing during the winter period. RGR having a positive significant correlation with minimum temperature shows that growth would be better at higher minimum temperature. Sunshine hours showed a negative correlation with RGR . The direct effect of sunshine hours also was negative which means that indirect effects may be the cause of correlation. A positive significant correlation was seen for rainfall also.

4.8. Influence of irrigation and nutrients on yield and yield components: Mature phase.

The role of moisture and nutrients in influencing the yield of *Hevea* has been studied in a field trial started in 1991 at the Regional Research Station, Agartala, Tripura of R.R.I.I. Yield of rubber is related mostly to volume of latex, duration of flow, dry rubber content (DRC) and plugging index (PI), which in turn is related to soil moisture and nutrient content and weather parameters. The study conducted was aimed at monitoring the influence of irrigation and various doses of major nutrients viz. N, P and K on the yield and yield components of Hevea in Tripura. Results of the study are summarized below.

4.8.1 Volume of latex.

Irrigation at fortnightly intervals that maintained a soil moisture potential of -0.033 MPa (I_1) increased the volume of latex significantly in plots receiving 40 kg ha^{-1} NPK (Table 20). Volume of latex in the unirrigated plots receiving 40 kg ha^{-1} NPK was also high but not significant. Increasing the dose of fertilizers beyond the 40 kg level resulted in a yield depression. Treatments with irrigation registered a higher volume of latex compared to unirrigated plots. Comparing various treatments under irrigated and unirrigated conditions it is observed that I_1 NPK_0 had 15.7 per cent more volume of latex than I_0 NPK_0 and I_1 NPK_1 had 10.1 per cent more than I_0 NPK_1. The highest volume was recorded for treatment I_1 NPK_2, which was 17.3 per cent higher than I_0 NPK_2. In

Table 20. Influence of irrigation and nutrients on yield and yield components in a nine year old rubber planting.

Treatments	Volume	DRC	PI	Sugar (ppm)	Inorganic P (ppm)
I_1NPK_0	89.75	24.58	2.85	2970	115.66
I_1NPK_1	95.35	24.39	2.74	3370	124.86
I_1NPK_2	110.40	24.97	2.32	3450	201.04
I_1NPK_3	108.40	24.70	2.64	3140	152.06
I_0NPK_0	75.65	25.44	3.09	2660	109.47
I_0NPK_1	85.70	25.41	2.76	2660	120.47
I_0NPK_2	91.30	26.97	2.74	2930	141.26
I_0NPK_3	77.25	25.69	3.23	2920	161.54
LSD	19.00 (P=0.05)	ns	ns	410 (P=0.05)	41.56 (P=0.01)

I_1 - Irrigated NPK$_0$- No fertilizer applied NPK$_1$ - NPK at 30 kg ha^{-1}

I_0 - Unirrigated NPK$_2$ - NPK at 40 kg ha^{-1} NPK$_3$ - NPK at 80 kg ha^{-1}

Table 21.

Changes in volume of latex due to interaction of irrigation, nutrients and months.

	Irrigated				Unirrigated			
Months	0	30	40	80	0	30	40	80
January	84.0	91.0	99.0	103.0	58.5	71.0	97.5	63.5
February	21.5	27.0	33.5	28.0	34.0	23.5	26.0	23.0
April	45.0	52.5	69.5	62.5	41.5	42.5	50.5	40.5
September	63.5	72.0	72.0	74.0	61.5	56.0	67.0	68.5
October	98.0	106.0	140.5	144.0	102.0	117.5	97.0	97.5
November	141.0	180.0	170.0	165.5	110.0	120.5	127.5	143.0
December	170.5	161.5	179.0	207.5	147.5	167.0	173.5	148.5
January	124.0	127.0	166.0	157.0	108.0	94.5	103.5	103.0
February	60.0	59.0	63.0	55.5	31.5	49.0	39.5	27.0
March	89.5	77.5	111.5	87.0	62.0	115.5	131.0	58.0

F ratio : ns

plots receiving 80 kg NPK, the depression in volume of latex was noticed in both irrigated and unirrigated plots, the magnitude of depression being more in plots which were unirrigated. The effect of irrigation was seen to be particularly evident from October to January where a yield increase of 19.6 per cent was noticed in the irrigated plots compared to unirrigated plots(Table 21). Yield was significantly high in plots receiving fertilizers at 40 and 80 kg ha^{-1} with irrigation. Phosphorus and potassium has been reported to increase the volume of latex by delaying plugging. Higher levels of P and K can influence latex flow characteristics. Flow of latex is governed by P/Mg ratio (Yip and Gomez, 1980). High P is found to offset the ratio and delay plugging. Similarly high K will reduce the uptake of Mg, the combined effect resulting in delayed plugging and higher volume of latex. Increasing the level of N, P and K beyond 40 kg has been observed to depress yield. At 80 kg of N the requirement of K to maintain N/K balance will be higher. Similar is the case with phosphorus. As a result of this, P/Mg ratio is likely to affect flow of latex by changing plugging characteristics. The interrelationship of P/Mg, K/Mg ratios in latex and PI on yield of latex is depicted in figs 19 and 20. At low P/Mg values, PI was observed to be the highest resulting in the lowest yield. Highest volume of latex was obtained in a P/Mg of 1.31 to 1.37 at PI 2.32. K/Mg ratio in latex was observed to influence PI. At low K/Mg ratio, PI was the highest. Critical K/Mg ratio as evidenced by this study is 3.56 to 3.80. Potassium when applied in larger quantities can result in higher uptake of K as a result of luxury consumption and can affect the use of nitrogen, thereby affecting production of biomass and consequently biosynthesis of latex.

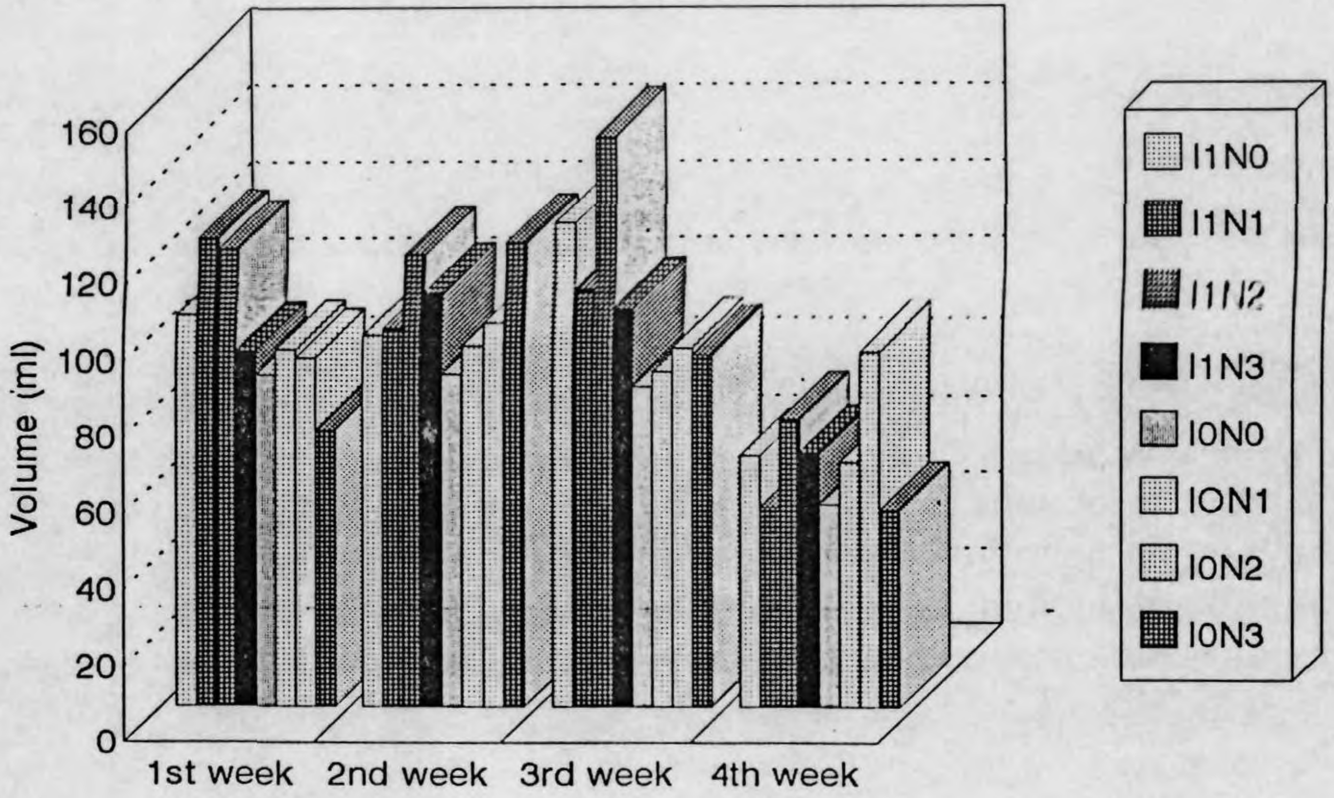


Fig.14. Influence of irrigation and nutrients on weekly yield: Jan'93

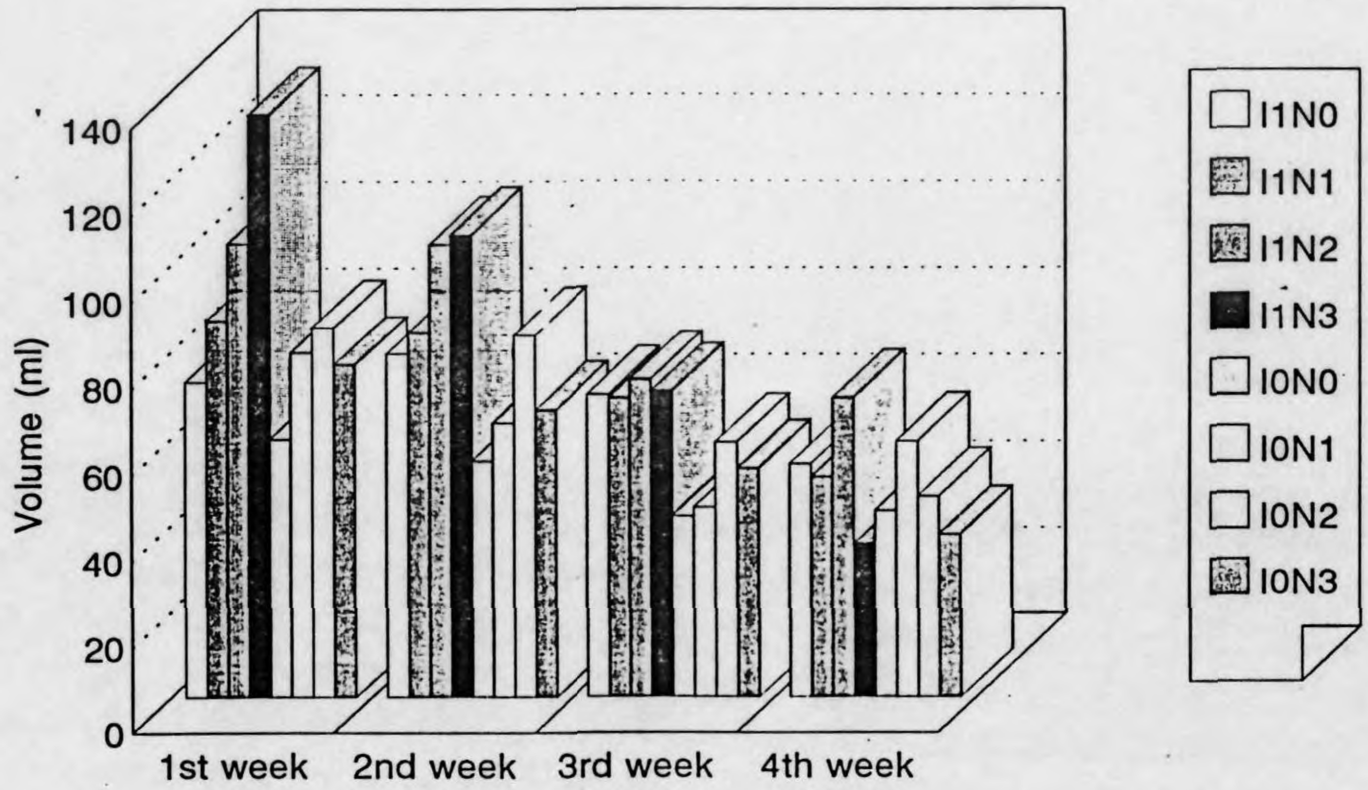


Fig. 15. Influence of irrigation and nutrients on weekly yield: Feb'93

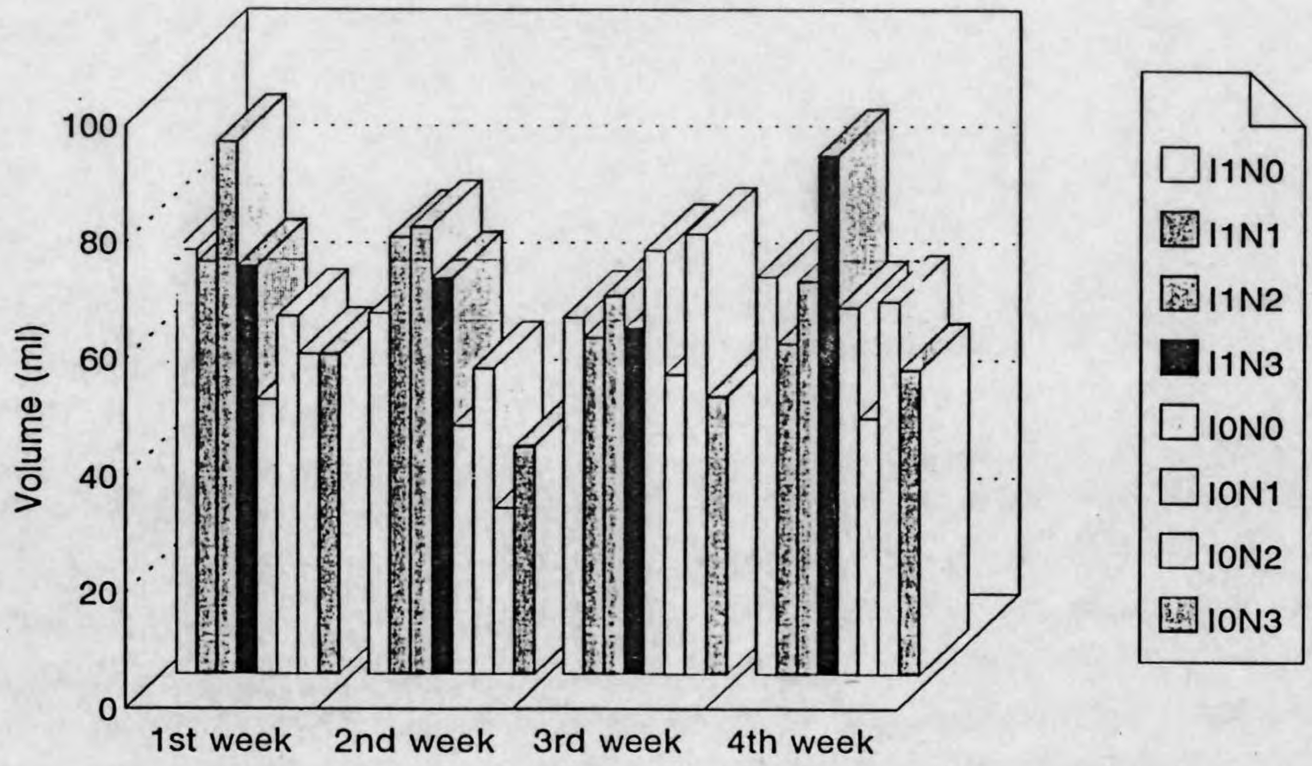


Fig.16. Influence of irrigation and nutrients on weekly yield: March'93

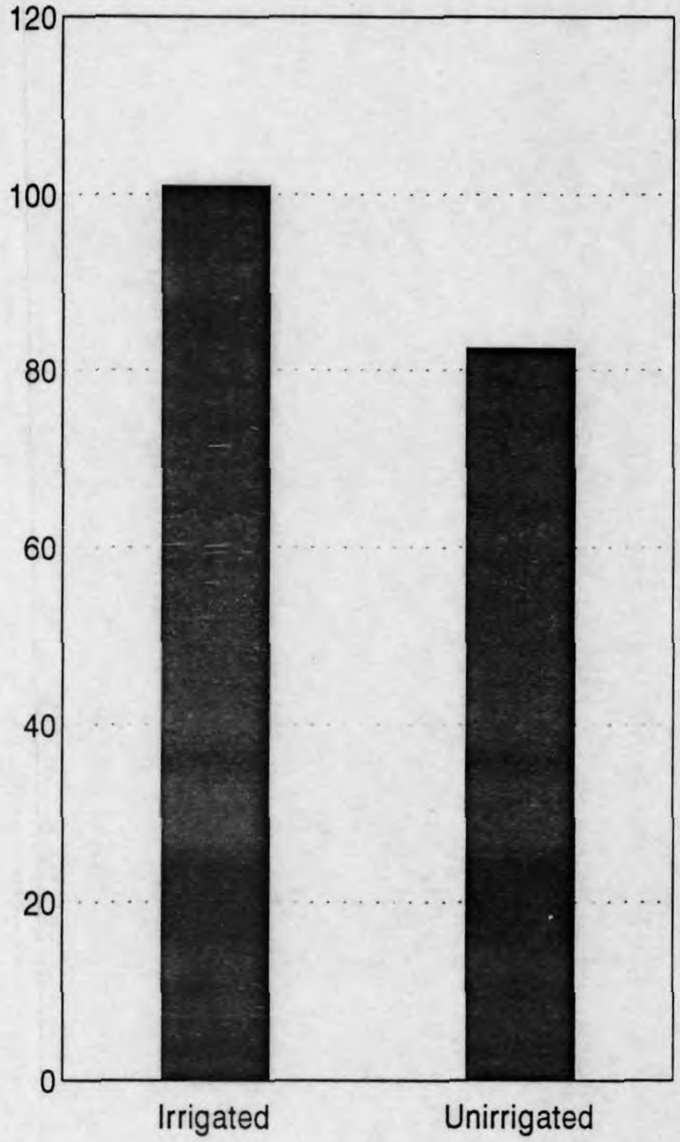


Fig. 17. Mean volume of latex per cm tapping cut (ml/cm)

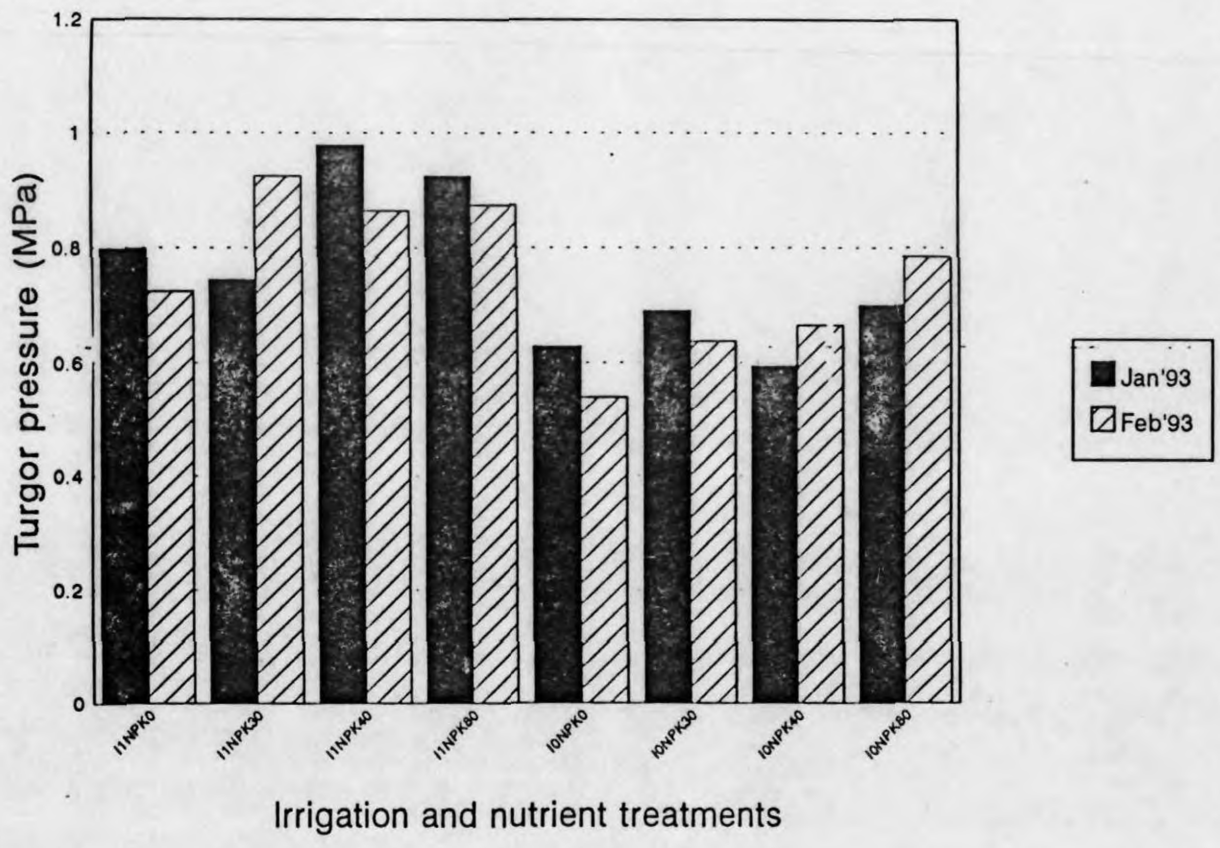


Fig.18. Latex vessel turgor

Fig. 19 Yield in relation to P/Mg in latex and PI.

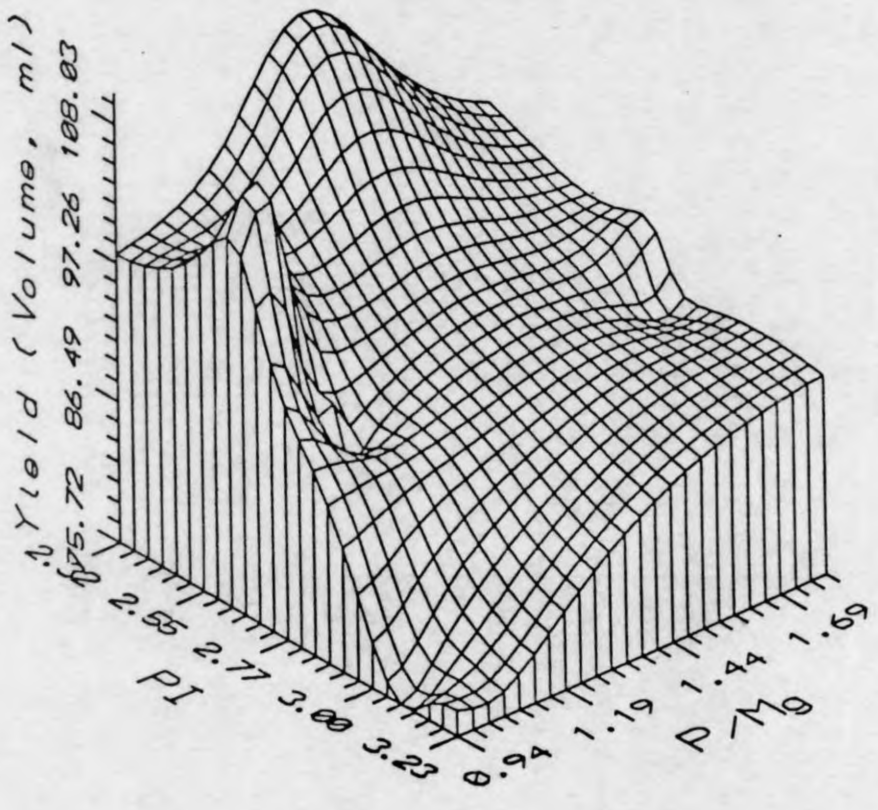
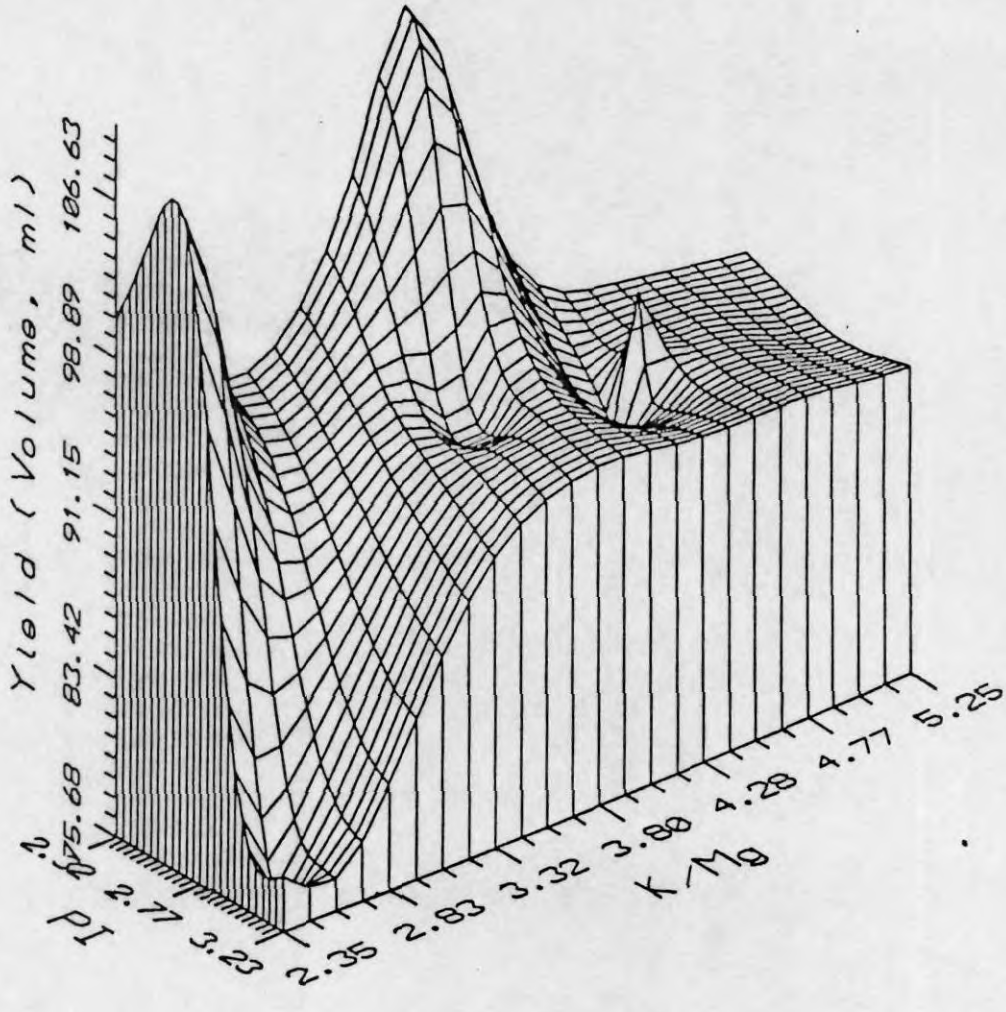


Fig. 20 Yield in relation to K/Mg in latex and PI.



To monitor the changes in yield very closely, weekly yields were taken from Jan'93 to March '93 (Fig. 14, 15 &16). Variation in yield was noticed in the different weeks during this period. During the first and second week of February, I_1 NPK$_3$ registered the highest volume of latex (Fig.15). However during third week I_1 NPK$_3$ was comparable with I_1 NPK$_0$ only, and in the fourth week the yield was low though not significant. Lowest temperature was recorded during the first week of February,93 and during this time the higher doses of nutrients with irrigation has helped to tide over winter stress as evidenced by the volume of latex generated by plants. Treatment I_1 NPK$_3$ was superior to I_1 NPK$_0$, I_1 NPK$_1$ and I_1 NPK$_2$. The positive influence of temperature gets narrowed down as temperature increased from second week of February and beyond. There was significant reduction in yield in all treatments during February (Fig.15) compared to January (Fig. 14). The extent of variation being 23.4 per cent in I_1 NPK$_2$ to 6.0 percent in I_1 NPK$_3$. There was reduction in volume during March'93 also (Fig.16). While comparing the influence of irrigation it was observed that there was a higher volume of latex in irrigated plots in all the three months. Nutrient application at 40 kg NPK has increased the volume of latex in both irrigated and unirrigated plots compared to no fertilizer applied plots during Jan, Feb and March'93. Further increase of nutrient dose reduced the volume of latex. The data suggests that efficacy of nutrient uptake and its influence on volume of latex was more pronounced when fertilizers were supplied with irrigation. In winter high level of nutrient did not help in maintaining higher volume of latex when soil moisture was a constraint. Influence of fertilizer alone has been observed to influence volume of latex favorably up to 30 kg level of NPK. However the optimum nutrient combination observed in this study is 40 kg⁻¹ NPK with irrigation. Irrigation has definitely helped plants to tide over the winter stress by maintaining a higher volume of latex in January. Reduction of yield during February and March can be attributed to the stress in plants as a result of annual leaf fall and consequent reflushing, carryover effect of low temperature and a sudden increase in air temperature from March.

Correlation studies performed using data of weekly yield (volume) during winter period (Jan, Feb and March) to assessthe influence of different treatments and meteorological parameters on volume of latex (Table 23) indicate that temperature both maximum and minimum and RH had a more pronounced influence on yield in January. The positive significant correlation of T.max during Jan and Feb'93 suggests that increase in temperature during winter has helped to maintain a higher yield. During March meteorological parameters in general did not influence yield. It can thus be inferred that irrigation in conjunction with nutrients general helped to maintain a higher yield.

Irrigation was given at fortnightly interval and volume of latex monitored weekly during January'93 (Fig.14), it was observed that the yield during the first and third week was higher than the second and fourth week. This may be due to irrigation imposition during the first and third week. By February, high yields were again recorded in the irrigated plots in the first week(Fig.15). Irrigation given during the first week was seen to influence the yield level in the second week also. Though there was a decline in the yield from the third week onwards the yield in the irrigated plots was 30 % higher than that in the unirrigated plots. Yield

Table 22. Seasonal variation of yield and yield components in a nine year old rubber planting given irrigation and nutrients.

Months	Volume	DRC	PI	Sugar (ppm)	Inorganic P (ppm)
January'92	83.44	15.64	1.96	4240	217.84
February	27.06	17.05	3.32	2870	235.55
April	50.63	31.82	5.38	2480	80.53
September	66.81	34.02	3.59	1840	58.64
October	112.81	35.36	2.38	2820	88.55
November	144.69	31.62	1.56	3810	116.99
December	169.38	22.39	1.05	4420	154.37
January'93	122.87	18.93	1.31	4860	202.35
February	48.06	23.30	5.01	1420	206.96
March	91.50	22.56	3.24	2160	123.06
LSD (P=0.01)	15.74	1.46	0.55	600	49.80

Table 23.
Relationship of total volume and meteorological parameters during Jan-March'93

January'93

	T.max	T.min	RH	SSH
I_1 NPK_0	0.674**	0.550*	0.630**	-0.233
I_1 NPK_1	0.636**	0.533*	0.674**	-0.208
I_1 NPK_2	0.552*	0.233	0.336	0.214
I_1 NPK_3	0.539*	0.306	0.291	0.029
I_0 NPK_0	0.837**	0.753**	0.758**	-0.432
I_0 NPK_1	0.549*	0.335	0.413	0.022
I_0 NPK_2	0.604*	0.460	0.520*	-0.144
I_0 NPK_3	0.834**	0.626**	0.597*	-0.225

February'93

	T.max	T.min	RH	SSH
I_1 NPK_0	0.307	-0.011	0.231	-0.092
I_1 NPK_1	-0.086	-0.243	0.059	0.128
I_1 NPK_2	0.539*	0.170	0.264	-0.210
I_1 NPK_3	0.508*	-0.017	0.286	-0.089
I_0 NPK_0	0.662**	0.315	0.542*	-0.488
I_0 NPK_1	0.609*	0.232	0.569*	-0.454
I_0 NPK_2	0.697**	0.407	0.191	-0.311
I_0 NPK_3	0.568*	0.373	0.278	-0.369

March'93

	T.max	T.min	RH	SSH
I_1 NPK_0	-0.315	-0.227	-0.233	-0.291
I_1 NPK_1	-0.210	-0.612*	-0.068	-0.119
I_1 NPK_2	-0.202	-0.628**	-0.029	-0.098
I_1 NPK_3	0.089	0.239	-0.083	0.015
I_0 NPK_0	0.426	0.479	0.014	0.276
I_0 NPK_1	0.474	-0.309	0.031	0.398
I_0 NPK_2	0.069	-0.401	0.271	0.184
I_0 NPK_3	0.199	-0.542*	-0.012	0.200

I_1 - Irrigated
I_0 - Unirrigated

NPK_0- No fertilizer applied
NPK_2 - NPK at 40 kg ha^{-1}

NPK_1 - NPK at 30 kg ha^{-1}
NPK_3 - NPK at 80 kg ha^{-1}

* significant at 5 % level.
** significant at 1 % level.

during March also showed a similar trend in all the four weeks (Fig. 16). Clearly the impact of irrigation was seen to be more pronounced during January which corresponds to peak winter period. In the traditional rubber growing region however a different seasonal pattern in latex yield is observed, with higher yield during wet months and lowest yield during dry season (Pakianathan *et al*, 1989). There are only a few reports from India on the influence of irrigation on yield from the traditional rubber growing region.

Yield was worked out on the basis of unit length of tapping cut to eliminate the variation in girth of trees and reported in ml cm^{-1} (Fig. 17). The volume of latex thus obtained was found to be 17.7 % higher in the plots which received irrigation along with nutrients, compared to unirrigated plots with nutrients. Nutrient addition of 40 kg ha^{-1} NPK gave the highest yield irrespective of irrigation treatments when the data during the entire study period was analysed (Table 20). Increase in yield by 18 % was obtained in plots with 40 kg NPK in irrigated and unirrigated plots combined, compared to no fertilizer control. However application of higher nutrient level at 80 kg ha^{-1} did not enhance the yield level. In the traditional rubber growing region Mathew *et al* (1989) observed significant yield increase in response to application of nitrogen at 80 kg ha^{-1}. Where the soil phosphorus level was low the annual mean yield showed an increasing trend with 90 kg ha^{-1} P_2O_5 application (Potty *et al*,1976). Significant yield response to added potassium at 32 kg ha^{-1} K_2O over the 16 kg level was reported by Punnoose *et al* (1994) during the 6 th, 7 th and 8 th year after commencement of tapping. The influence of major nutrients on yield could be a direct effect or the effect mediated through growth of bark, bark renewal etc. (Samsidar *et al*, 1976). Yield response to applied fertilizers was observed only after four years in some trials in Malaysia (Sivanadyan, 1973). The trial area under investigation was under the fertilizer schedule of 35 kg ha^{-1} NPK, which is the general fertilizer recommendation for Tripura. Irrigation and nutrient treatments were imposed in the 9th year of planting. Mean yield observed in the of 11th years show significant response to NPK application at 40 kg level. Soils of Tripura has been subjected to shifting cultivation and consequently most areas are degraded. Response to added nutrients as observed in this experiment proves that a higher nutrition than the one being followed will be beneficial to plants in these soils. The yield response of plants to application of 40 kg ha^{-1} NPK in this experiment suggest that the ad hoc fertilizer recommendation for mature rubber in this region which is 35 kg ha^{-1} NPK, needs to be refined for realizing the production potential of mature rubber.

4.8.2 Latex turgor pressure.

The turgor pressure of latex vessels was monitored in January and February 1993 (Fig 18). Turgor recorded in January was significantly higher turgor in the irrigated plots compared to the unirrigated plots. However, during February this was not so. This suggests that the influence of irrigation is seen to be more during the winter period of January when there is a low mean minimum temperature. Irrigation in conjunction with nutrients thus enhanced the latex turgor which was also reflected in the volume of latex during January. January appeared to be more crucial and responding more to irrigation than February. The irrigation regimen to be followed month wise need to be monitored more closely for evolving guidelines on the duration and period of irrigation to be followed during the winter stress period.

4.8.3. Dry rubber content (DRC %)

DRC was not significantly influenced by the irrigation and nutrient treatments (Table 20) when the mean DRC was evaluated over the entire period. However significant changes in DRC was seen during different months (Table 22). The irrigation, nutrient and monthly interaction on DRC content of latex was highly significant (Table 24). DRC obtained during Jan and Feb'92 irrespective of the treatments was significantly lower than that obtained between April to November ,92. During Jan and Feb'92, DRC was higher in $I_1 NPK_2$ compared to $I_1 NPK_0$. In the unirrigated plots however both $I_0 NPK_2$ and $I_0 NPK_3$ plots recorded higher DRC than no fertilizer plots. In the post winter period of April the highest DRC in irrigated plots was observed in $I_1 NPK_3$, while in the unirrigated plots the highest DRC was in $I_0 NPK_1$. During September'92 when irrigation was withdrawn, higher DRC was observed in $I_1 NPK_1$ plots. However in I_0, NPK_2 plots recorded the highest DRC the increase in DRC being 17.4 per cent over $I_0 NPK_0$. A significant drop in DRC content was noticed from November onwards in treatments $I_1 NPK_0$, $I_1 NPK_1$ and $I_1 NPK_3$ compared to the content during October. The drop in DRC in the unirrigated plots was not so drastic. The drop has been mainly due to higher latex volume obtained from Nov,92 to Jan,93, irrespective of treatments. In unirrigated plots NPK application of 30 and 40 kg ha^{-1} resulted in latex attaining a comparable DRC as that in the irrigated plots

Table 24. Changes in DRC(%) due to interaction of irrigation, nutrients and months.

	Irrigated				Unirrigated			
Months	0	30	40	80	0	30	40	80
January	16.23	15.91	15.04	18.24	14.12	15.19	15.96	14.40
February	17.50	16.26	17.87	18.14	16.59	16.77	16.87	16.37
April	31.78	25.17	33.13	33.39	31.62	33.71	33.57	32.16
September	34.18	34.98	33.22	33.00	30.64	35.16	37.10	33.90
October	35.30	38.36	34.04	33.58	34.89	34.01	35.81	36.88
November	29.50	30.50	29.83	26.78	32.39	31.62	32.45	31.87
December	20.22	22.24	24.53	19.26	27.11	23.21	28.12	22.42
January	17.45	16.64	19.18	17.88	19.83	18.48	22.06	19.91
February	22.43	21.28	19.76	24.97	23.74	24.42	25.92	23.86
March	21.13	22.57	23.11	21.70	23.45	21.55	21.88	25.12

LSD(P=0.01) : Treatments x months = 4.13

(Table 20). However, the latex volume in unirrigated plots were lower than in irrigated plots. During winter months of Dec'92 and Jan'93 there was a significant drop in DRC (Table 22). Latex volume in these months was observed to be high. The normal variation in rubber content is to the extend of 5 % and may not exceed 10 %, whereas differences in the volume of latex collected in each tapping can vary from 50 to 100 % between trees and hence the direct effect of rubber content on yield can be masked by the large difference in volume of latex (Sethuraj,1992). Seasonal variation in yield is more a function of volume of latex than rubber content.

In the irrigated and unirrigated plots 40 kg NPK kg ha^{-1} recorded the highest DRC in Dec'92 and Jan'93. During Feb'93 DRC was higher in all treatments compared to Dec'92 and Jan'93 but the corresponding latex volume in Feb'93 was low. The low latex volume and DRC observed in Feb'93 may be due to stress conditions posed by low temperature during Feb'93 (Appendix 1) on latex biosynthesis. The direct effect of climate on biosynthesis of rubber has not been studied in detail. Fall in PI during winter in China is indicative of a fall in rubber content as well (Xu and Pan, 1990). This assumes importance when viewed in the context of Tripura which is situated near the same latitude and experiencing low temperatures during winter.

4.8.4. Plugging index (PI)

PI (Milford *et al*, 1969) indicates the intensity of flow restriction mechanisms operating in the latex vessels after tapping.

Table 25. Changes in PI due to interaction of irrigation, nutrients and months.

	Irrigated				Unirrigated			
Months	0	30	40	80	0	30	40	80
January'92	2.17	1.76	1.72	1.76	1.95	2.24	1.55	2.16
February	4.09	3.02	3.17	3.18	3.12	3.49	3.16	2.36
April	4.97	5.18	3.62	4.22	5.15	5.09	5.30	5.54
September	3.54	3.40	3.05	3.30	3.82	3.35	3.57	3.94
October	2.88	2.73	2.33	1.99	2.78	2.14	2.43	2.78
November	1.83	1.30	1.31	1.24	1.72	1.43	1.34	1.34
December	1.11	0.96	1.02	1.03	1.15	1.16	1.04	1.12
January'93	1.21	1.18	1.33	0.98	1.33	1.63	1.37	1.46
February	4.08	4.20	3.50	4.38	6.00	4.81	5.18	7.11
March	2.59	3.64	2.22	4.31	3.93	2.24	2.42	4.57

LSD (P=0.05) Treatments x months = 1.55

Mathematically this index is a time flow constant. Irrigation and nutrients did not significantly influence the PI (Table 20). In general a lower PI was seen in the irrigated plots compared to the unirrigated plots. This is in agreement with the work of Haridas (1984) who showed that there is a definite influence of irrigation on the PI and yield. It is also seen that the 40 kg ha^{-1} NPK applied plots had lower PI. This could be due to the flow characteristics which increased the mean volume as a result of irrigation and nutrient addition. Influence of P and K has been observed to be more pronounced at 40 kg and the lower PI observed in this treatment may be due to the changes in P/Mg ratio brought about by P and K.

Significant seasonal variations in the PI was noticed between different months when values of all treatments were pooled (Table 22). PI values of January, February and April'92 was significantly different from each other, with lower PI in Jan which increased progressively up to April. In September also PI was high though this was significantly lower than April'92. The drop in PI continued up to December. Progressive decline in PI was accompanied by an increase in latex volume. Annual yield depends on the average values of initial flow rate, PI and rubber content over different seasons of a year. The environmental condition leading to lower initial flow and higher plugging will reduce yield. The wide fluctuation seen in PI can be considered the most sensitive yield component affected by environmental factors.

Influence of treatments and monthly interaction on PI was significant (Table 25). During October'92 to January'93 when PI started falling, lowest PI was observed in I_1 NPK_3. High latex volume obtained in

Table 26. Changes in concentration of sugar (ppm) due to interaction of irrigation, nutrients and months.

	Irrigated				Unirrigated			
Months	0	30	40	80	0	30	40	80
January'92	4650	4300	4800	3750	3950	3900	4500	4050
February	2250	4950	4350	3000	2200	2000	2150	2100
April	2150	2800	2800	2900	2200	2450	2400	2150
September	1900	1950	2100	2000	1650	1700	1850	1600
October	2250	3250	3100	2750	2100	3050	2800	3250
November	4000	4300	4000	3650	3500	3800	3900	3300
December	4750	4100	5300	4350	4500	5450	3100	3800
January'93	4250	4600	4950	5050	2950	6900	5100	5050
February	1400	1350	1250	1400	1350	1550	1550	1500
March	2050	2050	1900	2550	2250	2100	1950	2400

LSD(P=0.05): Treatments x months = 1200

this treatment in Oct'92, Dec'92 and Jan'93 suggests that NPK at 80 kg ha^{-1} could be utilized by the plants effectively in presence of adequate moisture during this period. In the unirrigated plots however, lower PI was observed in NPK_1 and NPK_2 plots.

4.8.5. Total sugars

Concentration of sugar in latex was measured and the mean values are given in Table 20. Sugar content in latex was significantly higher in I_1 NPK_1 and I_1 NPK_2 compared to other treatments. Mean values presented show that irrigation and nutrients in general has enhanced the latex sugar concentration as compared to unirrigated plots with the same nutrients. There has been a significant variation in latex sugar concentration during different months. In general significantly higher sugar concentration in latex was observed during winter months (Jan'92, Nov'92, Dec'92 and Jan'93) compared to other months (Table 22). This is in conformity with the findings of Jacob *et al* (1989). The level of sucrose in latex together with inorganic phosphorus, Mg, thiols (R-SH), pH of latex and redox potential have been implicated in the biosynthesis of rubber (Sethuraj, 1992). The higher sucrose content observed in 40 and 80 kg NPK application in irrigated as well as in unirrigated plots could be due to the fact that plants well supplied with K^+ is capable of increasing the transport rate of sucrose in the phloem by a factor of ~ 2 (Marschner, 1986). A high sucrose content in the laticifers can result in high turgor pressure and thus constitute a high potential force for the expulsion of cell contents (Pakianathan *et al*, 1989).

A significant treatment x month interaction was observed in the concentration of sugar in latex (Table 26). 40 kg ha^{-1} applied plots in irrigated and unirrigated plots recorded significantly high sugar concentration in latex in February,92 compared to other treatments. In January'92 also these treatments showed high sugar content. A build up in concentration of sugar in latex started showing by October in I_1 NPK_1, I_1 NPK_2 and I_0 NPK_3 plots. High latex sugar was recorded during the period from November'92 to January'93 in 40 and 80 kg NPK applied plots. In February'93 a sharp decline in sugar was observed. A resultant decline in volume of latex suggests that sugar is important in latex production. Irrigation has helped in higher production of sugar. Many authors have demonstrated an important role for sucrose in latex production (Auzac and Pujarniscle, 1961 ; Esbach *et al*, 1986 ; Low, 1978; Tupy, 1969 ; Tupy and Primot, 1976). A high content of sucrose may indicate good loading of this precursor to the laticifers. Prevot *et al* (1984) has suggested that a high sucrose content in latex may also indicate low metabolic utilization of sucrose and hence low productivity .

4.8.6. Inorganic phosphorus (Pi)

The concentration of Pi in the latex was measured and the content was seen to be significantly influenced by the different treatments (Table 20). There was a higher content of Pi in the 40 kg NPK applied irrigated plots and 80 kg NPK applied in the unirrigated plots. Significant variation of Pi was seen during the different months. A higher content was observed during the winter period (Table 22). Since the Pi content indicates the energy metabolism of latex influencing energy transfer and isoprene synthesis (Jacob *et al*,1989), higher Pi obtained during winter might have led to high yield during this period.

4.9. Interrelationships among yield , yield components and meteorological parameters.

Yield is the integrated effect of yield components and their relationship with the environmental factors. In order to interpret variation in yield the interrelationship existing between yield and the component factors needs to be understood. Information on yield of *Hevea* and its relation with plant and non-plant factors is available (d' Auzac et al, 1989, Sethuraj and Mathew, 1992). Studies on the interrelationship of yield, its components and meteorological parameters are however scanty. Therefore the interrelationship of yield, yield components and meteorological parameters were worked out based on the results obtained from the experiment in the mature phase using correlation analysis (Table 27). DRC was not significantly correlated to volume of latex. Plugging index showed strong negative correlation with volume of latex. Correlation between PI and yield has been demonstrated by several authors (Milford *et al*, 1969; Paardekooper and Somosorn, 1969). Seasonal variation in PI is noticed and this is considered as a sensitive yield component affected by environmental factors (Sethuraj,1992). Inorganic phosphorus did not show any significant relation with volume of latex. However, sugar was positively related to volume of latex. T.max showed a negative relationship with volume. Production of latex has been reported to be optimum at a temperature of 26 - 28° C (Shangpu, 1986). High temperature was found to retard latex flow and reduce yield (Lee and Tan,

Table 27

Interelationship of yield, components of yield and meteorological parameters

	DRC	PI	Pi	Sugar	Tmax	Tmin	RH	WS	SSD	Evapo	Rain	Volume
DRC	1.000	0.254	-0.510	-0.274	0.837	0.793	0.060	0.331	0.235	0.382	0.518	0.073
PI	0.254	1.000	-0.087	-0.591	0.549	0.233	-0.553	0.768	0.147	0.654	0.519	-0.714
Pi	-0.510	-0.087	1.000	0.207	-0.490	-0.517	-0.014	-0.232	-0.170	-0.264	-0.222	-0.093
Sugar	-0.274	-0.591	0.207	1.000	-0.461	-0.289	0.396	-0.493	-0.064	-0.355	-0.596	0.482
Tmax	0.837	0.549	-0.490	-0.461	1.000	0.827	-0.274	0.729	0.358	0.759	0.523	-0.198
Tmin	0.793	0.233	-0.517	-0.289	0.827	1.000	0.055	0.404	0.077	0.508	0.382	-0.035
RH	0.060	-0.553	-0.014	0.396	-0.274	0.055	1.000	-0.661	-0.639	-0.565	-0.018	0.282
WS	0.331	0.768	-0.232	-0.493	0.729	0.404	-0.661	1.000	0.348	0.944	0.319	-0.535
SSD	0.235	0.147	-0.170	-0.064	0.358	0.077	-0.639	0.348	1.000	0.402	-0.251	0.325
Evapo	0.382	0.654	-0.264	-0.355	0.759	0.508	-0.565	0.944	0.402	1.000	0.140	-0.423
Rain	0.518	0.519	-0.222	-0.596	0.523	0.382	-0.018	0.319	-0.251	0.140	1.000	-0.443

n=160

* Significant at 5 % level
** Significant at 1 % level

1979). Minimum temperature did not show significant correlation with volume. Sunshine duration (SSD) had a positive and strong relationship with yield. This assumes significance since the area experiences low temperature during winter. The availability of longer SSD during this period might have helped in the biosynthesis of rubber. Effect of SSD on crop growth and productivity is often mediated through its effects on photosynthesis and crop water requirement. In the traditional regions lower latex production during rainy season can be attributed to reduced sunshine hours (Rao and Vijayakumar,1992). The influence of RH on yield was also positive and significant. Evaporation and rainfall exerted a negative influence on volume of latex. The trend in the relationship was similar when yield from individual treatments were correlated with the yield components and meteorological parameters (Table 29).

4.10. Direct and indirect effects of yield components and meteorological parameters on yield: Path analysis .

Path analysis was performed to quantify the interaction between the independent variables and measure their contribution to the dependent variable. Direct and indirect effects of each variable contributing to the yield is established. A significant path coefficient between the dependent and independent variables indicate that a change in one will result in a relative change in the other when additional influences are removed (Chandrashekar, 1994).

Table 28
Direct (diagonal elements) and indirect (off diagonal elements) effect of yield, yield components and meteorological parameters

	DRC	PI	Pi	Sugar	Tmax	Tmin	RH	WS	SSD	Evapo	Rain	
DRC	**0.081**	-0.119	0.010	-0.032	0.229	0.088	0.007	0.102	0.116	-0.291	-0.118	0.073
PI	0.021	**-0.467**	0.002	-0.070	0.150	0.026	-0.068	0.236	0.072	-0.498	-0.118	-0.714
Pi	-0.041	0.041	**-0.020**	0.025	-0.134	-0.058	-0.002	-0.071	-0.084	0.201	0.051	-0.093
Sugar	-0.022	0.276	-0.004	**0.118**	-0.126	-0.032	0.049	-0.151	-0.031	0.271	0.136	0.482
Tmax	0.068	-0.256	0.010	-0.055	**0.274**	0.092	-0.034	0.224	0.176	-0.579	-0.119	-0.198
Tmin	0.064	-0.109	0.010	-0.034	0.226	**0.111**	0.007	0.124	0.038	-0.387	-0.087	-0.035
RH	0.005	0.258	0.000	0.047	-0.075	0.006	**0.124**	-0.203	-0.315	0.431	0.004	0.282
WS	0.027	-0.358	0.005	-0.058	0.200	0.045	-0.082	**0.307**	0.172	-0.719	-0.073	-0.535
SSD	0.019	-0.069	0.003	-0.008	0.098	0.009	-0.079	0.107	**0.493**	-0.306	0.057	0.325
Evapo	0.031	-0.305	0.005	-0.042	0.208	0.057	-0.070	0.290	0.198	**0.762**	-0.032	-0.423
Rain	0.042	-0.242	0.004	-0.071	0.143	0.043	-0.002	0.098	-0.124	0.107	**-0.228**	-0.443

R square 0.793
Residual 0.454

Table 29. Correlation coefficients of yield in relation to yield components and meteorological parameters.

	DRC	PI	Pi	Sugar	T.max	T.min	RH	WS	SSD	Evap	Rain	Yield
$I_1 N_0$	0.110	-0.767	0.117	0.695**	-0.299	-0.175	0.215	-0.574*	0.402	-0.493	-0.544*	1.00
$I_1 N_1$	0.175	-0.766**	-0.093	0.329	-0.185	-0.032	0.361	-0.593	0.315	-0.455	-0.486	1.00
$I_1 N_2$	0.141	-0.721**	-0.297	0.417	-0.162	0.024	0.278	-0.547*	0.356	-0.411	-0.453	1.00
$I_1 N_3$	-0.124	-0.788**	0.298	0.599*	-0.239	-0.103	-0.068	-0.562*	0.295	-0.449	-0.456	1.00
$I_0 N_0$	0.303	-0.720**	-0.236	0.619*	-0.208	-0.039	0.378	-0.581	0.240	-0.460	-0.406	1.00
$I_0 N_1$	0.017	-0.747**	-0.045	0.524*	-0.162	0.013	0.146	-0.485	0.419	-0.393	-0.362	1.00
$I_0 N_2$	0.061	-0.743**	-0.434	0.353	-0.262	-0.022	0.197	-0.523*	0.403	-0.420	-0.546	1.00
$I_0 N_3$	0.209	-0.696**	0.009	0.535*	-0.132	0.053	0.437	-0.587	0.261	-0.438	-0.427	1.00

I_1 - Irrigated N_0- No fertilizer applied N_1 - NPK at 30 kg ha^{-1}

I_0 - Unirrigated N_2 - NPK at 40 kg ha^{-1} N_3 - NPK at 80 kg ha^{-1}

4.10.1. Direct effects.

Path analysis results revealed that T.max, PI, SSD, evaporation and rainfall are the major variables directly affecting yield (Table 28). Comparison of "r" with direct effects of these variables indicated a true relationship of latex volume with SSD and rainfall because correlation coefficients and direct effects were similar both in sign and magnitude (Singh and Chouhhury,1985). While the direct effects of PI, evaporation and rainfall was negative, T.max, and SSD were positive. In the order of relative importance, evaporation was first followed by T.max, PI, SSD and rainfall. Direct effects of DRC, Pi, Sugar and T.min was not of much consequence.

4.10.2. Indirect effects.

Indirect effect of wind speed (WS) affecting volume of latex was through PI, T.max, (SSD) and evaporation. The direct influence of T.max was positive while the indirect effect of T.max via evaporation was negative. Indirect effect of RH on yield was through PI, evaporation and SSD. Though the direct effect of WS on yield was positive, the indirect effects were actually responsible in influencing yield through evaporation, PI and T.max. Indirect effects of PI via other yield components were negligible. However indirect of sugar via PI was good. A good indirect effect of sugar via PI indicates that PI is influenced by sugar.

Correlation analysis has pointed out that PI, latex sugar concentration, T.max, RH, WS, SSD and Rain are the primary factors affecting yield. However, path analysis results showed that PI, SSD and evaporation are the primary factors directly affecting yield. The other variables are secondary, mainly acting through the primary factors.

4.10.3. Residuals.

Residual value of 0.46 obtained in path analysis in this study indicated that only 56 percent of the variability in yield was explained by the factors included and 46 percent due to factors not considered in this study. When the variables of latex yield, rubber content, initial flow rate, turgor pressure, latex solute potential and girth were included Chandrashekar (1994) reported 42 percent variability in yield.

CHAPTER V

SUMMARY AND CONCLUSIONS

Rubber cultivation is taken up in Tripura in a big way to meet the growing demand of rubber. Rubber planted in this non-traditional region encounters stresses of various kinds unlike those in the traditional region. Specific agromanagement practices to overcome the stresses encountered in this region are therefore needed. A field experiment was taken up to study the influence of nutrients and soil moisture in modulating the growth of young *Hevea* plants in the early years of planting in Tripura.

5.1. Immature phase.

Higher moisture availability increased plant height. The influence of moisture on plant height was more pronounced during winter. Nitrogen, phosphorus and potassium application at 40 kg ha^{-1} was found to improve plant height. Plant girth also responded to higher moisture regime during Jan-Apr'93. NPK application of 40 kg ha^{-1} produced the highest number of whorls.

From the early growth period biomass production was significantly influenced by high soil moisture availability. The influence was higher during December to April. Biomass production was enhanced by NPK application of 40 kg ha^{-1}. A higher RGR was observed in -0.03 MPa moisture regime during Oct-Dec'92 and from Jan-Apr'93. RGR was also found to be positively correlated with temperature both maximum and minimum.

In general root biomass was higher in -0.03 MPa compared to -0.50 MPa moisture regime. In the -0.03 MPa moisture regime highest root biomass was observed in 23-46 cm depth while in -0.50 MPa it was in the top layer (0-23 cm). Application of NPK at 40 : 80 : 40 kg ha^{-1} registered the highest root biomass.

Availability of higher soil moisture level influenced the physiological processes of plants. Transpiration of plants was higher in -0.03 MPa and -0.10 MPa than in -0.50 MPa moisture regime. The extent of reduction in transpiration in -0.50 MPa was higher during winter. Nitrogen and potassium at higher doses showed a regulatory influence on transpiration. Stomatal conductance of plants growing in -0.03 MPa moisture regime was higher. A lower g_s was recorded in plots receiving high P and K nutrition. The influence of soil moisture and nutrient interaction on g_s was significant during the winter period.

Bark nutrient content increased with higher level of nutrient application in the case of N and .K. Bark Ca was lower in NPK applied plots. Bark N was higher in -0.50 while bark K was higher in -0.03 MPa moisture regime.

.Leaf nutrient status was also observed to increase progressively with higher nutrient addition in soil. Leaf N values was in the high range of critical level when 40 kg ha^{-1} NPK was applied. Leaf P was in the low to medium range while leaf K was in the medium range even at the highest level of application (80 kg ha^{-1}).

The study revealed that during immature phase, the growth pattern of young *Hevea* plants which are subjected to environmental stress can be regulated to a certain extent by appropriate management of soil moisture and nutrients. Stress factors mainly, low temperature coupled with low soil moisture affect plant growth during the period from October to April. The extent of impact of stress varies from year to year. The results of the study in the immature phase show that maintaining a higher soil moisture level helps the plants to mitigate the stress factors as evidenced by the growth performance and higher physiological activity. Similarly different levels and combinations of nutrients also were seen to influence and regulate the growth pattern. The plants showed better response to phosphorus than the other two nutrients. Higher levels of P has been observed to maintain a higher growth rate during winter. Maintaining the soil moisture in the range of -0.03 to -0.10 MPa with higher doses of P can help plants tide over stress conditions. In N.E. India it has been observed that when the temperature drops below 10°C plant growth is affected considerably. The most promising high yielding clone RRII 105 is affected by winter stress in this region (Sethuraj *et al*, 1989). During the early establishment period moisture and nutrient management can offset the deleterious effect of winter. The results obtained in this study indicate that an NPK combination of 40 kg ha^{-1} has been effective when applied along with irrigation to a level of -0.03 MPa. Irrigation to maintain a soil moisture tension of -0.03 to -0.10 MPa at least during the years when temperature falls below 10°C would definitely help maintaining a satisfactory growth rate. Irrigation could also be considered when there is late planting and when plants cannot be established before the onset of winter. Though the growth pattern of *Hevea* is influenced by the total rainfall, the distribution pattern is important. In Tripura after November there is a prolonged dry spell up to April. The soil moisture management through irrigation is therefore crucial for maintaining a steady growth rate.

5.2. Mature phase.

In the mature phase of *Hevea* yield is observed to be related to the climatic conditions. Latex flow pattern is altered when the temperature drops during winter. A field experiment was started in October 1991 at RRS, Tripura to study the influence of irrigation and selected nutrient combinations on the performance of mature rubber during different months.

Irrigation and NPK application of 40 kg ha^{-1} significantly increased the volume of latex. Effect of irrigation was most evident from October-January when nearly 20 per cent yield increase was obtained. Yield of latex was found to be related to yield components and meteorological parameters. Irrigation helped in raising the volume yield of latex by 18 per cent over the entire period. Monthly variations in yield was noticed and higher volume of latex was obtained during October-January. Flow of latex is influenced by P/Mg ratio in latex (Yip and Gomez, 1980). In this study a critical P/Mg ratio of 1.31 to 1.37 and a K/Mg ratio of 3.56 to 3.80 in latex was found to be associated with high yield. Turgor pressure of latex vessels was found to be higher in the irrigated plots.

A lower DRC was observed during January, February and March. In the irrigated treatments the DRC content was lower than in the unirrigated plots but the volume of latex showed the opposite trend. Treatment effects on PI was not significant. However a lower PI was observed in the irrigated plots. Seasonal variation in PI was observed. Plots supplied with 40 kg ha^{-1} NPK showed low PI. Concentration of sugar in latex showed that irrigation and nutrients enhanced the latex sugar concentration in I_1 NPK_{30} and I_1 NPK_{40} plots. A higher inorganic phosphorus content was observed during winter period

The interrelationship of yield, yield components and meteorological parameters showed that PI was strongly and negatively correlated to volume of latex. T.max also showed negative relation with yield. Sugar concentration in latex, SSD and RH showed positive and significant relationship with yield. Results of path analysis to delineate the direct and indirect effects on yield revealed that T.max, PI, SSD, evaporation and rainfall are the major variables directly affecting yield, Direct effects of DRC, Pi, sugar and T.min was not of much consequence. Variability in yield up to 56 per cent was explained by factors considered in this study.

The study of the mature phase of *Hevea* has revealed that the influence of irrigation along with higher than the current recommended dose of nutrients, augment the yield level considerably. Irrigation is not normally practiced in the traditional regions during summer months, nor it is being done in N.E. India. Whenever higher productivity is targeted, irrigation to provide a soil moisture regime in the range of -0.03 MPa at least during winter months will be necessary for trees to withstand stresses during this period. The present study has provided useful information which may be used for refining the present agromanagement practices in Tripura. The following guidelines are suggested.

1. Irrigation to provide a soil moisture regime of -0.03 to -0.10 MPa during winter period from Oct-Jan is necessary to promote uniform growth and yield.

2. The present recommendation of 35 kg ha^{-1} NPK for mature rubber need to be revised to 40 kg ha^{-1} NPK for realizing the production potential of rubber in Tripura.

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Appendix. I Meteorological parameters of the study site from 1991 - 1993.

Year	Month	Temperature Max (°C)	Temperature Min (°C)	RH FN (%)	RH AN (%)	Wind speed (km/hr)	Sun-shine (hr)	Evapo-ration (mm)	Rain fall (mm)
1991	January	25.0	9.9	97	66	2.1	7.6	2.4	23.2
	February	29.0	15.3	85	42	3.7	7.6	3.6	40.6
	March	33.0	19.5	88	58	4.5	8.9	5.3	83.6
	April	33.6	22.1	87	55	7.1	7.3	4.3	163.9
	May	31.5	21.8	90	75	6.5	3.6	2.6	812.7
	June	32.0	25.0	92	81	8.5	3.6	2.6	263.5
	July	32.5	25.4	92	78	8.5	4.5	3.6	153.8
	August	32.6	24.9	91	71	6.3	5.3	3.5	282.9
	September	30.7	24.4	92	75	5.6	3.5	2.6	280.2
	October	31.3	22.3	92	67	2.9	5.6	2.6	278.2
	November	29.3	14.9	93	57	1.7	8.3	3.4	0.0
	December	25.5	11.0	92	61	2.0	7.1	2.1	137.2
1992	January	24.0	10.4	93	58	2.0	6.5	1.6	0.0
	February	25.7	12.6	91	47	3.3	5.9	2.2	73.2
	March	31.0	21.6	93	42	9.2	8.1	5.3	0.0
	April	35.1	23.1	88	50	9.8	8.2	5.1	56.4
	May	32.7	22.3	93	64	5.9	7.3	4.1	278.4
	June	32.6	25.5	91	40	6.2	5.4	3.9	214.0
	July	31.4	28.7	92	78	7.5	4.0	2.0	196.2
	August	31.5	25.4	92	73	4.9	4.7	2.2	121.8
	September	32.2	24.4	93	72	4.6	6.1	2.2	192.8
	October	31.1	23.3	92	66	2.9	7.0	2.1	158.2
	November	29.8	21.4	92	52	1.6	7.6	1.9	2.0
	December	26.1	10.0	91	43	1.8	8.1	1.5	0.0

cont......

1993	January	24.7	10.4	91	43	2.4	6.6	1.5	0.0
	February	28.5	8.5	88	45	4.9	7.7	2.1	153.4
	March	28.6	20.8	88	37	4.7	7.7	2.5	48.6
	April	32.8	19.7	88	56	4.4	7.7	2.7	115.2
	May	30.7	20.6	89	75	5.1	7.2	2.2	723.4
	June	31.7	23.2	90	75	7.9	4.8	1.9	523.4
	July	31.4	28.7	86	97	7.5	4.0	2.0	196.2
	August	33.6	25.0	90	82	6.9	3.2	2.3	196.2
	September	31.5	24.4	93	78	3.8	4.5	1.7	235.8
	October	32.0	22.9	94	72	2.1	5.9	2.4	104.4
	November	29.0	16.9	94	59	1.4	8.1	2.2	82.0
	December	27.5	11.8	93	44	1.4	8.3	1.6	0.0