INTER-RELATIONSHIP OF APPLIED NUTRIENTS ON GROWTH, PRODUCTIVITY AND LATEX FLOW CHARACTERISTICS OF *Hevea brasiliensis* Muell. Arg.

BY

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "Inter-relationship of applied nutrients on growth, productivity and latex flow characteristics of *Hevea brasiliensis* Muell. Arg." is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship, or any other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled "Inter-relationship of applied nutrients on growth, productivity and latex flow characteristics of *Hevea brasiliensis* Muell. Arg." is a record of research work done independently by Sri. K.I Punnoose under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship, or associateship to him.

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INTRODUCTION

INTRODUCTION

Natural Rubber which has multifarious uses in the daily life of man is nature's one of the most versatile industrial raw materials. Hevea brasiliensis MUELL-ARG., commonly called the Para rubber tree produces 99 per cent of the world's natural rubber (George *et al.* 1980). Rubber is predominantly grown in countries enjoying a tropical climate.

In India, commercial cultivation of rubber was started in Kerala in 1902. It's cultivation was later extended to parts of Tamil Nadu and Karnataka states and gradually to the Andaman and Nicobar islands. Subsequently it was introduced to the North-Eastern states and to the states of Andra Pradesh, Maharastra, Orissa and Goa. The area under rubber cultivation in India by the end of 1991-92 was 4.5 lakh ha(Rubber Board, 1991). The production of natural rubber during the period 1991-92 was 3.7 lakh tonnes (All India Rubber Industries Association, 1992). Now, about 85 per cent of the total area under rubber cultivation is in Kerala State and the three South Indian States viz: Kerala, Tamil Nadu and Karnataka jointly account for 92 per cent of the total area (Rubber Board, 1991).

The per hectare productivity of the crop increased from 284 kg ha^{-1} in 1950-51 to 1075 kg ha^{-1} in 1990-91 (Rubber Board, 1991). This has been achieved through the use of high yielding clones and by the adoption of scientific cultivation practices. The domestic production and consumption of natural rubber were increasing side by side at a fast rate. However, during the last few years consumption used to overtake domestic production and this necessitated import of natural rubber to the tune of about 30,000 tones a year (Rubber Board, 1991). With a view to increasing production, attempts are being made to extend rubber cultivation to more areas in the non-traditional tracts. It is equally or even more important to increase total production by enhancing the productivity in traditional areas which are ideally suited for rubber cultivation. The productivity can be increased by planting high yielding clones as well as by scientific cultivation practices. The former takes considerable time while the latter can be achieved in a shorter period.

Scientific manuring is an important agro-management practice by which yield of rubber trees can be improved in a relatively short period. Work done by the Rubber Research Institutes of Malaysia, Sri Lanka and India have clearly established the need for scientific manuring for maximising the yield of rubber.

The present general recommendation for rubber under tapping is 30 kg each of N, P_2O_5 and K_2O ha^{-1} yr^{-1}. But reports from elsewhere indicated that rubber responded to higher levels of fertilizers. However, experimental evidences are few under Indian conditions to support this. So there is need for increasing the per hectare productivity of rubber with higher levels of N,P and K fertilization.

Investigations on the inter-relationship of nutrients and the intraction between soil, leaf and latex nutrients are likely to give important clues for scheduling fertilizer application. Such studies of a comprehensive nature are very much limited.

The present study has been conducted in three locations. Kulasekharam represents Tamil Nadu and Balussery represents North Kerala and Karnataka. Thodupuzha represents the middle belt of Kerala where rubber is extensively cultivated. Hence the trial has been located in such a way as to represent three agroclimatic regions to cover almost 92 per cent of the rubber growing area in the country.

Since, rubber is a perennial crop, and destructive sampling is neither feasible nor possible, the need for soil/tissue analysis is felt very much for scheduling fertilizer application. Hence an attempt is made to identify the material to be analysed to determine the requirement of nutrients.

Hence the investigation is carried out with the following objectives.

(1) To assess the response to nutrient applications on growth characters, yield and latex flow characteristics.

(2) To determine the inter-relationship between soil and plant nutrients on yield.

(3) To ascertain the relative response to nutrient applications in different agroclimatic situations

(4) To make economic analysis of manuring

(5) To identify the specific material for nutrient diagnosis.

REVIEW OF LITERATURE

2 REVIEW OF LITERATURE

The present study involves investigations of applied nutrients on growth, yield, latex flow characteristics and nutrient concentrations in soil, leaf and latex of rubber. In order to obtain maximum benefits from nutrients applied through fertilizer, the interaction between various nutrients and the inter-relationship among different plant and soil characters have to be clearly understood. The present state of knowledge on these aspects is reviewed here.

2.1 Effects of applied nutrients

Application of N,P, K and Mg have been found to influence various growth and yield characters, latex flow characteristics and nutrient status of soil, leaf and latex.

2.1.1 Effect of nutrients on growth

The effect of applied nutrients on various growth characters of rubber viz., girth, girth-increment, bark thickness, rate of bark renewal and leaf litter addition reported by different workers are reviewed.

Jeevaratnam (1965) reported that adequate nourishment implies a situation where none of the essential nutrients for plant growth is allowed to become a factor limiting growth at any stage of the plant's life history. A mature stand of rubber producing about 1400 kg rubber ha^{-1} yr^{-1} requires 39 kg N, 8 kg P_2O_5, 34 kg K_2O and 11 kg MgO for growth alone annually (Rubber Research Institute of Malaya, 1972).

Owen et al. (1957), Rubber Research Institute of Malaya (1965b), Potty et al. (1980) and Rubber Research Institute of Sri Lanka (1983) reported that manuring improved the girth of trees under tapping. The beneficial effects of manuring on girth increment of trees were reported by Rubber Research Institute of Malaya (1940), Owen et al. (1957), Mainstone (1969) and Pushparajah and Haridas (1977).

Dijkman (1951) emphasised that when nutrients were in deficiency the bark development especially regeneration of tapped bark was affected. Plants receiving complete nutrients gave more bark thickness (Samsidar BTE Hamzah et al. 1975). Reports of Rubber Research Institute of Malaya (1940) indicated that the effects of manures upon bark renewal were appreciable. Owen et al. (1957) and Pushparajah (1969) indicated that adequate manuring was necessary for the proper renewal of tapped bark.

2.1.1.1 Nitrogen

George (1963) reported that the response in girth to application of N increased with age of the tree. Reports of the Rubber Research Institute of Malaya (1965a, 1965b and 1971c) indicated that there was significant response in girth to application of N fertilizers. Shortage of N resulted in poor tree growth. Rubber Research Institute of Sri Lanka (1983) and

Sivanadyan and Gandimathi (1985) emphasised that N fertilizers improved the girth of trees. Dissanayake and Mithrasena (1986) obtained increased stem diameter by application of medium levels of N. Reports of the Rubber Research Institute of Sri Lanka (1986 and 1987) revealed that girth increment over an eleven year period gave significant response to N.

Owen *et al.* (1957) reported that the effect of N on girth and girth increment became more and more noticeable with time. Bolton (1964) and Kalam *et al.* (1980) obtained increased girth and girth increment from application of N fertilizers. Potty *et al.* (1980) reported that increasing the level of N from 30 to 60 kg ha^{-1} improved girth and girth increment of rubber trees. Pushparajah *et al.* (1983) noticed small responses in girth increment from N application. Sivanadyan (1983) obtained positive responses in girth to N applications in a set of five experiments. Clone GT1 gave good girth increment to N manuring. Yogaratnam and Weerasuriya (1984) reported positive response in girth to N applications. Girth increment over an eight year period was very marked with 12 and 24 per cent increases for first and second levels of N application. Report of the Rubber Research Institute of Malaysia (1976) indicated that application of N increased the amount of leaf litter returned annually to the soil.

2.1.1.2 Phosphorus

George (1963) reported that the main response in growth of mature rubber was for P application. Pushparajah *et al*. (1977) observed that P fertilizers were required for maximum growth of *Hevea* trees. Significant response in girth to application of P was observed by Rubber Research Institute of Malaysia (1978), Pushparajah *et al*. (1983) and Rubber Research Institute of Sri Lanka (1983). Owen *et al*. (1957) obtained significant and positive girth increment from application of P fertilizers. Bolton (1964) reported that application of P as rock phosphate increased both girth and girth increment of trees in Malaysia.

2.1.1.3 Potassium

Bolton (1964) and Guha and Pushparajah (1966) obtained positive response in girth and girth increment from application of K fertilizers. Reports of the Rubber Research Institute of Malaya (1971a and 1971b) indicated that lack of K resulted in poor girth. Application of K improved girth and girth increment. Potassium also encouraged good regeneration of bark and helped in maintaining healthy trees. Pushparajah *et al*. (1974) observed that K is important for good bark renewal. When fertiliser was withheld for a year or two the bark renewal during the period was poor. Reports of the Rubber Research Institute of Sri Lanka (1983, 1986 and 1989) indicated that application of K improved girth and girth increment of trees. Only medium levels of applications were required.

Owen *et al*. (1957) reported that there was no response in growth to K in most trials and negative effect was noticed in some cases. Punnoose *et al*. (1975) and Kalam *et al*. (1980) observed that higher levels of K depressed growth. There was relatively no response to K in growth (Pushparajah *et al*. 1983). Weerasuriya and Yogaratnam (1988) reported that only moderate levels of K were required for growth. At higher levels of application, K retarded growth.

2.1.1.4 Magnesium

Bolton and Shorrocks (1961) and Shorrocks (1965c) reported that application of magnesium lime stone increased the growth rate of rubber trees. Guha and Pushparajah (1966) obtained 8.5 to 14.3 per cent increased girth from Mg application. Reports of the Rubber Research Institute of Malaya (1969a and 1969b) indicated that Mg incorporation in fertilizer mixtures greatly improved growth. Where Mg deficiency occurred application of Mg fertilizers was found to increase rate of girth increment. Pushparajah *et al*. (1983) observed small responses in girth increment to Mg application. Report of the Rubber Research Institute of Sri Lanka (1987) indicated that application of moderate levels of Mg significantly increased girthing. Weerasuriya and Yogaratnam (1988) also obtained significant increases in girth of trees from Mg application.

2.1.1.5 Nutrient interactions on growth

Owen et al. (1957) obtained both positive and negative NP interactions of applied nutrients on growth in independent experiments. A positive NK interaction was also noticed in some cases. They also emphasised the importance of PK and NPK interactions on growth. Bolton and Shorrocks (1961) observed positive NP interaction and George (1963) obtained positive NK interaction on girth of trees. Reports of the Rubber Research Institute of Malaya (1971a and 1971b) indicated that, if K status of tree were low, application of N alone could depress growth. In such cases further increase in growth could be achieved by applying N in combination with K. It was also reported that in some situations growth of trees could be further increased by application of K in the presence of N than when applied alone. Yogaratnam and Weerasuriya (1984) obtained significant interaction between K and Mg on girth increment over a period of seven years.

It is seen that complete manuring in many cases improved girth of trees under tapping. Manuring was also important for regeneration of the tapped bark and when nutrients were in deficiency bark development was affected. The girth and girth increment of the tree were improved by application of N fertilizers. Application of N also enhanced leaf production.

Application of P had very favourable effect on girth and girth increment of the tree. Application of K while improving the girth and girth increment was also important for bark development. Regeneration of bark was affected when the supply of K was limited. However, higher levels of application of K depressed growth in some cases. When soils were low in Mg, its application enhanced the growth of trees.

2.1.2 Effect of nutrients on latex flow characteristics

Pushparajah et al. (1975) opined that K has important role on latex flow characteristics and stability of latex. Pushparajah (1977) reported that K generally had the largest effect on latex flow both in terms of flow rate and yield. Nitrogen, while increasing yield and duration of flow, did not affect the average rate of flow. When excessive levels of P or Mg were applied, the flow rates were also reduced. Pushparajah (1981) observed that when Mg levels were increased by regular application of Mg on soils particularly low in K, early plugging or high plugging index resulted. Yeang and Paranjothy (1982) reported that Ca and Mg were associated with high plugging index.

2.1.3 Effect of nutrients on yield

Beaufils (1957) reported that each of the elements N,P,K, Mg etc., can become a direct limiting factor for production in rubber if the supply is limited.

Report of the Rubber Research Institute of Malaya (1940) indicated that in a set of seven experiments the increase in yield from manuring ranged from 10 to 25 per cent. Guha and Pushparajah (1966) obtained 22 per cent increase in yield from combined application of N, P and K in Malaysia. Application of N and P gave 17 per cent and P and K 13 per cent increase in yield. Reports of the Rubber Research Institute of Ceylon (1966) and Pushparajah and Haridas (1977) indicated that NPK manuring significantly increased yield. When trees were manured yield increases of 90 to 350 kg ha^{-1} yr^{-1} were obtained (Rubber Research Institute of Malaya, 1967).

Beneficial effects of manuring on yield were also reported by Pushparajah (1969), Pushparajah _et al_. (1973), Potty _et al_. (1980), Rubber Research Institute of Sri Lanka (1988 and 1989) and Mathew _et al_. (1989).

Report of the Rubber Research Institute of Malaya (1969a) stressed that the nutrients in the fertilizer mixture must be balanced and in harmony with the tree's requirement. Guha _et al_. (1971) emphasised that optimum growth and yield can be expected only by such balanced nutrition and not by the indiscriminate application of fertilizers. In fact, indiscriminate application has often been found to depress yield instead of improving it.

Best results from fertilizer applications could be obtained if fertiliser application is considered as a long term policy (Rubber Research Institute Malaya, 1940). Owen _et al_.(1957) also opined that for mature rubber, NPK manuring is necessary on a long term basis.

2.1.3.1 Nitrogen

Owen *et al*. (1957) obtained response in yield to application of N in 16 out of 17 experiments. Reports of Rubber Research Institute of Malaya (1965a and 1971c) indicated that application of 30 kg N $^{-ha}$ is justifiable. A shortage of N, besides leading to poor growth of rubber, also causes significant depression in yield. Application of N increased yield by 8 to 16 per cent over control.

George (1962), Guha (1975), Punnoose *et al*. (1975), Potty *et al*. (1976) and Angkapradipta *et al*. (1986) obtained response in yield to application of N. Reports of the Rubber Research Institute of Sri Lanka (1983 and 1987) also indicated similar results.

Sivanadyan (1983) reported that the response to N application was positive and increased with time. A maximum of 26 per cent increase in yield was observed. Yogaratnam and Weerasuriya (1984) obtained response to higher levels of N application and the response became more marked with time. Report of the Rubber Research Institute of Sri Lanka (1986) indicated significant linear response in yield to N application. Yield increased significantly by 13 per cent when the first level of N was given. A further increase by 7 per cent was obtained when the level of N was increased. These responses were observed for several years indicating that the rubber tree requires continuous application of N.

2.1.3.2 Phosphorus

Owen *et al.* (1957) observed response in yield to P application in many field trials. Punnoose *et al.* (1975) reported that when soil P was low response in yield to application of P was generally obtained. Similar results were obtained by Potty *et al.* (1976) also. Pushparajah *et al.* (1976, 1977 and 1983) opined that most soils were found to give response to P application and that P fertilizers were required to maximize yield of *Hevea*.

Yogaratnam and Weerasuriya (1984) obtained increased yields from application of P fertilizers in several field trials. Yield increases of 19 to 22 per cent were observed from virgin panel. Responses from renewed panel were mostly below 10 per cent. Mathew *et al.* (1989) reported that response in yield to P application was noticed where there was legume ground cover during the immature phase.

2.1.3.3 Potassium

Owen *et al.* (1957) reported both positive and negative responses in yield when K alone was given. Reports of the Rubber Research Institute of Malaya (1971a and 1971b) emphasised that potassium, one of the two important nutrients required by mature rubber was needed for enhancing yield and for maintaining healthy trees. Lack of K resulted in poor growth and reduced yields. Correct application of K fertilizers increased yields in the range of 20 to 30 per cent. Pushparajah *et al*. (1983) obtained positive response in yield to application of K.

Guha (1975) stated that the response in yield to K application started from the first year of experimentation which became more pronounced during subsequent years. The first level of K was better than the second level. Angkapradipta *et al*. (1986) observed quadratic response to application of K. Reports of the Rubber Research Institute of Sri Lanka (1986 and 1987) indicated that application of K at first and second levels increased yield over control. The first level of application gave 9 per cent increase in yield while the second level gave 15 per cent increase over control. Another report of the Rubber Research Institute of Sri Lanka (1989) revealed response only upto medium level of K application.

Potassium has a pronounced positive effect on bark quality and latex stability and ultimately resulted in increased yields (Rubber Board, 1984). Yogaratnam and Weerasuriya (1984) obtained significant increase in yield from K application. The magnitude of this response was higher in the virgin panel ranging from 17 to 33 per cent in comparison with 13 to 18 per cent in the renewed panel.

John (1967) obtained significant response in yield to applied K at low and medium levels of soil K. No response was noticed at higher levels of soil K and negative response at very high levels of soil K. Punnoose *et al*. (1978) reported that when soil Mg was very high there was response in yield to K upto 100 kg K_2O ha^{-1} of application. Mathew et al. (1989) observed that response in yield to application of K was pronounced where there was legume ground cover during the immature phase.

2.1.3.4 Magnesium

Bolton and Shorrocks (1961) reported significant responses to application of Mg. The response increased with time. An increase of upto 14 per cent in yield was obtained. Reports of the Rubber Research Institute of Malaya (1969a and 1969b) indicated increase in yield from application of Mg. Guha (1975) also obtained responses in yield from application of Mg fertilizers.

Guha and Pushparajah (1966) reported that application of Mg though increased girth, did not result in corresponding increase in yield. Application of high levels of Mg added to trees of low P or K status may result in unstable lattices and precoagulation and hence lowering of yields, (Rubber Research Institute Malaya 1969a and 1969b and Rubber Research Institute Sri Lanka, 1987). Yogaratnam and Weerasuriya (1984) reported that application of Mg should be withheld when leaf Mg was already high.

2.1.3.5 Nutrient interactions on yield

Owen et al. (1957) reported occurrences of NP and PK interactions in some cases and NPK interaction in a few cases for yield of rubber. Response in yield to N was obtained only in the presence of added K. Reports of the Rubber Research Institutes of Malaya (1958) and Ceylon (1966) indicated similar positive NK interactions. If K status of the tree is low, application of N alone could depress yield and in such cases increase in yield could be achieved by applying N in combination with K (Rubber Research Institute Malaya, 1971b). Pushparajah (1977) also obtained positive NK interactions. However, Potty et al. (1976) reported negative NK interactions for yield.

George (1962) observed significant positive NP and NPK interactions in yield. Significant PK and NPK interactions were reported by the Rubber Research Institute of Malaya (1965a). Reports of the Rubber Research Institute of Malaya (1969a) indicated that application of excess Mg when the Mg status of the tree was already satisfactory, depressed K uptake and its relationship to N content in the tree was disturbed and again the yield was depressed.

Further reports from the Rubber Research Institute of Malaya (1971a and 1971b) indicated that K acted antagonistic to N, thus depression in yield resulting from excess application of N could be corrected by the use of K. Potassium played a role in balancing excess Mg in the tree, thus influencing latex stability and precoagulation situations. Potassium thus corrected the adverse effects of excess Mg and improved yield.

Guha (1975) obtained negative NP interaction for yield. Sivanadyan (1983) reported that the response in yield to N application was enhanced by K and Mg applications. While the Rubber Research Institute of Sri Lanka (1983) reported negative PK interaction, positive interaction was obtained by Yogaratnam and Weerasuriya (1984). A negative PMg interaction was reported by Mathew et al. (1989).

The literature cited above stressed the need to consider manuring of rubber as a long term policy. Balanced manuring is important for optimum yields and indiscriminate manuring reduced yields. Manuring in general increased yield by 10 or 25 per cent. The need for continuous application of N is indicated. The response became more marked with time.

Most soils responded to P applications especially when soil P was low. Response was greater when the tree was being tapped on virgin panel than on renewed panel. Chances of response to P were greater when there was legume ground cover during the immature phase. The responses obtained for K application in many cases were quadratic. Application of K appeared to have a pronounced beneficial effect on bark quality and latex stability which ultimately resulted in better yields. The response to K also was better on the virgin panel. When soil K levels were high, responses were less.

The response to Mg was less frequent compared to other nutrients. When in excess, Mg tended to induce precoagulation of latex in the tree and yields were reduced. The interactions of various nutrient on yield were important.

2.1.4 Effect of applied nutrients on soil nutrient status

Pushpadas <u>et al</u>. (1972 and 1978) reported that application of fertilizers increased the level of the respective nutrients in soil. The continued use of chemical fertilizers have been found to influence the chemical composition of soil (Rubber Research Institute Malaysia, 1976).

2.1.4.1 Nitrogen

Bolton (1960) and Pushpadas <u>et al</u>. (1972) reported that application of N reduced the status of exchangeable K, Ca and Mg in soil. Reports of the Rubber Research Institute of Malaysia (1976) showed that the application of N fertilizers increased the level of organic carbon in soil and reduced the exchangeable bases like K, Ca and Mg. The reduction in exchangeable K, Ca and Mg subsequent to application of N fertilizers was also reported by Pushparajah (1977), Pushpadas <u>et al</u>. (1978) and Dissanayake and Mithrasena (1986).

2.1.4.2 Phosphorus

Bolton (1960) reported that application of rock phosphate increased available P and exchangeable Ca of soil. Application of rock phosphate lead to accumulation of soil Ca (Pushaparajah, 1966). Reports of Pushpadas <u>et al</u>. (1972) and Rubber Research

Institute of Malaysia (1976) indicated that application of rock phosphate increased available P and exchangeable Ca and Mg in soil. Pushparajah (1977) and Pushpadas et al. (1978) observed that continued use of rock phosphate lead to the build up of available P and Ca in soil. Dissanayake and Mithrasena (1986) also observed increased Ca status of soil from rock phosphate application.

2.1.4.3 Potassium

Application of K increased the exchangeable K status of soil (Bolton 1960, Pushpadas et al. 1972 and Rubber Research Institute Malaysia, 1976). Pushpadas et al. (1978) reported that application of K fertilizers significantly increased the available K of soil. It also depressed the available Mg of soil. Increase in the exchangeable K status of soil from K application was also reported by Lau (1979) and Dissanayake and Mithrasena (1986).

2.1.4.4 Magnesium

Bolton (1960) and Bolton and Shorrocks (1961) reported that the Mg content of soil was increased by application of Mg fertilizers. Increase in the exchangeable Mg content of soil from application of Mg were reported by Guha and Pushparajah (1966) and Yogaratnam and Weerasuriya (1984). Dissanayake and Mithrasena (1986) observed gradual increase in the Mg content of soil from continuous application of Mg fertilizers.

It is seen that application of fertilizers generally increased the soil level of the nutrient carried by them. It is also observed that the application of one nutrient either enhanced or reduced the availability of other nutrients. This points to the importance of a multivariant approach in fertilizer application for rubber.

2.1.5 Effect of applied nutrients on leaf nutrient contents

Shorrocks (1961a) reported that application of P,K and Mg fertilizers increased the leaf contents of the respective nutrients. Shorrocks (1964) also noticed that N and K fertilizers increased N and K contents of leaf respectively. Increases in the leaf nutrient contents were observed by Nasution et al. (1985) from application of manures. Yogaratnam and De Mel (1985) obtained higher leaf N,P and K nutrients subsequent to application of fertilizers containing these nutrients.

2.1.5.1 Nitrogen

Application of N fertilizers increased the N content of leaf while the K and Ca contents were reduced (Shorrocks 1960, 1961a and 1961b). Shorrocks 1962 and 1964 also reported increases in leaf N content from application of N fertilizers. A consistant linear response to applied N on leaf Ca seemed to suggest that Ca status of *Hevea* plants could be monitored by applied N and this may be considered important in *Hevea* nutrition as precoagulation of latex in mature rubber trees due to excessive Ca in the tree is known (Southorn and Edwin, 1968).

Pushpadas et al. (1972) reported that N application did not affect leaf nutrient contents. Pushparajah et al. (1973) observed only small increases in leaf N from application of fertilizers. Pushpadas et al. (1978) reported that application of N depressed leaf Ca contents. Increases in leaf N and reduction in K contents consequent to application of N fertilizers were reported by Kalam et al. (1980), Sivanadyan (1983) and Yogaratnam and Weerasuriya (1984). Yogaratnam and De Mel (1985) reported that N fertilizers increased leaf N, but did not affect P and Mg contents. Application of N increased leaf N, but depressed Ca contents (Dissanayake and Mithrasena, 1986). Xu Nengkun et al. (1986) observed that N fertilizers while increasing the leaf N contents depressed the K and Mg contents.

2.1.5.2 Phosphorus

Increases in the P content of leaf from application of P fertilizers were reported by Shorrocks (1962), Pushpadas et al. (1978), Yogaratnam et al. (1984) and Yogratnam and Weerasuriya (1984). Bolton and Shorrocks (1961), Shorrocks (1961b) and Pushparajah (1969) observed that application of rock phosphate increased both P and Ca contents of leaf.

Reports of the Rubber Research Institute of Malaysia (1978) indicated that application of rock phosphate increased P and K contents of leaf. Application of P increased leaf P but did not affect leaf N, K or Mg contents. Pushpadas et al. (1972), Kalam et al. (1980) and Dissanayake and Mithrasena (1986) did not observe change in leaf P contents from application of P fertilizers.

2.1.5.3 Potassium

Significant increases in the leaf K contents from application of K fertilizers were reported by Shorrocks (1961a and 1964), Yogaratnam and Weerasuriya (1984) and Dissanayake and Mithrasena (1986). Reports of Pushpadas et al. (1978) and of the Rubber Research Institute of Sri Lanka (1986 and 1987) indicated that application of K increased the K content and at the same time depressed the Mg content of leaf.

Shorrocks (1961b) observed that application of potassium chloride increased leaf K, but did not affect leaf Mg content. Application of K at first and second levels significantly increased leaf K contents, but at the second level, the leaf Mg was reduced (Yogaratnam et al. 1984). Yogaratnam and De Mel (1985) reported that K application increased leaf K level, but did not affect leaf N and P contents. Xu Nengkun et al. (1986) reported that application of K reduced leaf Mg and N. Pushpadas et al. (1972) and Kalam et al. (1980) reported that K application ion did not affect leaf K contents.

2.1.5.4 Magnesium

Increases in the Mg content of leaf from application of Mg fertilizers were reported by Shorrocks (1961a and 1961b), Sivanadyan (1983), Yogaratnam *et al.* (1984) and Yogaratnam and Weerasuriya (1984). Similar results were also reported by the Rubber Research Institute of Sri Lanka (1986 and 1987).

Bolton and Shorrocks (1961) observed that application of magnesium lime stone resulted in an increase in leaf Mg content and in a reduction of leaf K, N and P contents. Application of Mg increased Mg content of leaf in some cases and reduced K, P and Ca contents (Shorrocks, 1965a). Pushparajah (1969) observed reduction in leaf K contents from application of Mg fertilizers. Dissanayake and Mithrasena (1986) reported that Mg application increased leaf Mg, but did not influence P contents. Depressing effects of Mg fertilizers on the levels of K and N in the tree were reported by Xu Nengkun *et al.* (1986).

2.1.5.5 Nutrient interactions

Nair (1957) reported that heavy applications of N have greatly worsened K deficiency in rubber which in turn affected N uptake itself. Bolton and Shorrocks (1961) observed that when both magnesium lime stone and potassium chloride were applied leaf K was reduced. Combined application of ammonium sulphate and rock phosphate resulted in significant reduction in leaf Mg content which became not significant when Mg was also supplied.

Application of N and P combined, resulted in significant reduction in leaf K and significant increase in leaf P and Ca.

Reports of the Rubber Research Institute of Malaya (1969a, 1969b and 1971b) indicated that indiscriminate heavy applications of K and Mg fertilizers may result in the deficiency of either Mg or K respectively indicating that the benefits of K and Mg dressing could only be obtained when the correct K-Mg balance in their application is maintained. Kalam et al. (1980) observed that combined application of Mg and P increased leaf N. There was a strong evidence of antagonistic effects of applied K and Mg on the plant uptake of K, Mg and Ca (Hardjono et al. 1981). Reports of the Rubber Research Institute of Sri Lanka (1986) indicated that applied K and Mg had significant interaction on the leaf K and Mg concentrations. Archer (1988) reported that heavy application of K was most likely to reduce uptake of Ca and Mg and would result in Mg deficiency unless Mg is supplemented.

An evaluation of the above reports indicates that application of fertilizers generally increased the leaf level of the particular nutrient contained in each of them. It is equally important to note that the application of one nutrient influenced the levels of some other nutrients in the leaf. The task of manipulating the leaf nutrient contents becomes even more complicated when combined application of two or more nutrients are considered.

2.1.6 Effect of applied nutrients on latex nutrient contents

Dijkman (1951) reported that a hectare stand of rubber yielding about 2000 kg of dry rubber annually removes through latex about 15.2 kg N, 6.0 kg P_2O_5 and 11.2 kg K_2O. Bolton and Shorrocks (1961) observed that application of magnesium lime stone resulted in significant increases in the latex Mg content. Combined application of N and P fertilizers significantly increased latex P. Increases in the N, P and K contents of latex from applications of ammonium sulphate, rock phosphate and potassium chloride respectively were reported by Shorrocks (1961b).

Application of ammonium sulphate increased N and Mg contents of latex while application of rock phosphate increased P content and reduced Mg content (Collier and Lowe, 1969). Increases in the K and P contents and reduction in Mg contents of latex from application of K fertilizers were observed by Pushparajah (1969). Pushparajah et al. (1975) reported that application of ammonium sulphate increased the N, K and Mg contents of latex. Application of rock phosphate increased the P and Ca contents. Increases in K and P contents and reduction in Ca and Mg contents from application of K fertilizers were also noted. Application of Mg increased Mg content and reduced K content of latex.

As in the case of leaf, the effects of applied nutrients, in many cases, get reflected in the latex contents of nutrients.

Applied nutrients either directly increase their contents or influence the contents of other nutrients in latex. This is significant in that an optimum relative concentration of various nutrients in latex is important for the stability of the latex colloidal system upon which depends high latex yields.

2.2 Inter-relationship of characters

Correlations between various plant and soil characters like growth, latex flow characteristics, yield, nutrient contents in soil, leaf and latex were reported by several workers.

2.2.1 Relation between yield and latex flow characters

Yip and Gomez (1975) and Wycherley (1977) reported that yield was negatively correlated with plugging index. Narayanan and Abraham (1976) and Samsidar BTE Hamzah and Gomez (1982) obtained positive correlation between yield and initial flow rate. Yeang and Paranjothy (1982) reported that yield was positively correlated with initial flow rate and dry rubber content and negatively correlated with plugging index. Mo Shanwen et al. (1988) also noticed positive correlation between yield and dry rubber content.

2.2.2 Relation between yield and nutrient contents in soil, leaf and latex

Beaufils (1957) reported that each of the elements N,P,K,Mg etc., can become a direct limiting factor for production. There is no doubt that yield has a strong relation to the nutrient status of the soil (Dyck 1939 and Shorrocks 1965a). Chapman (1941), Shorrocks (1962, 1965a and 1965b) and Pushparajah (1969) reported correlation between yield and leaf nutrient contents. However, Pushpadas et al. (1978) did not obtain correlation between yield and leaf contents of P and K in certain cases.

Yip and Chin (1977) reported that maximum yield was associated with a decrease in Mg and Ca contents of latex. Yip (1990) obtained positive correlation between yield and latex P and negative correlation of yield with latex Mg contents.

2.2.3 Relation between growth and soil and leaf nutrient contents

Bolton (1960) obtained increased growth rate of rubber trees when the soil N,P and K contents were high. Pushparajah et al. (1983) reported that the girth increament of trees was correlated to the nutrient status of soil.

Sivanadyan (1983) observed positive relation between leaf N content and girth increment of trees. Yogaratnam et al. (1984) reported high growth rate with high P,K and Mg contents of leaf. Weerasuriya and Yogaratnam (1988) also related growth with leaf nutrient contents.

2.2.4 Relation between latex flow characters and nutrient contents in leaf and latex

Collier and Lowe (1969) reported that the N content of leaf had a positive relation with total volume of latex while Mg was related to high plugging. Reports of the Rubber Research Institute of Malaya (1969b and 1971b) indicated that high Mg content of leaf and latex lead to high plugging indices. Pushparajah (1977) observed that high leaf K was associated with increase in the total volume of latex. Pushparajah (1977) and Yeang and Paranjothy (1982) reported that high Ca and Mg in leaf and latex were associated with high plugging index while high leaf N and P favoured high dry rubber contents of latex.

2.2.5 Relation between soil and leaf nutrients

Guha and Yeow (1966) reported that the leaf levels of N,P, K and Mg were generally related to the levels of the respective nutrients in the soil. Correlation between leaf Mg and soil exchangeable Mg was obtained by Pushparajah and Guha (1968). Pushpadas et al. (1972) failed to obtain correlation between leaf and soil nutrients when the soil nutrient status even in the control plots was high.

Lau et al. (1973) observed correlation between leaf K and soil exchangeable K. Pushpadas et al. (1978) and Yew and Pushparajah (1984) reported that the leaf N,P,K and Mg contents were related to the levels of the respective nutrients in soil.

Thus a good number of reports indicate that leaf nutrient contents are related to the soil nutrient levels.

There are reports that yield, growth and latex flow characters were related to the nutrient status of soil, leaf and or latex in one way or other. The yield was also found to be related to the various latex flow characters. The relationship between leaf nutrient contents and soil nutrient status is also brought out.

MATERIALS AND METHODS

3 MATERIALS AND METHODS

Field experiments were conducted on rubber trees under tapping. The details of materials used and methods followed for the experiments are given in this chapter.

3.1.Materials

3.1.1 Locations

The investigations were carried out in three locations representing respective agroclimatic regions in South India where about 92 per cent of the rubber growing area in India is located. The experiment was conducted simultaneously in three regions with the same treatments and statistical layout on rubber trees of same age and cropping history.

3.1.1.1 Kulasekharam

Kulasekharam is located in Kanyakumari District in Tamil Nadu and this experiment was laid out in New Ambady Rubber Estate which lies at 8° 26'N latitude and 77° 19'E longitude. This represents a potential rubber growing area. The land is almost level at the experiment site.

3.1.1.2 Thodupuzha

Thodupuzha is in Idukki District of Kerala State and the experiment was located in Malankara Rubber Estate and lies at 9° 55'N latitude and 76° 26'E longituude. The experiment site has a slope of 2-10 per cent. This location represents Central Kerala where there is maximum concentraction of rubber cultivation.

3.1.1.3 Balussery

This is in Kozhikode District of Kerala State and the experiment was laid out in Kinalur Rubber Estate which lies at 11^{o} 18'N latitude and 75^{o} 56' E longitude. The experiment area has a slope less than 6 per cent. This location represents the extensive rubber growing areas in northern Kerala.

3.1.2 Cropping history

In the three experimental areas the previous crop was also rubber. The present rubber trees were planted in 1978 using a high yielding clone GT 1. The spacing is 6.7 x 3.4 m in rectangular system. The legume cover crop Pueraria plaseoloides was established and maintained in the three areas during the immature phase of the trees. As the growth of the trees advanced the cover plants were gradually shaded out and by the time the present study was initiated there was not much of cover crop left. The trees were brought to tapping in 1985 when 70 per cent of the trees attained a girth of 50 cm at a height of 125 cm from bud union. The remaining trees were brought to tapping subsequently whenever thay attained the required girth. A 3^3 NPK experiment was initiated in 1986 in the three locations with three levels of 0,15 and 30 kg each of N and P_2O_5 and three levels of 0,20 and 40 kg K_2O ha^{-1}. These treatements were continued upto 1988 and in 1989 the present investigation was superimposed with a new set of treatments.

3.1.3 Soil

The soil at Kulasekharam is red soil and that in the other two sites is laterite. At Kulasekharam the soil is deep whereas it is shallow in the other locations. The physical and chemical composition and properties of the soil in the three locations are given in Tables 1 and 2.

3.1.4 Weather and climate

The total annual rainfall and its distribution are distinctly different in the three locations. During the period of the experiment (1989, 1990 and 1991) the mean total annual rainfall were 2041, 4006 and 3774 mm at Kulasekharam, Thodupuzha and Balussery respectively. Both the South-West and the North-East monsoons are active at Kulasekharam. In the other two locations the North-East monsoon is weak. In Balussery, a prolonged drought of 3 to 4 months is experienced. Regarding maximum and minimum temperature and relative humidity there is not much differece among the three regions. The weather conditions that prevailed in the three experiment areas during the period of the study and the mean of previous 27 years are given in Appendix I,II and III.

Table 1 Physical properties and mechanical composition of soil

Location	Soil Depth	Bulk density	Particle density	Total porosity (per cent)	Mechanical composition (per cent)				Textural class
					Course sand	Fine sand	Silt	Clay	
Kulasekharam	0-30	1.24	2.43	48.80	28.90	7.35	6.84	54.31	Clay
,,	30-60	1.20	2.40	49.70	19.75	4.70	4.65	68.15	Clay
Thodupuzha	0-30	1.25	2.47	50.30	30.71	10.60	10.40	46.00	Clay
,,	30-60	1.29	2.53	48.80	25.40	10.50	9.90	50.60	Clay
Balussery	0-30	1.32	2.60	49.00	45.10	12.00	10.00	30.20	Sandy clay loam
,,	30-60	1.29	2.60	49.80	47.40	11.31	8.28	27.00	Sandy clay loam

Table 2 Chemical composition of soil

Location	Organic carbon (per cent)	Available nutrients (kg ha^{-1})					pH
		N	P	K	Ca	Mg	
Kulasekharam	1.05	225	20	120	240	120	4.4
Thodupuzha	1.17	350	20	124	180	30	4.5
Balussery	1.14	280	40	90	360	70	4.9

3.1.5 Clone

The Clone selected for the three locations is GT 1. It is a primary clone developed at the Gondang Tapen Estate in Northern-Sumatra, Indonesia (Amin et al. 1973 and Joseph et al. 1980). It is a high yielding clone with desirable secondary characters. Girth increment on tapping is average. Thickness of virgin bark is average, while that of renewed bark is below average. The clone shows a progressive increase with average initial yield and high subsequent yield. It has good tolerance to pink disease and brown bast, average to above average tolerance to powdery mildew disease and wind damage and average to below average tolerance to *Phytophthora* disease. GT 1 is recommended in Malaysia and India for both small holdings and large estates for planting on a large scale (Rubber Research Institute of Malaysia, 1989 and Rubber Board, 1993).

3.1.6. Duration

The study was conducted during 1989, 1990 and 1991. Imposition of the treatments was started from April, 1989 and various observation were recorded from July, 1989 onwards. The observations were completed in September, 1991.

3.1.7 Fertilizers

Urea analysing 46 per cent N, Mussorie rock phosphate containing 22 per cent P_2O_5, muriate of potash analysing 60 per cent K_2O and commercial magnesium sulphate containing 16 per cent MgO were used for the experiments.

3.2 Methods

The technical programme of the experiment laid out in the three locations is given below. The field layout is the same in all the three locations.

3.2.1 Treatments

The treatments consisted of factorial combinations of three levels each of nitrogen, phosphorus and potassium and two levels of magnesium which are given below.

I) Nitrogen

n_0 - No N

n_1 - 40 kg N ha^{-1}

n_2 - 80 kg N ha^{-1}

II) Phosphorus

p_0 - No P_2O_5

p_1 - 30 kg P_2O_5 ha^{-1}

p_2 - 60 kg P_2O_5 ha^{-1}

III) Potassium

k_0 - No K_2O

k_1 - 40 kg K_2O ha^{-1}

k_2 - 80 kg K_2O ha^{-1}

IV) Maganesium

m_0 - No MgO

m_1 - 10 kg MgO ha^{-1}

3.2.1.1 Treatement combinations

There are 54 treatment combinations as given below

$n_0p_0k_0m_0$	$n_0p_1k_0m_0$	$n_0p_2k_0m_0$
$n_0p_0k_0m_1$	$n_0p_1k_0m_1$	$n_0p_2k_0m_1$
$n_0p_0k_1m_0$	$n_0p_1k_1m_0$	$n_0p_2k_1m_0$
$n_0p_0k_1m_1$	$n_0p_1k_1m_1$	$n_0p_2k_1m_1$
$n_0p_0k_2m_0$	$n_0p_1k_2m_0$	$n_0p_2k_2m_0$
$n_0p_0k_2m_1$	$n_0p_1k_2m_1$	$n_0p_2k_2m_1$
$n_1p_0k_0m_0$	$n_1p_1k_0m_0$	$n_1p_2k_0m_0$
$n_1p_0k_0m_1$	$n_1p_1k_0m_1$	$n_1p_2k_0m_1$
$n_1p_0k_1m_0$	$n_1p_1k_1m_0$	$n_1p_2k_1m_0$
$n_1p_0k_1m_1$	$n_1p_1k_1m_1$	$n_1p_2k_1m_1$
$n_1p_0k_2m_0$	$n_1p_1k_2m_0$	$n_1p_2k_2m_0$
$n_1p_0k_2m_1$	$n_1p_1k_2m_1$	$n_1p_2k_2m_1$
$n_2p_0k_0m_0$	$n_2p_1k_0m_0$	$n_2p_2k_0m_0$
$n_2p_0k_0m_1$	$n_2p_1k_0m_1$	$n_2p_2k_0m_1$
$n_2p_0k_1m_0$	$n_2p_1k_1m_0$	$n_2p_2k_1m_0$
$n_2p_0k_1m_1$	$n_2p_1k_1m_1$	$n_2p_2k_1m_1$
$n_2p_0k_2m_0$	$n_2p_1k_2m_0$	$n_2p_2k_2m_0$

3.2.2 Design and layout

Design - 3^3 x 2 factorial split plot

Replicaations - 2

Main plot treatments - 27 combinations of N,P and K (3^3)

Sub plot treatments - 2 levels of Mg

Number of blocks per replication - 3

Number of plots per block

Main plots - 9

Sub plots - 18

Partial confounding was adopted with NP^2K^2 confounded in the first replication and NP^2K in the second replication.

Plot size	Main Plot	- gross	- 36 trees
		- net	- 16 trees
	Sub Plot	- gross	- 18 trees
		- net	- 8 trees

Spacing - 6.7 x 3.4 m

The layout plan of the experimental field is given in Fig.1.

3.2.3 Cultural operations

The fertilizers as per the treatments were applied every year in two equal split doses. The first dose was given in May (pre-monsoon) and second in September (post-monsoon) (Rubber Board, 1993). The pre-monsoon application was done after the receipt of a few showers, but before the onset of the regular

FIG.1 LAY OUT PLAN

Replication I

Block									
BLOCK I	1	2	3	4	5	6	7	8	9
	M 0	M 1	M 0	M 1	M 0	M 1	M 0	M 1	M 0
	110	012	220	021	101	122	000	211	202
	M 1	M 0	M 1	M 0	M 1	M 0	M 0	M 1	M 0
BLOCK II	18	17	16	15	14	13	12	11	10
	M 1	M 1	M 0	M 1	M 0	M 0	M 1	M 0	M 1
	210	020	201	011	121	112	100	002	222
	M 0	M 0	M 1	M 0	M 1	M 1	M 0	M 1	M 0
BLOCK III	19	20	21	22	23	24	25	26	27
	M 0	M 0	M 1	M 0	M 1	M 1	M 0	M 1	M 1
	212	022	120	111	001	221	010	200	102
	M 1	M 1	M 0	M 1	M 0	M 0	M 1	M 0	M 0

Replication II

Block									
BLOCK I	1	2	3	4	5	6	7	8	9
	M 0	M 0	M 1	M 1	M 1	M 0	M 1	M 1	M 0
	121	011	000	212	201	022	110	220	102
	M 1	M 1	M 0	M 0	M 0	M 1	M 0	M 0	M 1
BLOCK II	18	17	16	15	14	13	12	11	10
	M 1	M 0	M 1	M 1	M 0	M 0	M 1	M 0	M 1
	012	111	100	001	122	221	210	020	202
	M 0	M 1	M 0	M 0	M 1	M 1	M 0	M 1	M 0
BLOCK III	19	20	21	22	23	24	25	26	27
	M 1	M 0	M 1	M 0	M 0	M 1	M 1	M 0	M 0
	112	222	010	101	200	021	002	120	211
	M 0	M 1	M 0	M 1	M 1	M 0	M 0	M 1	M 1

Note:

110 indicates 40 kg N, 30 kg P_2O_5 and no K_2O

012 indicates no N, 30 kg P_2O_5 a nd 80 kg K_2O

220 indiates 80 kg N, 60 kg P_2O_5 and no K_2O

M0 - No MgO M1 - 10 kg MgO ha^{-1}

Levels of N : 0, 40 and 80 kg ha^{-1}

Levels of P_2O_5 : 0, 30 and 60 kg ha^{-1}

Levels of K_2O : 0, 40 and 80 kg ha^{-1}

Levels of MgO : 0, and 10 kg ha^{-1}

south-west monsoon. The post-monsoon application was done after the south-west monsoon but before the onset of the north-east monsoon when a brief relatively rainfree period was available. Both applications were done when there was adequate moisture in the soil. The fertilizer was broadcasted in rectangular patches in between rows of trees, each patch serving four trees, after clearing the leaf litter on the ground. The fertilizer was then lightly forked into the soil and the leaf litter was put back to cover the fertilizer applied patches (Ananth 1966 and Rubber Board, 1993).

Prophylactic spraying against abnormal leaf fall (Phytophthora) was done as a routine estate operation in the experiment areas at Thodupuzha and Balussery where there was chance of incidence of the disease during the south-west monsoon season. This was given as ariel spray using 6.2 l of 40 per cent oil based copper oxychloride paste in 37 l of diluent oil ha^{-1} during the month of May before the beginning of the monsoon (Rubber Board, 1993). In Kulasekharam area this disease occured only in a mild form and no prophylactic spray was given. Powdery mildew (Oidium) disease was controlled by sulphur dusting in the Kulasekharam area as a prophylactic measure.

Tapping was done alternate daily on half spiral system. The tapping pannels were protected with polyethylene rain guards in the three locations to facilitate tapping during rainy season.

During the period of the experiment tapping was being done on the second side of virgin bark.

3.2.4 Observations

Observations were recorded from the healthy and normal trees in the net plot.

3.2.4.1 Yield

The latex collected in the collecting shells after tapping was coagulated in situ using one per cent acetic acid. The cup lumps from the individual trees were collected on metal hooks, air dried for a week in shade and thereafter dried in a smoke house for 25 days. After complete drying the lumps were weighed. Yield was similarly recorded every month (Owen *et al.* 1957). Yield recording was continued for a period of two years from July, 1989 to June 1991. From these data the mean yield was worked out and expressed as g tree $^{-1}$ tapping $^{-1}$.

3.2.4.2 Girth

In order to gauge the growth rate, the girth of trees was recorded (Dissanayake and Mithrasena, 1986) in July, 1989 and July, 1991. The measurement of girth was done at a height of 150 cm from the bud union every time (Owen *et al.* 1957). From these girth data the girth increment for the period July, 1989 to July, 1991 was worked out.

3.2.4.3. Thickness of virgin bark and rate of bark renewal

The thickness of the virgin bark and that of the renewed bark which was tapped two years ago were recorded in July 1991 using a Schlieper bark measuring guage (De Jonge,1957). The thickness of the two year renewed bark was then computed as percentage of the thickness of the virgin bark and this denotes the rate of bark renewal for the two year period of the experiment.

3.2.4.4 Leaf litter

The dry weight of the leaf that fell on the ground during the annual leaf fall in February was recorded in 1990 and 1991. For this, four patches were selected at random by throwing a 1 m^2 quadrat and the dry weight was computed as t ha^{-1} (Rubber Research Institute Malaya, 1972).

3.2.4.5 Latex flow characteristics

The characters connected with the flow of latex were recorded three times viz., July 1990, October 1990 and April 1991 corresponding to the wet, moderately wet and dry seasons in a one year cycle. Two trees were selected from each sub plot for the recording of observation. When the tree is tapped the latex obtained during the initial five minutes was separately collected and the volume was measured. This is referred to as the initial volume. After about 2-3 hours when the dripping of latex was complete the entire volume of latex including the initial volume was measured for each tree and this is referred to as total volume' (Milford et al. 1969).

The initial flow rate was worked out as

$$\frac{\text{initial 5 minutis volume}}{5}$$

This is expressed in ml. Another parameter called plugging index' was computed from the initial flow rate and total volume and is an index of the duration of latex flow after tapping (Milford et al. 1969 and Paardekooper and Samosorn, 1969).

$$\text{Plugging index} = \frac{\text{Initial flow rate X 100}}{\text{Total volume}}$$

The dry rubber content of latex was also determined three times simultaneously with the recording of the flow characters described above. When the flow of latex was over and dripping of latex ceased the latex obtained from the recording trees was pooled and 10 ml of it was transferred into a weighed 50 ml beaker and the weight along with the latex was determined. The latex thus transferred was diluted with 20 ml water and coagulated by adding about 1 ml of 1 per cent acetic acid. The next day the coagulated lump of rubber was washed in water, made into a thin film and dried in an oven at about 85^{o}C until constant weight was obtained (Rubber Research Institute Malaysia, 1973).

The weight of the dry rubber and that of the fresh latex taken are calculated. Now the dry rubber content of latex is computed as

$$\frac{\text{Weight of dry rubber} \times 100}{\text{Weight of fresh latex}}$$

3.2.5 Chemical analysis

3.2.5.1 Soil analysis

Soil samples were collected from each sub plot in September, 1989 and 1990 during the course of the experiment and also in September, 1991 just after the experiment was completed. Soil was collected from 0-30 cm depth just prior to the post monsoon fertilizer application of the respective year.

Organic carbon was determined by the dichromate-sulphuric acid digestion method (Walkley and Black, 1934). The available nitrogen was estimated by Alkaline permanganate method (Subbiah and Asija, 1956). For the determination of available P, the soil was extracted with Bray No.2 (Bray and Kurtz, 1945) reagent and the concentration of P in solution was measured in a UV spectrophotometer after developing colour using chloromolybdic acid-stanus chloride reduction method (Hesse, 1971). The soil was extracted using Morgan's reagent and available K was determined by flame-photometric method (Jackson, 1973). Available Ca and Mg were determined from the same extract using a GBC Double Beam atomic absorption spectrophotometer

Model No. 902. The organic carbon content was worked out as percentage and those of available N, P, K, Ca and Mg as kg ha^{-1}.

3.2.5.2 Leaf analysis

Leaf samples were collected from each sub plot in September (Lu and He,1982) 1989, 1990 and 1991. Three trees were selected from each sub plot for leaf sampling. Three healthy disease free twigs from each tree were collected (Lu and He, 1982). From each twig the lower most four trifoliate leaves from the upper most mature whorl were selected. The leaflets were separated and the petioles were cut and removed and the leaf laminae secured. The leaves thus obtained were dried in an oven at 70 oC for three days and powdered in grinder.

Nitrogen was determined by Micro kjeldahl method (Piper, 1950). Phosphorus was determined by molybdenum blue method in a spectrophotometer (Jackson, 1973). Potassium was determined in a flame photometer (Jackson, 1973). Both Ca and Mg concentrations were read in a GBC Double Beam atomic absorption spectrophotometer model No. 902. The nutrient contents were expressed as percentage.

3.2.5.3 Latex analysis

In September, 1990 latex was collected from the observation trees after the flow and dripping were complete. The latex was pooled and about 25 ml sample was collected in a petri dish to represent each sub plot. The samples were dried in an oven at

80°C for three days (Rubber Research Institute Malaysia, 1973) and obtained as a thin film.

For the estimation of nitrogen, 0.1 g of the dried rubber film was heated with a catalyst mixture containing potassium sulphate, copper sulphate, selenium and concentrated sulphuric acid thereby converting the N to ammonium compounds. From this the N content was estimated.

Another 0.1 g of the dried rubber film was ashed at 550°C digested with sulphuric acid and extracted with water. From this, P was estimated spectrophotometrically. For the estimation of K, Ca and Mg, 5 g of rubber film was ashed at 550°C digested with nitric acid and extracted with water. From this, K was estimated using an Autoanalyser. Calcium and Magnessium were estimated using the atomic absorption spectrophotometer (Rubber Research Institute Malaysia, 1973). The contents of various nutrients in latex are expressed as ppm of the dry rubber film.

3.2.6 Statistical analysis

The data collected were analysed statistically by applying the technique of analysis of variance for 3^3 partially confounded factorial split plot experiment in randomised block design and significance was tested by F-test (Cochram and Cox, 1965). The standard error of means and least significant differences (critical difference) have been worked out for the probability level of 0.05 for all analyses where F-test was significant.

When F-test was not significant the critical difference values have not been worked out.

The observations recorded at Thodupuzha were used for various correlation studies, this location being more representative of the majority of potential rubber growing areas. The yield for the year April 1990 to March 1991, the girth increment for 1989-91 and the latex flow characters recorded in October 1990 were correlated with the soil, leaf and latex nutrient contents of samples collected in 1990. The correlations between yield and latex flow characters also were worked out. Economic analysis of the yield data was also done.

The statistical analysis of the data were carried out using the IBM -PC/AT-386 system of HCL-Busybee model computer installed in the Department of Agricultural Statistics of College of Agriculture, Vellayani, Kerala Agricultural University.

4 RESULTS AND DISCUSSION

An experiment was conducted in three locations representing three major rubber growing areas in South India to study the effect of applied nutrients viz; N,P,K and Mg on growth, yield, latex flow characteristics and on soil, leaf and latex nutrients for *Hevea* rubber tree. The various observations recorded were statistically analysed and the important results are presented and discussed.

4.1 Effect of nutrients

4.1.1 Growth characters

The results on various growth characters are presented below.

4.1.1.1 Girth increment

4.1.1.1.1 Effect of nutrients

The girth increment for the two year period 1989-91 for the three locations is presented in Table 3. It is seen that application of N significantly improved the girth increment at both 40 and 80 kg levels and the higher level gave significantly the highest girth increment in all the three locations (Fig. 2 to 4). In the case of P, there was significant response at both 30 and 60 kg levels in all locations. The 30 kg level was significantly better than the 60 kg level at Kulasekharam and Balussery whereas at Thodupuzha these levels were on par. There was significant response to application of K at both 40 and 80 kg levels in all the three locations and between these levels there was no significant difference. With regard to Mg it had a definite response in all the locations.

The highest level of N has given the maximum girth increment in all the three locations. Eventhough the N content of soil (Table 2) was not poor it would not have been sufficient to support optimum growth. It is also seen from Table 28 that the leaf N contents were significantly increased from applications of N which also might have contributed to better growth rate with N application. Application of N has increased leaf production in the three locations as evidenced from Table 12 which gives the weight of leaf litter. Better foliage might have improved growth through higher photosynthetic rate of the tree. Brady (1988) also reported that N increased cell size and contributed to higher growth. Owen *et al*. (1957), Bolton (1964), Kalam *et al*. (1980) and Potty *et al*. (1980) also reported high girth increment from higher level of application of N.

Application of P has given higher girth increment. The increased leaf production (Table 12) from P application might have improved the photosynthetic activity of the tree and resulted in better growth. Phosphorus being an essential constituent of ADP, ATP and several other organic compounds in the plant might have promoted the metabolism of the tree and improved the growth (Sutcliff and Baker, 1974).

The 30 kg level of application of P has given the highest girth increment in all the three locations. This indicates that P beyond a certain level is not at all required for girth increment. The available P content of the soil in the three locations was not poor (Table 2). It is also noticed that the leaf production has not increased beyond the 30 kg level of application and a depressing effect was noticed at the 60 kg level (Table 12). Bolton (1964), Pushparajah et al. (1983) and Rubber Research Institute of Sri Lanka (1983) also reported responses to medium levels of P application.

It is seen that application of K improved the girth increment. Through increased leaf production (Table 12) and better photosynthesis K might have contributed to better growth. Potassium being essential for chlorophyll development and photosynthesis, its application enhanced dry matter production and growth (Brady, 1988).

The middle level of K seems to be sufficient in the three experimental sites. It might be possible that the K content of the soil (Table 25) was raised to a satisfactory level for optimum growth with the lower dose of application and further increase in K status of soil with higher dose was not useful. It is also seen from Table 12 that K application beyond 40 kg has not improved leaf production which could be another reason for the above result. Punnoose et al. (1975), Kalam et al. (1980)

Table 3 Effect of nutrients on girth increment, 1989-91 (cm)

Treatments Nutrients kg ha^{-1}	Kulasekharam	Thodupuzha	Balussery
N_0	3.92	4.00	4.00
N_{40}	5.03	4.98	4.90
N_{80}	5.33	5.28	5.11
F-ratio	S^{**}	S^{**}	S^{**}
P_0	4.26	4.30	4.26
P_{30}	5.06	5.04	4.95
P_{60}	4.96	4.93	4.80
F-ratio	S^{**}	S^{**}	S^{**}
K_0	4.48	4.42	4.37
K_{40}	4.92	4.93	4.81
K_{80}	4.89	4.91	4.83
F-ratio	S^{**}	S^{**}	S^{**}
SE (N,P,K)	0.03	0.053	0.015
CD (N,P,K)	0.07	0.155	0.044
Mg_0	4.74	4.71	4.64
Mg_{10}	4.78	4.80	4.70
F-ratio	S^{**}	S^{*}	S^{**}
SE (Mg)	0.003	0.023	0.011
CD (Mg)	0.010	0.067	0.033

S^{*} : Significant at P = 0.05 level

S^{**} : Significant at P = 0.01 level

RESULTS AND DISCUSSION

FIG. 4 EFFECT OF NUTRIENTS ON GIRTH INCREMENT (cm) - BALUSSERY

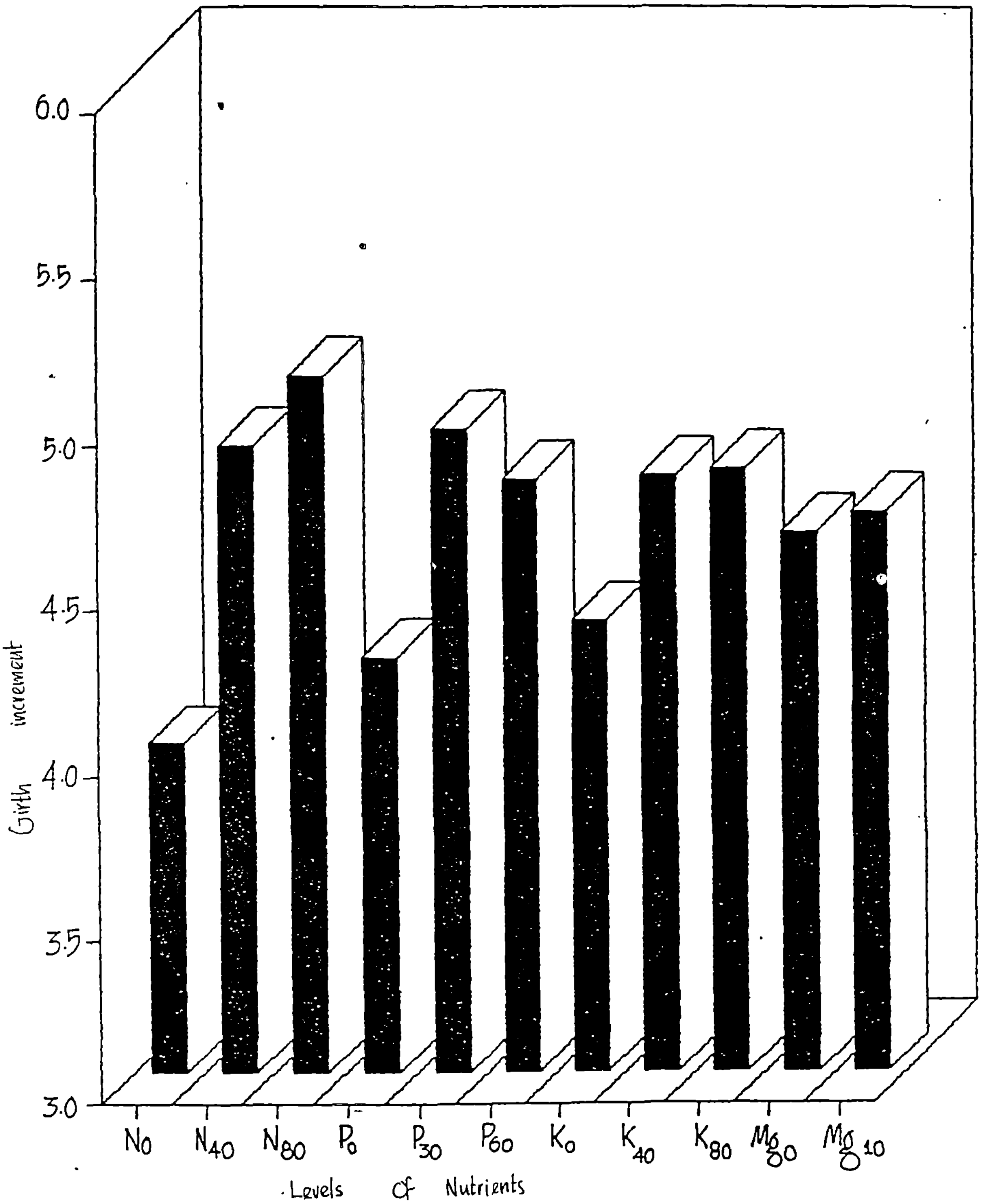


FIG. 3 EFFECT OF NUTRIENTS ON GIRTH INCREMENT (cm)-
THODUPUZHA

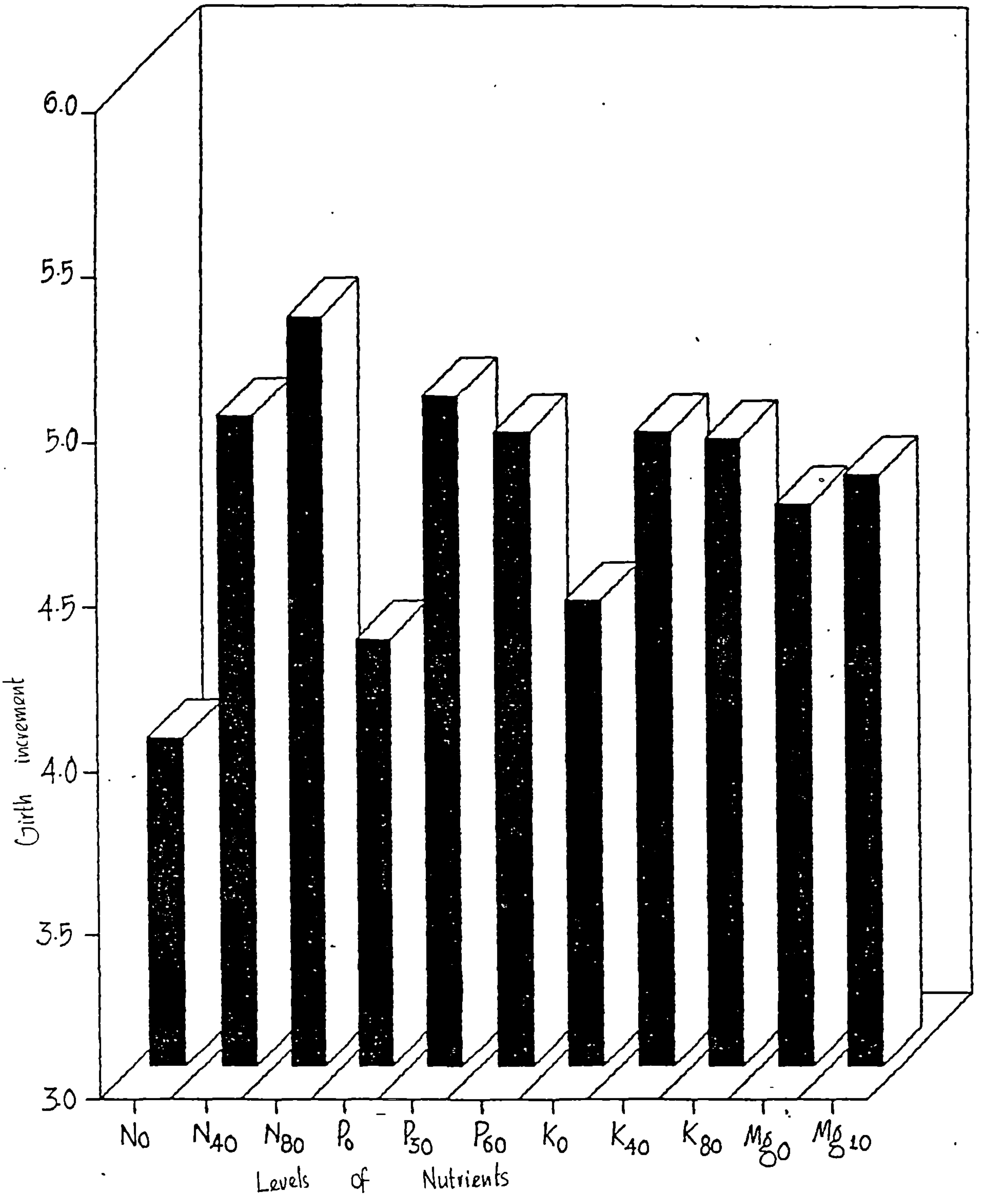


FIG.2 EFFECT OF NUTRIENTS ON GIRTH INCREMENT (cm)-
KULASEKHARAM

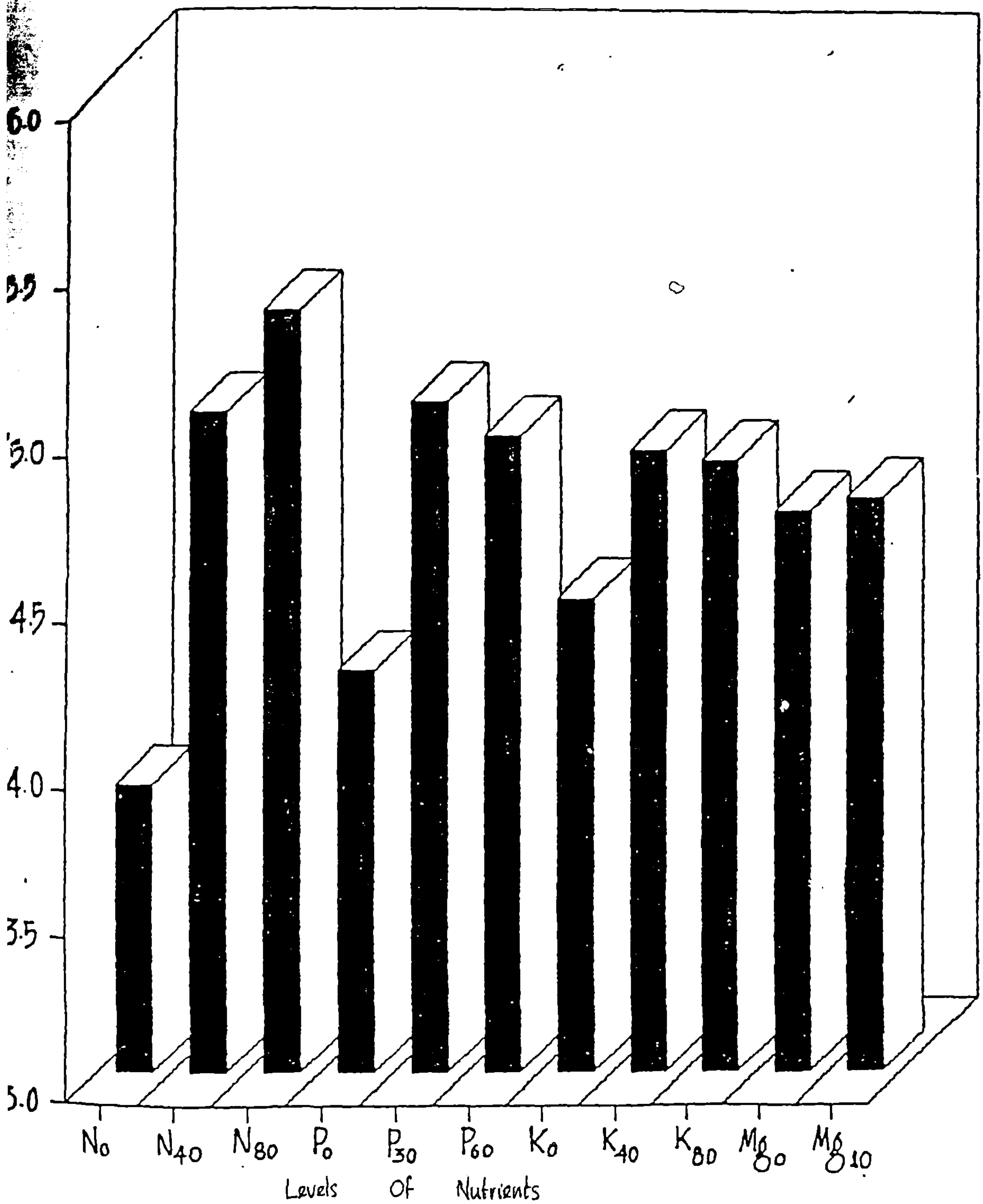
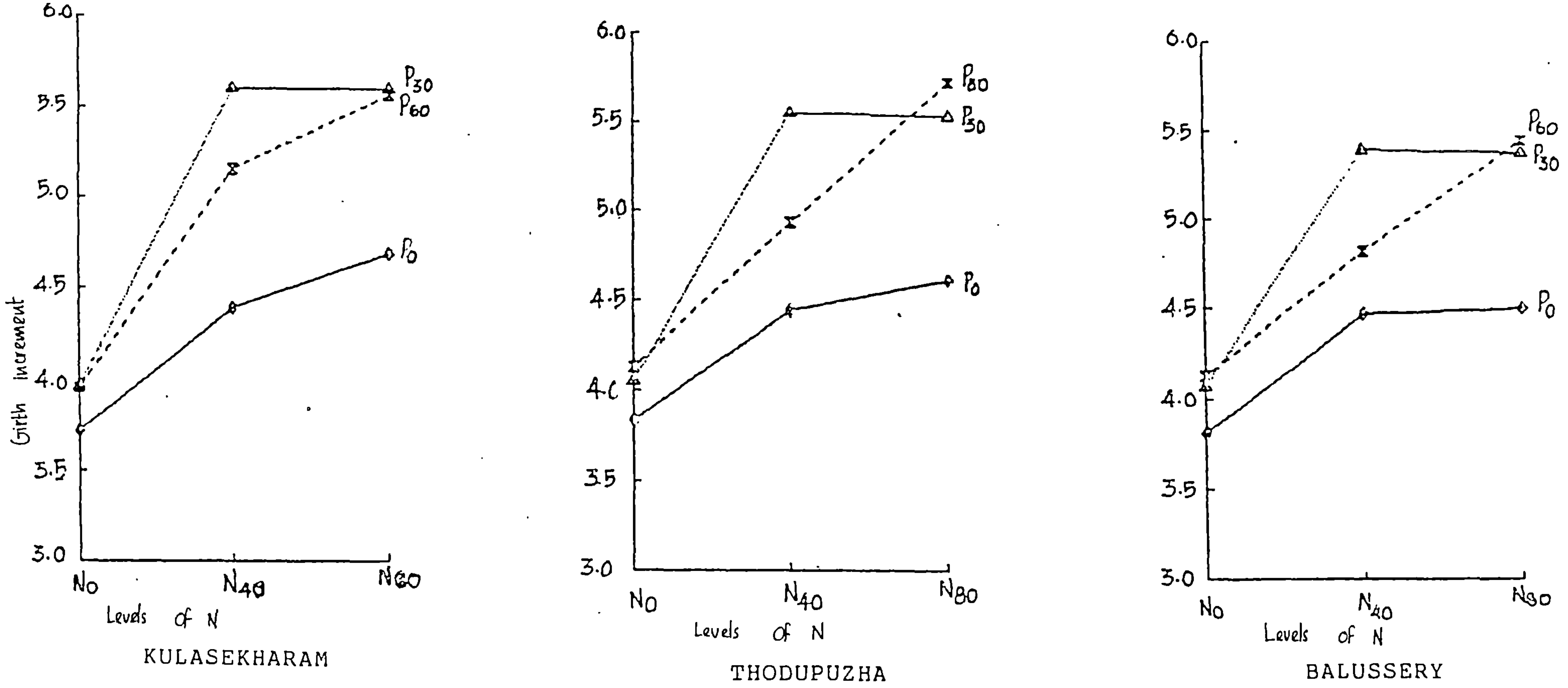


FIG.5 EFFECT OF NP INTERACTION ON GIRTH INCREMENT (cm)-



and Weerasuriya and Yogaratnam (1988) also reported that only moderate levels of K were required for girth increment.

In the case of Mg the trend is very clear and specific where its application has given significant girth increment, thereby showing the necessity for addition of this nutrient at a specific rate for growth in all the locations. Magnesium is an essential constituent of chlorophyll and it is important for photosynthesis and growth (Sutcliff and Baker, 1974). Application of Mg has increased the leaf Mg levels (Table 32) and this in turn might have increased the photosynthetic rate of the tree resulting in improved growth. This increased production of leaf (Table 12) from application of Mg obtained in the three locations further support the result obtained here. Guha and Pushparajah (1966), Pushparajah et al. (1983) and Weerasuriya and Yogaratnam (1988) reported similar response to Mg fertilizer.

4.1.1.1.2 Effect of nutrient interactions on girth increment

The interactions NP, NK, PK, NMg, PMg and KMg were significant in the three locations and are presented and discussed below.

4.1.1.1.2.1 Interaction NP

The NP interaction was significant in the three locations and is presented in Table 4. It is indicated that though N is the nutrient primarily responsible for growth it is unable to manifest without adequate level of P. When the level of P is less there is no advantage in increasing the level of N alone. This is further strengthened by the comparison of the interaction N_{40} P_{30} and N_{80} P_{60}. Both the above combinations were on par and this indicates that there is no need for higher level of P. However at the 60 kg level of P there was a substantial increase in girth increment by application of 80 kg N (Fig. 5).

While considering the main effect of P, eventhough there was no difference between the 60 and 30 kg levels, the interaction effect of 80 kg N and 60 kg P is clearly dominating over other interactions. Whenever the N level is to be increased it should be followed by a proportionate increase in the level of P as well. If the level of P is to be kept at 30 kg, then the level of N also should be kept at the medium level.

The role of P is not as evident as the role of N. It acts as a limiting factor in the absence of higher level of N.. With the 60 kg level of P, there is a profound influence for N at the 80 kg level. Eventhough N_{80} P_{60} combination has given the maximum girth increment, 40 kg N has manifested its efficiency with 30 kg level of P. The interaction table clearly shows that balanced application of the two nutrients is more beneficial and economical even if the dose is kept at the middle level. The inference is that the combination 40 kg N and 30 kg P is sufficient as far as girth increment is concerned. Similar NP interactions were noticed by Owen et al. (1957) and Bolton and Shorrocks (1961).

It was seen from main effects that 30 kg level of P was sufficient and beyond that there was no response. The interaction table reveals that there is a substantial decrease of girth increment by P_{60} level over P_{30} level at the N_{40} level. This trend in the interaction is reflected in the main effect of P wherein, it could be seen that beyond 30 kg of P there was a decrease.

4.1.1.1.2.2 Interaction NK

In the experiment at Kulasekharam application of N at 40 and 80 kg levels progressively increased the girth increment at all the levels of K (Table 5). In the absence of N, application of K had little influence on the girth increment (Fig. 6). With the 40 and 80 kg levels of N, application of K at 40 kg significantly improved the girth increment and increasing the level of K to 80 kg did not have any further significant effect. The interaction N_{80} K_{40} gave the highest girth increment which was significantly superior to N_{40} K_{40} and on par with N_{80} K_{80}. This interaction effect is reflected in the main effect of these nutrients also (Table 16) wherein N_{80} was the best dose of N while for K, the 40 kg level was sufficient.

At Thodupuzha also application of K behaved in the same manner with the different levels of N (Table 5). With the different levels of K, application of N at 40 and 80 kg progressively increased the girth increment (Fig. 6). However at K_{40}, the increase from N_{40} to N_{80} was not significant. The

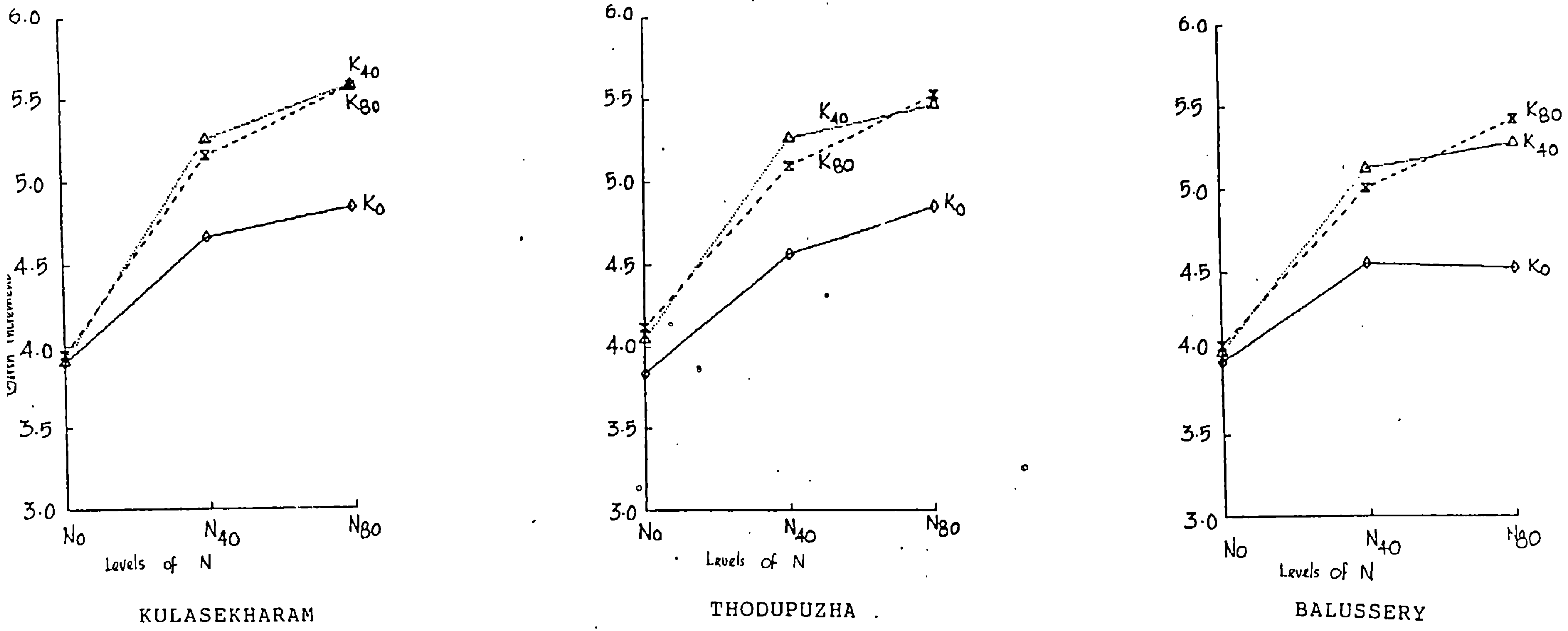
Table 4 Effect of NP interaction on girth increment (cm)

Levels of N	Levels of P_2O_5			For NP combinations	
	P_0	P_{30}	P_{60}	SE	CD
Kulasekharam					
N_0	3.71	3.96	4.09		
N_{40}	4.39	5.61	5.08	0.040	0.130
N_{80}	4.69	5.61	5.70		
Thodupuzha					
N_0	3.83	4.05	4.13		
N_{40}	4.44	5.55	4.93	0.091	0.268
N_{80}	4.61	5.53	5.72		
Balussery					
N_0	3.81	4.07	4.13		
N_{40}	4.47	5.40	4.82	0.026	0.076
N_{80}	4.50	5.38	5.45		

Table 5 Effect of NK interaction on girth increment (cm)

Levels of N	Levels of K_2O			For NK combinations	
	K_0	K_{40}	K_{80}	SE	CD
Kulasekharam					
N_0	3.90	3.91	3.95		
N_{40}	4.67	5.26	5.16	0.04	0.13
N_{80}	4.85	5.58	5.57		
Thodupuzha					
N_0	3.84	4.05	4.12		
N_{40}	4.57	5.27	5.10	0.091	0.268
N_{80}	4.86	5.47	5.53		
Balussery					
N_0	3.95	4.01	4.05		
N_{40}	4.55	5.13	5.01	0.026	0.076
N_{80}	4.62	5.28	5.42		

FIG. 6 EFFECT OF NK INTERACTION ON GIRTH INCREMENT (cm)-



highest girth increment was obtained for N_{80} K_{80} which was on par with N_{40} K_{40} and N_{80} K_{40} and superior to N_{40} K_{80}.

Application of K in the absence of N did not significantly affect the girth increment (Table 5) at Balussery. With N_{40}, application of K at 40 kg significantly increased the girth increment, but further increasing the level of K to 80 kg resulted in a small but statistically significant reduction(Fig.6). With 80 kg N, application of K progressively improved the girth increment upto the K_{80} level. The 80 kg N interacted very favourably with K_{80}, with the result the N_{80} K_{80} combination gave the highest girth increment which was superior to N_{40} K_{40}, N_{40} K_{80} and N_{80} K_{40}. In the main effect of N, the best dose was N_{80} and for K the highest girth increment was given by K_{80}, though it was on par with K_{40} (Table 3).

For N, the 80 kg dose was required in the three locations. While the 40 kg level of K was sufficient at Kulasekharam and Thodupuzha, the 80 kg K gave good interaction with N_{80} at Balussery. This may probably be due to the relatively low K status of soil in this location (Table 2). Owen et al. (1957), George (1963) and Rubber Research Institute of Malaysia 1971a and 1971b reported NK interaction.

4.1.1.1.2.3. Interaction PK

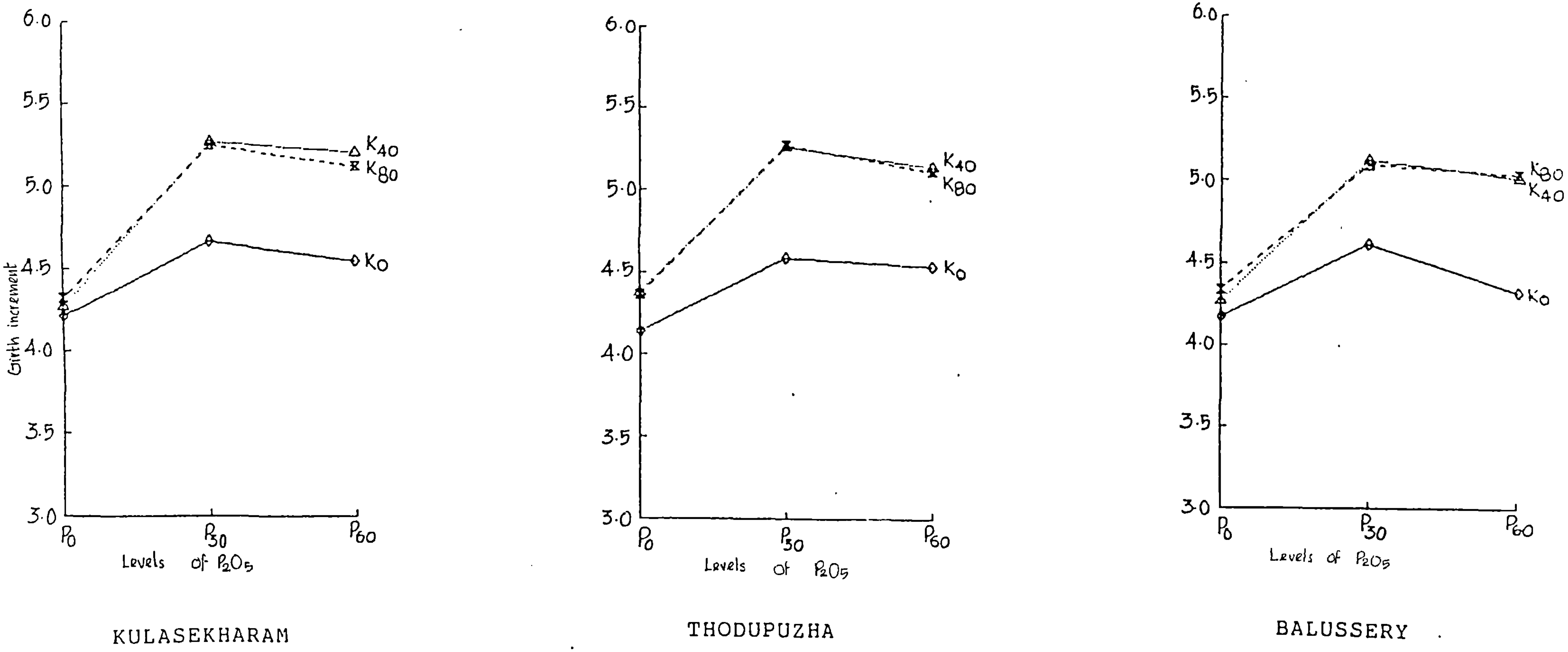
In the experiment at Kulasekharam, at Po level, application of K did not affect the girth increment. With the P_{30} and P_{60}

levels, application of K at 40 kg significantly improved the girth increment and increasing the level of K to 80 kg did not further affect the girth increment (Table 6). Application of P at 30 kg significantly improved girth increment at all the levels of K application (Fig. 7). Increasing the level of P to 60 kg resulted in a reduction in girth increment, which became significant at K_{80}. The interaction P_{60} K_{80} was found to be very unfavorable for girth increment. In the main effect of P, it is seen (Table 3) that P_{60} is significantly inferior to P_{30} for girth increment. The above interaction of P_{60} with K_{80} might have contributed to the reducing effect of P_{60} on girth increment. The best interaction was found to be $P_{30}K_{40}$ which was superior to P_{60} K_{80} and on par with P_{30} K_{80} and P_{60} K_{40}.

The effect of application of K_{40} and K_{80} at different levels of P were the same at Thodupuzha also (Table 6). Application of P at 30 kg significantly improved the girth increment at all the levels of K (Fig.7). Increasing the dose of P to 60 kg resulted in a reduction in girth increment eventhough this reduction was not significant. It is seen from the interaction table that increasing the level of P above 30 kg and that of K above 40 kg was not beneficial. This interaction effect is reflected in the main effect also (Table 3) where P_{30} and K_{40} were found to be the adequate doses for girth increment.

At Balussery, application of K at 40 kg significantly improved the girth increment at all the levels of P and further

FIG. 7 EFFECT OF PK INTERACTION ON GIRTH INCREMENT (cm)-



increasing the level of K to 80 kg had no significant effect (Table 6). Application of P at 30 kg significantly increased the girth increment at all the levels of K (Fig. 7). Increasing the level of P to 60 kg resulted in a reduction in girth increment which came out significant at K_0 and K_{40}. In the main effect of P in this location, (Table 3) for the P_{60} level there was a significant reduction in girth increment compared to the P_{30} level. This reduction could be the result of the above negative interaction of P_{60} with K. The highest girth increment was obtained for the interaction P_{30} K_{40} which was significantly better than P_{60} K_{40} and P_{60} K_{80} and on par with P_{30} K_{80}. The parity of K_{80} with K_{40} obtained in the interaction is reflected in its main effect also (Table 3).

Therefore, in all the three locations the interaction P_{30} K_{40} was found to be optimum, which agrees with the main effects of P and K obtained in these locations where levels above P_{30} and K_{40} were not useful. Owen et al. (1957) also reported PK interaction on growth.

4.1.1.1.2.4 Interaction NMg

Application of N at 40 and 80 kg levels progressively improved the girth increment both in the presence and absence of Mg in all the three locations (Table 7). Application of Mg gave higher girth increment in most cases in the three locations though the increases were not marked (Fig. 8).

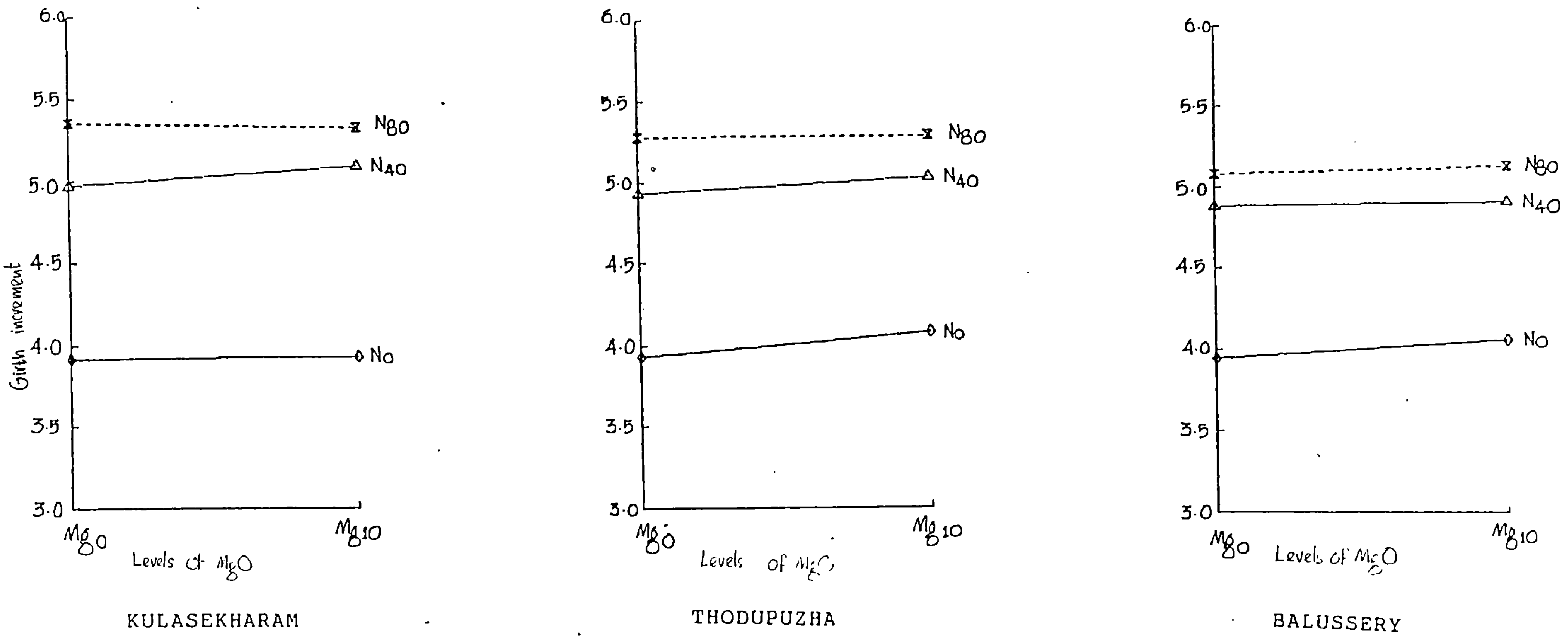
Table 6 Effect of PK interaction on girth increment (cm)

Levels of P_2O_5	Levels of K_2O K_0	K_{40}	K_{80}	For PK combinations SE	CD
Kulasekharam					
P_0	4.21	4.27	4.32		
P_{30}	4.67	5.27	5.25	0.04	0.13
P_{60}	4.55	5.21	5.12		
Thodupuzha					
P_0	4.14	4.38	4.36		
P_{30}	4.59	5.26	5.27	0.091	0.268
P_{60}	4.54	5.14	5.11		
Balusserry					
P_0	4.17	4.27	4.34		
P_{30}	4.62	5.13	5.10	0.026	0.076
P_{60}	4.33	5.02	5.04		

Table 7 Effect of NMg interaction on girth increment (cm)

Levels of N	Levels of MgO Mg_0	Mg_{10}	For N Mg combinations SE	CD
Kulasekharam				
N_0	3.92	3.93		
N_{40}	4.97	5.09	0.01	0.02
N_{80}	5.35	5.32		
Thodupuzha				
N_0	3.93	4.08		
N_{40}	4.93	5.03	0.040	0.116
N_{80}	5.28	5.29		
Balussery				
N_0	3.95	4.06		
N_{40}	4.88	4.91	0.020	0.057
N_{80}	5.08	5.13		

FIG. 8 EFFECT OF NMg INTERACTION ON GIRTH INCREMENT (cm)-



4.1.1.1.2.5 Interaction PMg

Application of P at 30 kg gave a significant increase in girth increment over the P_0 level both in the presence and absence of Mg in all the three locations (Table 8). Further increasing the level of P to 60 kg resulted in a reduction which was significant in all cases except for the interaction P_{60} Mg_{10} at Thodupuzha which was on par with the interaction P_{30} Mg_{10}. Application of Mg gave higher girth increment with the different levels of P in the three locations (Fig. 9).

4.1.1.1.2.6 Interaction KMg

Application of K at 40 kg gave a significant improvement in girth increment above the K_0 level both in the presence and absence of Mg (Table 9). Further increasing the level of K was not generally useful. Application of Mg generally improved the girth increment with all the levels of K in all the locations (Fig. 10).

4.1.1.2 Effect of nutrients on virgin bark thickness

Application of N significantly increased the virgin bark thickness in all the three locations (Table 10). The highest thickness was given by N_{80} level which was not significantly different from the N_{40} level. Both N_{80} and N_{40} levels were superior to N_0 level. In the case of P also both P_{60} and P_{30} levels were significantly better than P_0 level in all the

Table 8 Effect of PMg interaction on girth increment (cm)

Levels of P_2O_5	Levels of MgO Mg_0	Mg_{10}	For PMg combinations SE	CD
Kulasekharam				
P_0	4.24	4.29		
P_{30}	5.03	5.10	0.01	0.02
P_{60}	4.96	4.96		
Thodupuzha				
P_0	4.25	4.34		
P_{30}	5.00	5.08	0.040	0.116
P_{60}	4.88	4.97		
Balusserry				
P_0	4.21	4.31		
P_{30}	4.96	4.94	0.020	0.057
P_{60}	4.74	4.86		

Table 9 Effect of KMg interaction on girth increment (cm)

Levels of K_2O	Levels of MgO Mg_0	Mg_{10}	For KMg combinations SE	CD
Kulasekharam				
K_0	4.46	4.48		
K_{40}	4.88	4.96	0.01	0.02
K_{80}	4.89	4.89		
Thodupuzha				
K_o	4.37	4.48		
K_{40}	4.92	4.94	0.040	0.116
K_{80}	4.86	4.97		
Balusserry				
K_o	4.37	4.38		
K_{40}	4.82	4.80	0.020	0.057
K_{80}	4.73	4.93		

FIG. 9 EFFECT OF PMg INTERACTION ON GIRTH INCREMENT (cm)-

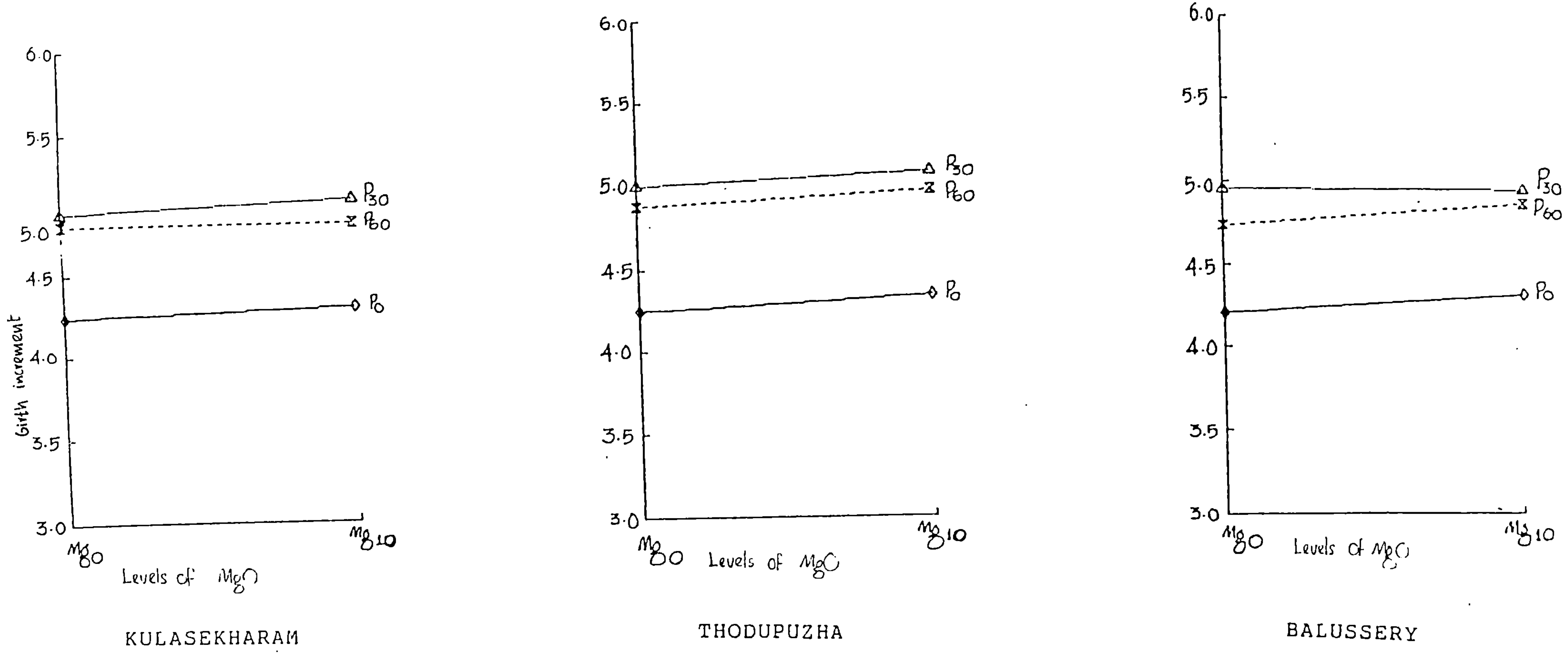
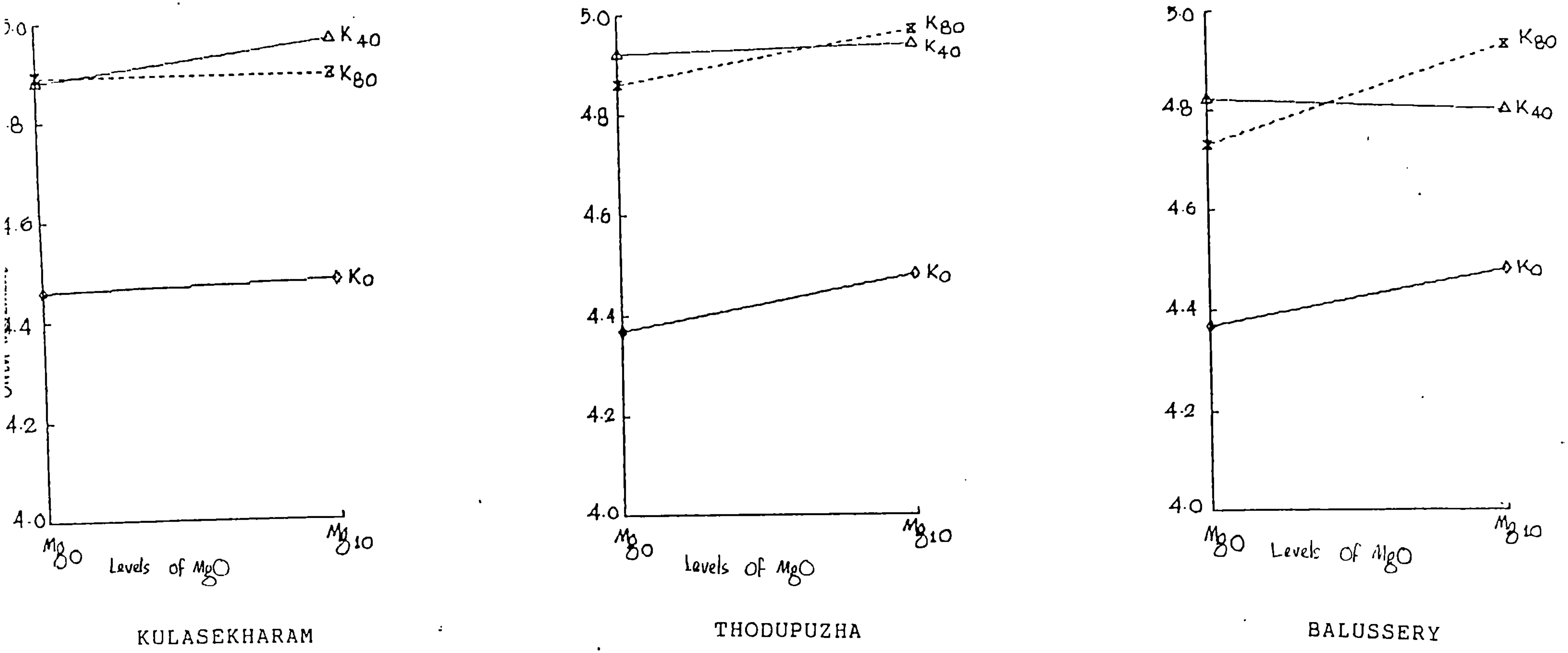


FIG. 10 EFFECT OF KMg INTERACTION ON GIRTH INCREMENT (cm)-



locations. The P_{60} level gave the highest virgin bark thickness which was on par with the P_{30} level.

Application of K at both K_{80} and K_{40} levels gave significantly higher virgin bark thickness over the K_0 level in all the three locations. The highest thickness was registered by the K_{80} level which was not significantly different from the K_{40} level. The effect of application of Mg was not significant in any of the locations. However there was numerical increase in the bark thickness with application of Mg in all locations. The interactions were not important and therefore not presented and discussed.

It is seen that application of N,P and K significantly improved the virgin bark thickness in all the locations. The medium level of these nutrients appeared to be sufficient and beyond which the increase was not appreciable. Though the effect of Mg was not significant, its application showed a trend in increasing the bark thickness. The favourable effects of N,P and K on bark thickness which is a growth parameter is manifested here. It may also be noted that the positive effect of applied nutrients on bark thickness was also reflected in the girth increment already discussed. The girth of the tree is a measurement which also includes the thickness of the bark and a greater bark thickness to a certain extent can lead to a higher girth of the trunk (Owen et al. 1957). The positive response obtained here in the thickness of virgin bark to applied

Table 10 Effect of nutrients on virgin bark thickness, 1991 (mm)

Treatments Nutrients kg ha^{-1}	Kulasekharam	Thodupuzha	Balussery
N_0	7.92	7.88	7.76
N_{40}	8.17	8.02	7.87
N_{80}	8.18	8.05	7.92
F-ratio	S^{**}	S^{**}	S^{**}
P_0	7.91	7.96	7.75
P_{30}	8.08	8.14	7.89
P_{60}	8.27	8.16	7.91
F-ratio	S^{**}	S^{**}	S^{**}
K_0	8.00	7.91	7.80
K_{40}	8.11	8.00	7.87
K_{80}	8.15	8.04	7.88
F-ratio	S^{**}	S^{**}	S^{*}
SE (N,P,K)	0.03	0.029	0.023
CD (N,P,K)	0.09	0.084	0.069
Mg_0	8.07	7.96	7.84
Mg_{10}	8.10	8.00	7.86
F-ratio	NS	NS	NS
SE (Mg)	0.02	0.013	0.02
CD (Mg)	-	-	-

S^{*} : Significant at P = 0.05 level

S^{**} : Significant at P = 0.01 level

NS : Not significant

nutrients are in agreement with the findings of Dijkman (1951) and Samsidar BTE Hamzah *et al*. (1975).

4.1.1.3 Effect of nutrients on rate of bark renewal

The effect of applied nutrients on the rate of bark renewal for the two year period 1989-91 is presented in Table 11. Comparisons are made for the transformed values of angles.

Application of N has significantly increased the bark renewal at both 40 and 80 kg levels in all the three locations. The 80 kg level gave the highest bark renewal rate which was significantly superior to the 40 kg level at Thodupuzha, while in the other two locations these levels were on par. The response to application of P at both 30 and 60 kg levels was significant in the three locations. The highest bark renewal rate was registered by the 60 kg dose which was significantly higher than the 30 kg dose at Kulasekharam and Thodupuzha, while at Balussery they were on par.

In the case of K, its application at both 40 and 80 kg levels were significantly better than the K_0 level for bark renewal in the three locations. The K_{40} level was found to be generally sufficient for good bark renewal. The effect of application of Mg was not significant in any of the locations. The nutrient interactions were not important and hence not presented.

Table 11 Effect of nutrients on rate of bark renewal, 1991

Treatments Nutrients kg ha^{-1}	Kulasekharam		Thodupuzha		Balussery	
	Angles	per cent	Angles	per cent	Angles	Per cent
N_0	53.17	64.07	52.65	63.17	53.66	64.88
N_{40}	58.08	71.82	57.12	70.52	57.57	71.13
N_{80}	58.25	71.83	58.55	72.64	58.80	73.03
F-ratio	S^{**}		S^{**}		S^{**}	
P_0	52.80	63.45	54.13	65.64	54.17	65.70
P_{30}	57.28	70.55	56.70	69.71	57.65	71.22
P_{60}	59.43	73.71	57.49	70.98	58.21	72.11
F-ratio	S^{**}		S^{**}		S^{**}	
K_0	54.16	65.53	54.84	66.71	55.47	67.82
K_{40}	57.42	70.72	56.99	70.19	57.19	70.45
K_{80}	57.92	71.47	56.49	69.43	57.37	70.77
F-ratio	S^{**}		S^{**}		S^{*}	
SE (N,P,K)	0.280		0.257		0.462	
CD (N,P,K)	0.822		0.755		1.356	
Mg_0	56.43	69.14	56.04	68.92	56.46	69.33
Mg_{10}	56.58	69.34	56.18	68.63	56.89	70.02
F-ratio	NS		NS		NS	
SE (Mg)	0.137		0.209		0.225	
CD (Mg)	-		-		-	

S^{*} : Significant at P = 0.05 level

S^{**} : Significant at P = 0.01 level

NS : Not significant

It is seen that application of N,P and K have improved the bark renewal in the three experimental sites. Renewal of tapped bark is a wound healing activity and is considered as a part of the process of growth of the tree (Dijkman, 1951). The importance of N, P and K for growth needs no further emphasis. Reports of the Rubber Research Institute of Malaya (1940) and Pushparajah (1969) indicated that application of N, P and K fertilizers was important for proper bark renewal.

4.1.1.4 Effect of nutrients on leaf litter

The mean leaf litter production as influenced by the various nutrients during 1990 and 1991 is presented in Table 12. It is seen that application of N at both 80 and 40 kg levels significantly increased the leaf litter production compared to the N_0 level in all the locations during both the years. The N_{80} level was superior to the N_{40} level in all cases except at Thodupuzha during 1991.

Application of P at 30 kg level significantly increased the leaf litter production over P_0 level and gave the highest value in all locations during the entire period. Increasing the level of P beyond 30 kg was not found to be useful. In the case of K, its application at both 40 and 80 kg levels significantly increased the litter production over the K_0 level in all cases. The K_{40} level gave the highest mean value. Increasing the level of K from 40 to 80 kg resulted in a reduction in litter production which came out significant in all cases except during 1991 at Thodupuzha and during 1990 at Balussery.

At Kulasekharam, Thodupuzha and Balussery there were small increases in litter production with application of Mg which became significant only at Balussery during 1991. The interactions were not important.

There was response to N even upto 80 kg level. Nitrogen is the chief element related to growth and its application has resulted in the enlargement of foliage (Brady, 1988). Though, the N content of the soil in the three locations (Table 2) was not low it would not have been sufficient to support optimum growth. Application of P has increased the production of leaf in all the locations. Phosphorus is also important for growth and its application has lead to production of more foliage (Sutcliff and Baker, 1974). The 30 kg level of P has given the maximum leaf litter and more than this level was not at all useful for leaf production. The available P content of the soil in the three locations (Table 2) was medium and hence high application rates were not useful.

Application of K also has helped in increasing the leaf production. The role of K in dry matter production and growth is very important (Brady, 1988). It is seen that the medium level of K application was sufficient. It could be possible that the K content of the soil (Table 25) was raised to a satisfactory level for optimum growth with the 40 kg level of

Table 12 Effect of nutrients on leaf litter (t ha^{-1})

Treatments	Kulasekharam		Thodupuzha		Balussery	
Nutrients kg ha^{-1}	1990	1991	1990	1991	1990	1991
N_0	2.837	3.036	2.676	2.771	3.176	3.349
N_{40}	3.149	3.351	2.978	3.125	3.462	3.612
N_{80}	3.213	3.418	3.017	3.161	3.574	3.701
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}
P_0	2.957	3.161	2.778	2.925	3.335	3.470
P_{30}	3.212	3.411	3.038	3.189	3.511	3.672
P_{60}	3.030	3.234	2.854	2.943	3.366	3.511
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}
K_0	2.969	3.173	2.721	2.852	3.281	3.409
K_{40}	3.172	3.378	2.978	3.105	3.483	3.639
K_{80}	3.058	3.255	2.972	3.100	3.448	3.605
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}
SE (N,P,K)	0.01	0.01	0.013	0.014	0.015	0.012
CD (N,P,K)	0.03	0.03	0.038	0.042	0.043	0.034
Mg_0	3.068	3.265	2.876	3.004	3.391	3.547
Mg_{10}	3.075	3.272	2.904	3.034	3.417	3.555
F-ratio	NS	NS	NS	NS	NS	S^{**}
SE (Mg)	0.010	0.010	0.011	0.004	0.004	0.001
CD (Mg)	-	-	-	-	-	0.002

S^{**} : Significant at P = 0.01 level

NS : Not Significant

application and further increase in the K status of the soil (Table 25) with higher levels of its application was not useful. Weerasuriya and Yogaratnam (1988) reported that only moderate levels of K were required for production of foliage.

4.1.2 Effect of nutrients on latex flow characteristics

The latex flow characteristics viz; the initial flow rate, total volume, plugging index and dry rubber content of latex were recorded in July and October, 1990 and in April, 1991 in the three locations. But, only the data for October are presented (Table 13, 14 and 15) since during this period the yield is higher and the leaves have matured and have a more or less steady status of nutrients.

4.1.2.1 Initial flow rate

At Kulasekharam the effect of N was significant and there was progressive increase in the initial flow rate with incremental doses of its application (Table 13). The N_{80} level gave the highest value which was superior to the N_{40} level, both the former levels being superior to N_0. At Thodupuzha, there was significant reduction in the initial flow rate with progressive increase in the level of N from N_0 upto N_{80} (Table 14). At Balussery, the N_{40} level gave the highest initial flow rate which was not significantly different from the N_{80} level, both being superior to N_0 level (Table 15).

Application of P at both P_{30} and P_{60} levels significantly increased the initial flow rate in all the three locations over the P_0 level. The P_{60} and P_{30} levels were on par at Kulasekharam and Thodupuzha, while the former dose was superior at Balussery.

It is seen from Tables 13, 14 and 15 that application of K at both 80 and 40 kg levels significantly increased the initial flow rate in all the three locations over the K_0 level. The K_{40} and K_{80} levels were on par in all the locations. It is also noticed that application of Mg significantly increased the initial flow rate in all the locations.

Application of N has increased the initial flow rate at Kulasekharam and Balussery, while at Thodupuzha it had no favourable effect. The flow rate was increased by application of P, K and Mg in all the locations. The initial flow rate has of course a small contribution to the total yield, since it is the average of the initial five minutes flow. The positive effect of applied nutrients on this parameter was reflected in the yield of rubber also to a certain extent. The favourable effect especially of K can be attributed to the beneficial effect in translocating assimilates which is reflected in the production of latex. Pushparajah (1977) reported that the flow rate was increased by application of K and moderate levels of P and Mg while N had not much effect.

4.1.2.2 Total volume

Application of N at both 40 and 80 kg levels significantly increased the total volume of latex above the No level in all the three locations (Tables 13, 14 and 15). At Kulasekharam, application of N at 80 kg level gave the highest total volume, but it was on par with the 40 kg level. The N_{40} level gave the highest volume at Thodupuzha and Balussery which was superior to the N_{80} level.

It is seen from Tables 13, 14 and 15 that application of P at both 30 and 60 kg levels significantly increased the total volume over the Po level in all the locations. The P_{30} level gave the highest volume which was on par with the P_{60} level at Kulasekharam and Thodupuzha. Application of P at 60 kg gave the highest total volume at Balussery, but it was on par with the P_{30} level.

Application of K at both 40 and 80 kg levels gave significantly higher total volume in all the locations over the K_0 level. The K_{40} level gave the highest volume at Kulasekharam which was not significantly different from the K_{80} level. The K_{80} level gave the highest total volume at Thodupuzha and Balussery. At Thodupuzha the K_{80} level was on par with the K_{40} level, while at Balussery it was superior to the latter.

Application of Mg has significantly increased the total volume at Balussery. At Thodupuzha, though the effect was not significant, an increasing trend was noticed. A significant reduction in the total volume was noticed at Kulasekharam with Mg application.

It is seen that application of all the nutrients had a favourable effect on the total volume of latex in all the locations except for Mg at Kulasekharam, where its effect was negative. The total volume of latex is the component which has the closest positive relationship with the yield of rubber. This is also evident from the high positive correlation obtained between yield and total volume (Table 37) in this study. Application of nutrients by their role in improving photosynthesis and metabolic activity of the tree might have helped in the synthesis of more latex. This has been rightly reflected in the yield also (Table 16).

At Kulasekharam Mg might have encouraged more vegetative growth and consequently the total volume of latex and thereby the yield have suffered (Table 16).

4.1.2.3 Plugging index

Tables 13, 14 and 15 indicate that application of N at both 40 and 80 kg levels has significantly reduced the plugging index in the three locations. At Kulasekharam the 40 kg level gave the lowest value which was significantly lower than the one obtained with the N_{80} level. At Thodupuzha and Balussery the lowest index was given by the N_{80} level which was not significantly different from that obtained with the N_{40} level.

Application of P significantly increased the index in all the locations. The highest index was given by the P_{60} level in all places. At Kulasekharam, the P_{30} level gave significantly lower index compared to the P_{60} level, while in the other two locations the above levels were on par.

Application of K at both 40 and 80 kg levels significantly reduced the plugging index in all the locations. The 80 kg level gave the lowest index in all cases. The index obtained for K_{80} level was significantly lower than the one obtained for K_{40} level at Thodupuzha and Balussery while at Kulasekharam these levels were on par. Application of Mg significantly increased the plugging index in all the locations.

The plugging index generally gave a negative relation with yield. Application of N and K has reduced the plugging index while that of P and Mg helped to increase it. The increase in yield with application of N and K in this experiment could be to some extent related to the effect of these nutrients in lowering the plugging index.

The presence of Ca and Mg beyond a certain level leads to precoagulation of latex and early plugging or high plugging index (Pushparajah, 1981 and Yeang and Paranjothy, 1982). This could be the reason why the plugging index has been increased by application of P and Mg. It may be remembered here that application of P as rock phosphate also adds Ca along with P. Now the positive response in yield to application of P and Mg obtained in this experiment could be the result of the favourable effort from the application of these nutrients on the total volume and the dry rubber content of latex which more than compensated the possible adverse effects through plugging index.

4.1.2.4 Dry rubber content

The dry rubber content of latex was significantly increased by the application of N at both 40 and 80 kg levels in all the locations (Tables 13,14 and 15). The N_{80} level gave the highest dry rubber content in all the locations. The 80 and 40 kg levels were on par at Thodupuzha and Balussery whereas at Kulasekharam the 80 kg level was superior to the 40 kg level.

In the case of P also its application at P_{30} and P_{60} levels significantly increased the dry rubber content in all places over the P_0 level. The P_{30} level gave the highest dry rubber content in all the locations which was on par with the P_{60} level at Kulasekharam and Thodupuzha. At Balussery the P_{30} level was superior to the P_{60} level.

In all the locations application of K at both 40 and 80 kg levels significantly increased the dry rubber content. The K_{80} level gave the highest value which was on par with the K_{40} level in all places. Application of Mg significantly increased the dry

Table 13 Effect of nutrients on latex flow characteristics - Kulasekharam

Treatments Nutrients kg ha^{-1}	Initial flow rate (ml min^{-1})	Total volume (ml)	Plugging index	Dry rubber content (per cent)
N_0	3.67	128.44	2.86	38.98
N_{40}	4.00	146.74	2.73	39.82
N_{80}	4.12	148.05	2.78	39.90
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}
P_0	3.59	132.44	2.71	39.10
P_{30}	4.08	145.58	2.81	39.82
P_{60}	4.12	145.21	2.84	39.79
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}
K_0	3.64	127.63	2.85	39.13
K_{40}	4.10	148.63	2.76	39.77
K_{80}	4.05	146.98	2.76	39.81
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}
SE (N,P,K)	0.03	0.90	0.005	0.02
CD (N,P,K)	0.07	2.65	0.013	0.07
Mg_0	3.84	141.67	2.72	39.56
Mg_{10}	4.02	140.49	2.86	39.58
F-ratio	S^{**}	S^{*}	S^{**}	NS
SE (Mg)	0.01	0.35	0.004	0.02
CD (Mg)	0.03	1.00	0.012	-

S^{*} : Significant at P = 0.05 level

S^{**} : Significant at P = 0.01 level

NS : Not significant

Table 14 Effect of nutrients on latex flow characteristics – Thodupuzha

Treatments Nutrients kg ha^{-1}	Initial flow rate (ml min^{-1})	Total vol- ume (ml)	Plugging index	Dry rubber content (per cent)
N_0	3.40	117.19	2.89	38.65
N_{40}	3.31	123.13	2.69	39.11
N_{80}	3.25	121.68	2.67	39.24
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}
P_0	3.06	116.56	2.63	38.60
P_{30}	3.46	123.12	2.81	39.20
P_{60}	3.44	122.32	2.82	39.19
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}
K_0	3.22	112.57	2.84	38.65
K_{40}	3.39	124.68	2.71	39.12
K_{80}	3.36	124.76	2.70	39.22
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}
SE (N,P,K)	0.014	0.394	0.009	0.066
CD (N,P,K)	0.040	1.156	0.027	0.193
Mg_0	3.22	120.64	2.67	38.89
Mg_{10}	3.43	120.69	2.83	39.11
F-ratio	S^{**}	NS	S^{**}	S^{*}
SE (Mg)	0.011	0.307	0.007	0.062
CD (Mg)	0.031	–	0.021	0.181

S^{*} : Significant at P = 0.05 level
S^{**} : Significant at P = 0.01 level
NS : Not significant

Table 15 Effect of nutrients on latex flow characteristics – Balussery

Treatments Nutrients kg ha^{-1}	Initial flow rate (ml min^{-1})	Total volume (ml)	Plugging index	Dry rubber content (per cent)
N_0	3.07	110.48	2.78	37.60
N_{40}	3.25	123.93	2.62	38.34
N_{80}	3.21	122.24	2.62	38.41
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}
P_0	2.94	113.65	2.59	37.82
P_{30}	3.27	121.12	2.71	38.32
P_{60}	3.31	121.88	2.72	38.21
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}
K_0	3.11	112.77	2.76	37.95
K_{40}	3.20	121.17	2.64	38.18
K_{80}	3.22	122.71	2.62	38.23
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}
SE (N,P,K)	0.012	0.359	0.005	0.038
CD (N,P,K)	0.035	1.053	0.016	0.110
Mg_0	3.10	118.60	2.62	38.00
Mg_{10}	3.25	119.16	2.73	38.24
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}
SE (Mg)	0.003	0.180	0.004	0.026
CD (Mg)	0.010	0.540	0.013	0.075

S^{**} : Significant at P=0.01 level

rubber content at Thodupuzha and Balussery. At Kulasekharam also a similar trend was noticed though the effect of Mg was not significant.

It is seen that the dry rubber content of latex has been increased by application of the various nutrients. This could be the result of the favourable effect of these nutrients in improving the condition of the rubber tree to produce rubber. The volume of latex remaining constant, the yield is directly dependent on the dry rubber content of latex. The favourable effect of the various applied nutrients in increasing the dry rubber content of latex has been reflected in the yield of rubber also.

4.1.3 Effect of nutrients on yield

The mean yield expressed as g tree^{-1} tapping^{-1} for 1989-9 period is presented in Table 16.

4.1.3.1 Effects of nutrients

At Kulasekharam the highest yield was obtained for the 80 kg level of N (Fig. 11). But it was not significantly different from the 40 kg level. Both 40 and 80 kg levels were significantly superior to the no N treatment. Application of P at 30 kg gave maximum yield. Increasing the level of P from 30 to 60 kg reduced the yield eventhough this reduction was not significant. However, both the 30 and 60 kg levels of P gave significantly higher yield than no P. In the case of K its application at 40 kg gave the maximum yield. The 40 and 80 kg levels were on par and were superior to the K_0 level. Application of Mg significantly reduced the yield.

In the experiment at Thodupuzha application of N at 40 kg gave the maximum yield over no N and 80 kg level of N (Fig. 12). Increasing the dose of N to 80 kg resulted in a significant reduction eventhough the latter was significantly higher than the N_0 level. Application of P at 30 kg registered the maximum yield though it was on par with the 60 kg level. Both 30 and 60 kg levels were superior to P_0. In the case of K its application at 80 kg recorded the highest yield. The 40 kg level was not significantly different from the 80 kg level. Both 40 and 80 kg doses were significantly higher than K_0. Application of Mg at 10 kg significantly increased the yield.

At Balussery application of N at 40 kg gave the maximum yield, but it was not significantly different from the 80 kg dose (Fig. 13). Both 40 and 80 kg levels were significantly higher than N_0. In the case of P, the highest yield was noticed for the 60 kg level though, it was on par with the 30 kg level. Both 30 and 60 kg levels gave significantly higher yields over P_0. There was significant increase in yield with incremental doses of K. The 80 kg level gave the highest yield. Application of Mg significantly increased the yield.

Application of N has significantly increased the yield in all the three locations. The role of N in increasing the rate of photosynthesis and metabolism is an established phenomenon (Sutcliff and Baker, 1974 and Bidwell, 1979). This might have resulted in a direct increase in yield with application of N. This is further supported by the significant increase in leaf production (Table 12) with application of N. A better foliage might have increased the total photosynthesis of the tree and thereby the yield. The data on soil organic carbon and leaf N (Table 23 and 28) clearly show that these parameters are significantly increased by application of N fertilizer. A positive correlation is also observed (Table 38) for yield with soil and leaf N. This further supports the response in yield to N application. The dry rubber yield is a product of the volume of latex and its dry rubber content. It is seen from Tables 13, 14 and 15 that the total volume and dry rubber content at Kulasekharam, Thodupuzha and Balussery respectively are significantly increased by application of N. Again, there is a strong positive correlation obtained for yield with both total volume and dry rubber content (Table 37). This very favorably supports the response obtained for the application of N. Significant responses to application of N fertilizers were reported by Owen et al. (1957), George (1962), Guha (1975), Punnoose et al. (1975) and Potty et al. (1976).

It is seen that the 40 kg level of N was sufficient in all the locations. Similar results were reported by the Rubber

Research Institute of Ceylon (1966). At Thodupuzha application of N above 40 kg resulted in a depression in yield. Table 2 indicates that the available N status at Thodupuzha was higher than that in the other two locations. In this situation, application of N at higher level might have created an imbalance in the tree resulting in lower yields (Angkapradipta et al. 1986 and Rubber Research Institute Sri Lanka, 1986). It can also be noted from Table 14 that the total volume of latex at Thodupuzha was significantly depressed by the application of N beyond 40 kg level which might have contributed to the reduction in yield at the 80 kg level of N.

There is positive response to application of P at both 30 and 60 kg doses. Phosphorus is extremely important as a structural part of many compounds in the plant, notably nucleic acids and phospholipids and has important role in photosynthesis and energy metabolism (Bidwel, 1979). Application of P might have increased the yield by improving the photosynthetic activity and metabolism of the tree. The significant increase in leaf production (Table 12) with application of P might have improved the quantum of photosynthesis of the tree and thereby increased the yield. The significant increase in soil available P and leaf P contents (Tables 24 and 29) from application of P fertilizer further supports the response in yield to P application. Tables 13, 14 and 15 also indicates that application of P has significantly increased the total volume and dry rubber content of latex which were directly correlated with yield (Table 16). This observation further supports the response obtained to application of P. Responses in yield to application of P fertilizers were also reported by Pushparajah et al. (1983), Yogaratnam and Weerasuriya (1984) and Mathew et al. (1989).

Increasing the level of P above 30 kg does not further significantly improve the yield in any of the experimental sites. In fact there is marginal decrease in two locations. Table 12 shows that increasing the level of P beyond 30 kg did not further improve the growth of foliage in all the locations. This could be one reason why there is no response above the 30 kg level of P. The total volume and dry rubber content of latex (Tables 13, 14 and 15) were not generally improved further by application of P above 30 kg level. This, over and above other reasons strengthens the absence of additional increase in yield by raising the level of P above 30 kg.

Application of K significantly increases the yield at both 40 and 80 kg levels of application in all the locations. At Kulasekharam and Thodupuzha the 40 and 80 kg levels are on par. In the experiment at Balussery application of incremental doses of K progressively increases the yield.

Potassium is an activator in enzyme systems and has a definite role in the transport of ATP-ase (Sutcliff and Baker, 1974). It is important for the development of chlorophyll and for photosynthesis. Thus by enhancing the photosynthesis and

Table 16 Effect of nutrients on yield (g tree^{-1} tap^{-1})

Treatments Nutrients kg ha^{-1}	Kulasekharam		Thodupuzha		Balussery	
N_0	44.44		38.96		36.54	
N_{40}	50.72		41.72		41.65	
N_{80}	51.15		41.07		41.40	
F-ratio	S^{**}	$\overline{N_{80}N_{40}}N_0$	S^{**}	$N_{40}N_{80}N_0$	S^{**}	$\overline{N_{40}N_{80}}N_0$
P_0	45.55		38.81		37.77	
P_{30}	50.41		41.49		40.78	
P_{60}	50.35		41.45		41.04	
F-ratio	S^{**}	$\overline{P_{30}P_{60}}P_0$	S^{**}	$\overline{P_{30}P_{60}}P_0$	S^{**}	$\overline{P_{60}P_{30}}P_0$
K_0	44.50		38.18		37.67	
K_{40}	51.03		41.77		40.66	
K_{80}	50.78		41.80		41.26	
F-ratio	S^{**}	$\overline{K_{40}K_{80}}K_0$	S^{**}	$\overline{K_{80}K_{40}}K_0$	S^{**}	$K_{80}K_{40}K_0$
SE (N,P,K)	0.161		0.046		0.100	
CD (N,P,K)	0.472		0.134		0.294	
Mg_0	48.89		40.44		39.65	
Mg_{10}	48.65		40.73		40.07	
F-ratio	S^{**}	Mg_0Mg_{10}	S^{**}	$Mg_{10}Mg_0$	S^{**}	$Mg_{10}Mg_0$
SE (Mg)	0.043		0.003		0.024	
CD (Mg)	0.124		0.010		0.071	

S^{**} : significant at P=0.01 level

general metabolic activity of the plant K might have helped in increasing the yield. Table 12 indicates that leaf production has been significantly increased by application of K. This could have improved the photosynthetic rate of the tree resulting in increased yields. The soil available K as well as the leaf K contents were significantly improved (Table 25 and 30) by application of K. This again supports the positive response obtained from application of K. It is seen from Tables 13, 14 and 15 that the total volume and dry rubber content of latex which are directly correlated with yield (Table 37) were significantly increased by application of K in the three locations. It was also seen from Table 13, 14 and 15 that plugging index which is negatively correlated with yield (Table 37) was reduced by application of K. These observations further support the response obtained in yield to application of K.

The response in yield obtained here to application of K fertilizer are in agreement with the findings of Punnoose _et al_. (1975 and 1978), Pushparajah _et al_. (1983), Rubber Board (1984) and Angkapradipta _et al_. (1986).

At Kulasekharam and Thodupuzha application of K at 40 kg level is found to be sufficient. It can be seen from Tables 13, 14 and 15 on latex flow characteristics that the total volume, dry rubber content and plugging index were not significantly different for the 40 and 80 kg doses of K. At Balussery the 80 kg dose is superior to the 40 kg dose. It can be seen from

FIG.11 EFFECT OF NUTRIENTS ON YIELD (g $tree^{-1}$ tap^{-1})-
KULASEKHARAM

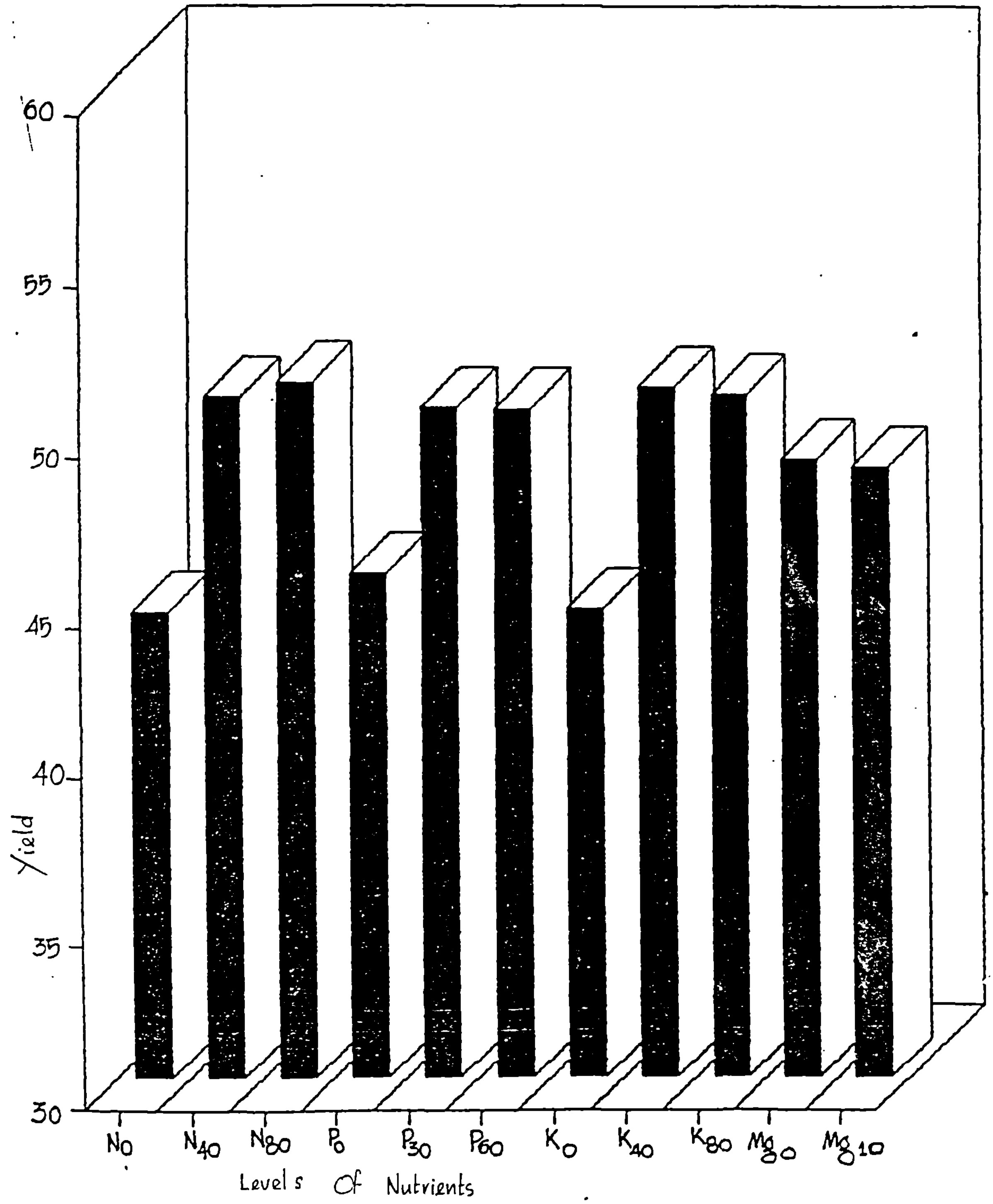


FIG.12 EFFECT OF NUTRIENTS ON YIELD (g $tree^{-1}$ tap^{-1})-
THODUPUZHA

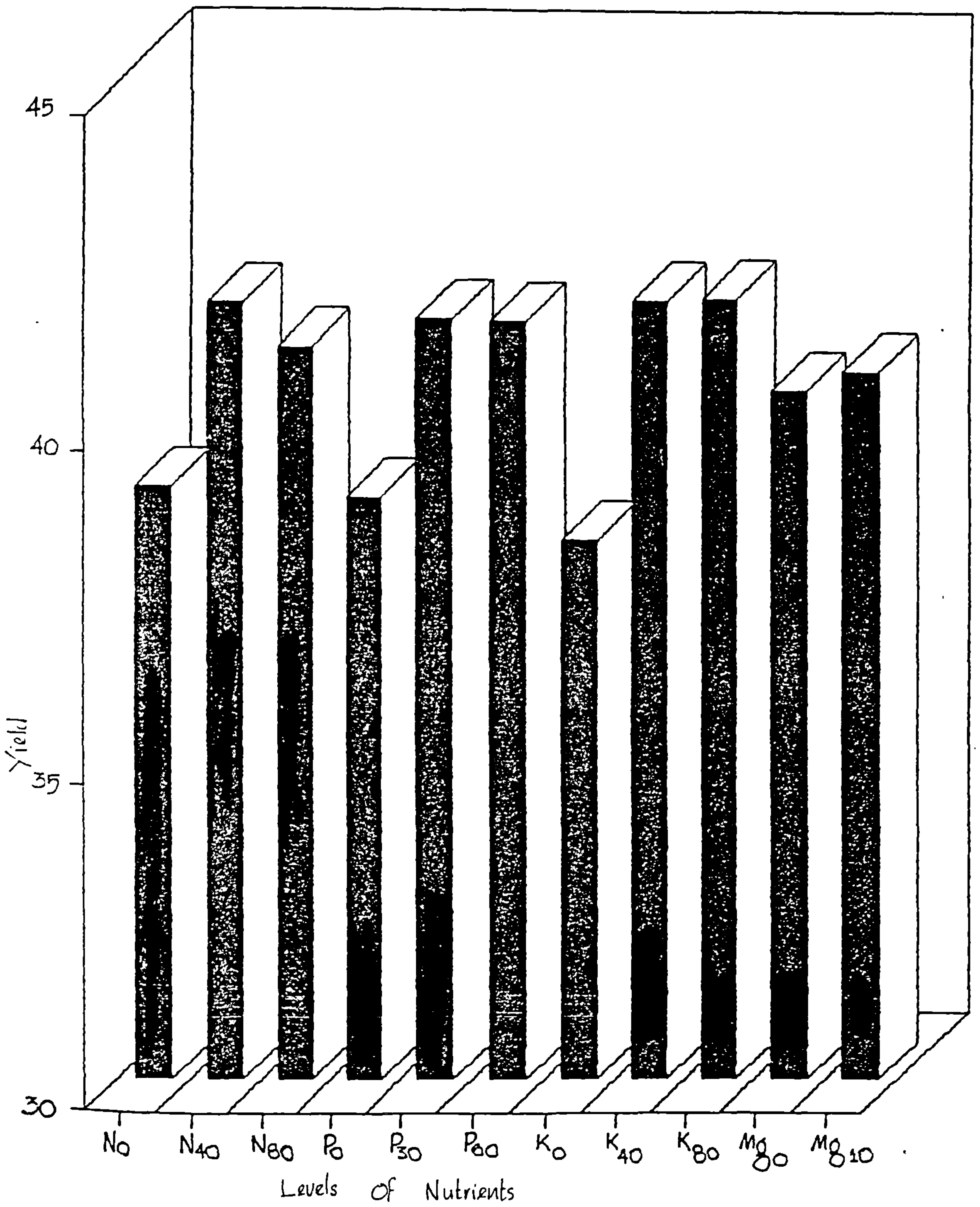


FIG. 13 EFFECT OF NUTRIENTS ON YIELD (g $tree^{-1}$ tap^{-1})- BALUSSERY

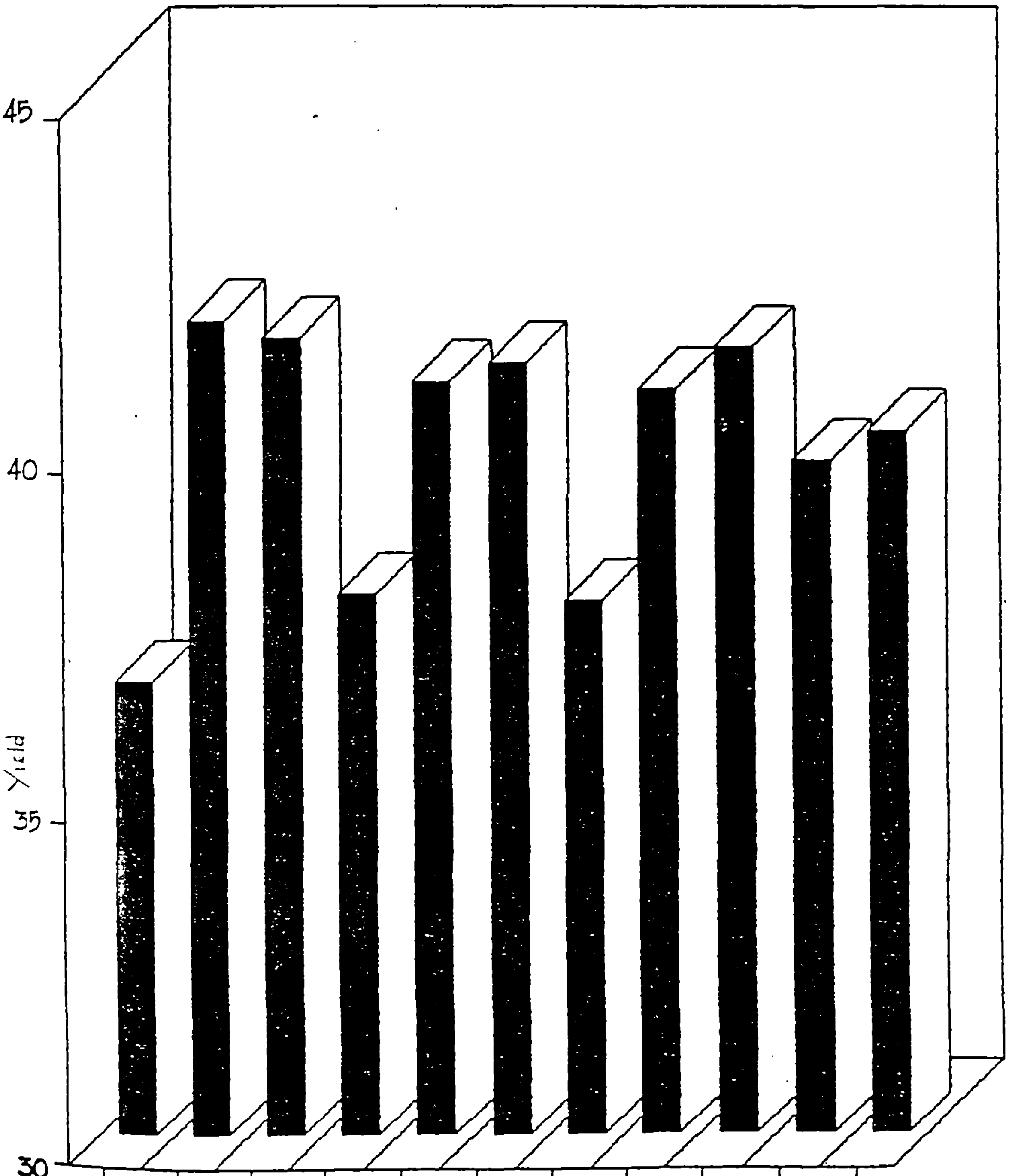


Table 2 that the soil K levels were initially lower at Balussery compared to the other locations. In this situation there is response to higher levels of K. When the soil Mg is already high (Table 27) there is need for higher levels of K to maintain the balance between K and Mg at a favourable level. Punnoose et al. (1978) reported that when soil Mg was high there was response to higher doses of K. This response to higher levels of K is further explained by the significantly higher total volume and dry rubber content and lower plugging index (Table 15) registered by the 80 kg level compared to the 40 kg level. The reports of Punnoose et al. 1978 and Rubber Research Institute of Sri Lanka 1986 and 1987 also indicated response to higher levels of K application.

Application of Mg depresses the yield at Kulasekharam, while it gives a definite response at Thodupuzha and Balussery. The soil Mg status was higher at Kulasekharam compared to the other two locations (Table 27). At Thodupuzha and Balussery the foliage was significantly improved by application of Mg (Table 12) and thereby contributed to a response to Mg application probably by enhancing the photosynthesis for which Mg has a great role (Sutcliff and Baker, 1974). But at Kulasekharam application of Mg has not improved the foliage. The significant reduction in total volume of latex (Table 13) with Mg could be another reason for the depression of yield at Kulasekharam with Mg application. At Thodupuzha and Balussery Mg was found to increase the total volume and dry rubber content of latex (Tables 14 and 15) in most cases and this might have resulted in increased yields with application of Mg. Tables 29 and 30 indicated that the leaf P and K were relatively low at Kulasekharam compared to the other two experimental sites and when Mg was added at low P and K conditions pre coagulation of latex might have set in resulting in depression in yield (Rubber Research Institute Malaya 1969a and 1969b). Depression in yield from application of Mg fertilizer was also reported by Guha and Pushparajah (1966) and Yogaratnam et al. (1984). On the contrary, positive responses to application of Mg were reported by Bolton and Shorrocks (1961), Guha (1975) and Mathew et al. (1989).

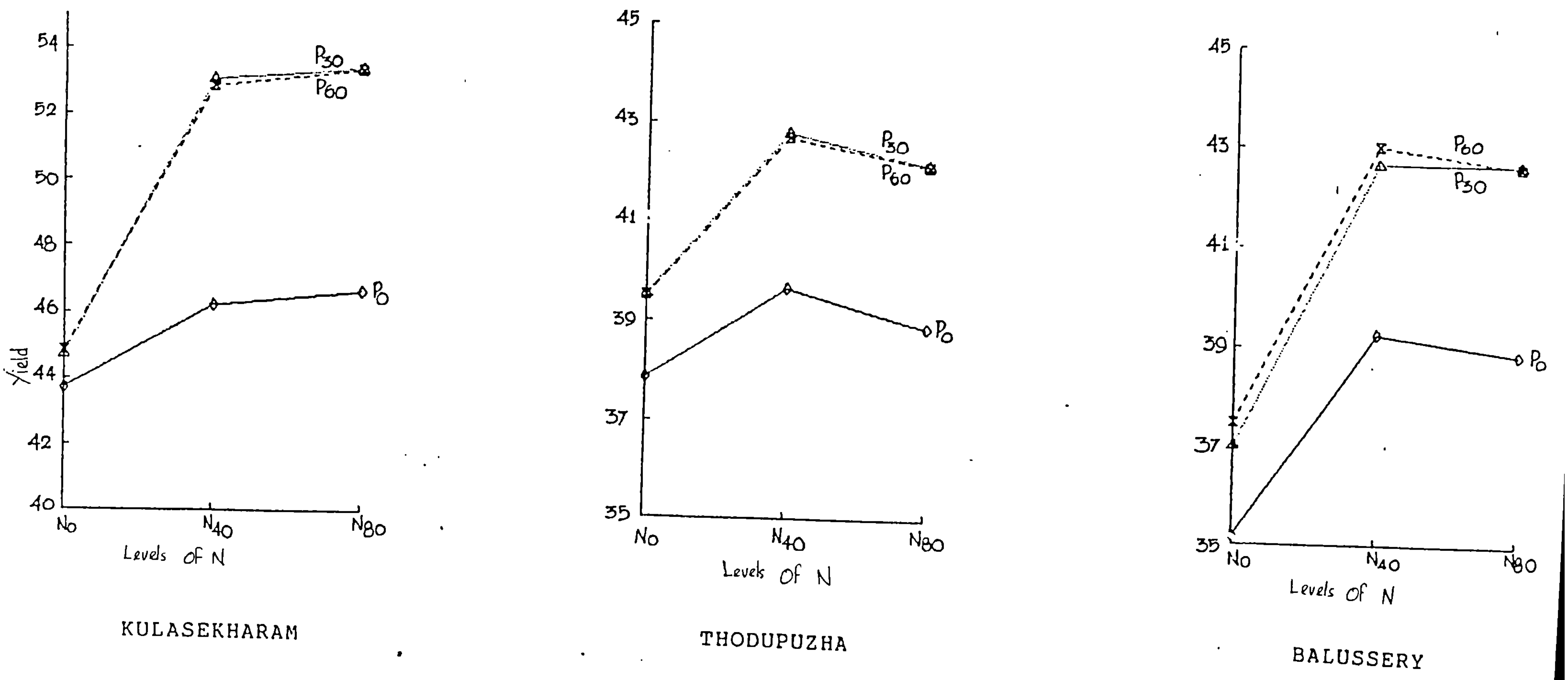
4.1.3.2 Effect of nutrient interactions on yield

The interactions NP,NK,PK,NMg,PMg and KMg were significant in the three locations and are presented and discussed below.

4.1.3.2.1 Interaction NP

In the absence of P, application of N has given significantly higher yield at N_{40} level beyond which further dose of N has not given a significant increase at Kulasekharam (Table 17). At P_{30} and P_{60} levels also the same trend was noticed (Fig.14). Phosphorus also behaved in the same manner with the different levels of N wherein the maximum response was obtained at P_{30} level beyond which there was no further increase. Highest yield was obtained at $N_{80}P_{30}$. This was on par with the

FIG.14 EFFECT OF NP INTERACTION ON YIELD (g $tree^{-1}$ tap^{-1})-



combinations $N_{80}P_{60}$, $N_{40}P_{30}$ and $N_{40}P_{60}$. The interaction clearly shows that the combination $N_{40}P_{30}$ gave a high yield comparable to other combination effects with still higher doses, thereby signifying the fact that more than these levels of N and P are not necessary. Similar NP interaction was obtained at Balussery also (Table 17 and Fig.14).

At Thodupuzha, with P_0, application of N has given significantly higher yield at N_{40} beyond which further dose of N resulted in a significant depression in yield. (Table 17). At P_{30} and P_{60} levels also a similar trend was noticed (Fig. 14). In the absence of N, application of P at 30 kg gave a significant increase in yield and further increasing the level of P was not useful. With the 40 and 80 kg levels of N also, P behaved in the same manner. The combination $N_{40}P_{30}$ gave the highest yield which was significantly higher than $N_{80}P_{30}$ and $N_{80}P_{60}$ and on par with $N_{40}P_{60}$. Similar NP interactions were reported by Owen et al. (1957), George (1962) and Guha (1975) on yield.

4.1.3.2.2 Interaction NK

At different levels of N, application of K at 40 kg has given a significant increase over the K_0 level in the experiment at Kulasekharam (Table 18). Increasing the dose of K to 80 kg level did not significantly influence the yield at N_0 and N_{80} levels, while at K_{40} level there was a significant reduction noticed (Fig. 15). It can be seen from the table that this

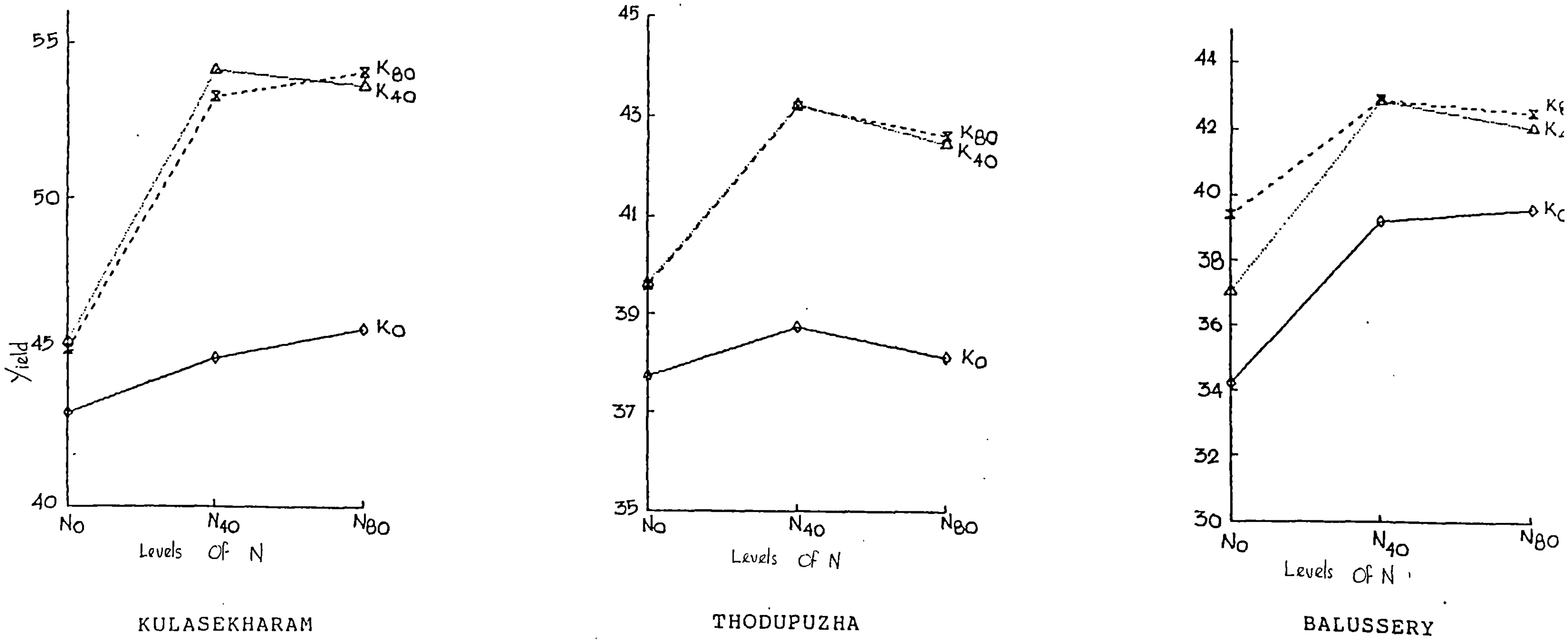
Table 17 Effect of NP interaction on yield (g $tree^{-1} tap^{-1}$)

Levels of N	Levels of P_2O_5			For NP combinations	
	P_0	P_{30}	P_{60}	SE	CD
Kulasekharam					
N_0	43.71	44.75	44.85		
N_{40}	46.25	53.06	52.86	0.279	0.817
N_{80}	46.68	53.41	53.35		
Thodupuzha					
N_0	37.86	39.53	39.50		
N_{40}	39.67	42.79	42.70	0.079	0.232
N_{80}	38.9C	42.16	42.14		
Balussery					
N_0	35.16	37.00	37.47		
N_{40}	39.26	42.66	43.02	0.174	0.510
N_{80}	38.88	42.67	42.63		

Table 18 Effect of NK interaction on yield (g $tree^{-1} tap^{-1}$)

Levels of N	Levels of K_2O			For NK interactions	
	K_0	K_{40}	K_{80}	SE	CD
Kulasekharam					
N_0	42.99	45.31	45.01		
N_{40}	44.77	54.12	53.27	0.279	0.817
N_{80}	45.74	53.64	54.06		
Thodupuzha					
N_0	37.71	39.62	39.57		
N_{40}	38.72	43.24	43.20	0.079	0.232
N_{80}	38.10	42.46	42.63		
Balussery					
N_0	34.19	37.05	38.39		
N_{40}	39.21	42.86	42.87	0.174	0.510
N_{80}	39.61	42.06	42.52		

FIG.15 EFFECT OF NK INTERACTION ON YIELD (g $tree^{-1}$ tap^{-1})-



detrimental effect of K_{80} could be eliminated by giving N_{80}. But $N_{40}K_{40}$ gave higher yield than $N_{80}K_{80}$. Therefore there is no need in increasing the dose of either N or K beyond 40 kg levels. It will be economically as well as productionally not sound. This shows that $N_{40}K_{40}$ is sufficient and increasing the dose of K upto 80 kg is definitely detrimental for yield in this location.

At Thodupuzha application of K at 40 kg level significantly increased the yield at all the levels of N (Table 18). Further increasing the level of K to 80 kg did not result in any further significant increase in yield (Fig. 15). Similarly application of N at 40 kg significantly increased the yield at all the levels of K. Increasing the level of N to 80 kg resulted in a significant reduction in yield at all the levels of K. This shows that the dose of N should not be increased above N_{40} in this location. The best interaction was $N_{40}K_{40}$ and further increasing the level of N was detrimental while increasing the level of K was not useful for yield. This is reflected in the main effects of N and K also wherein the 40 kg levels of N and K are the best doses (Table 16).

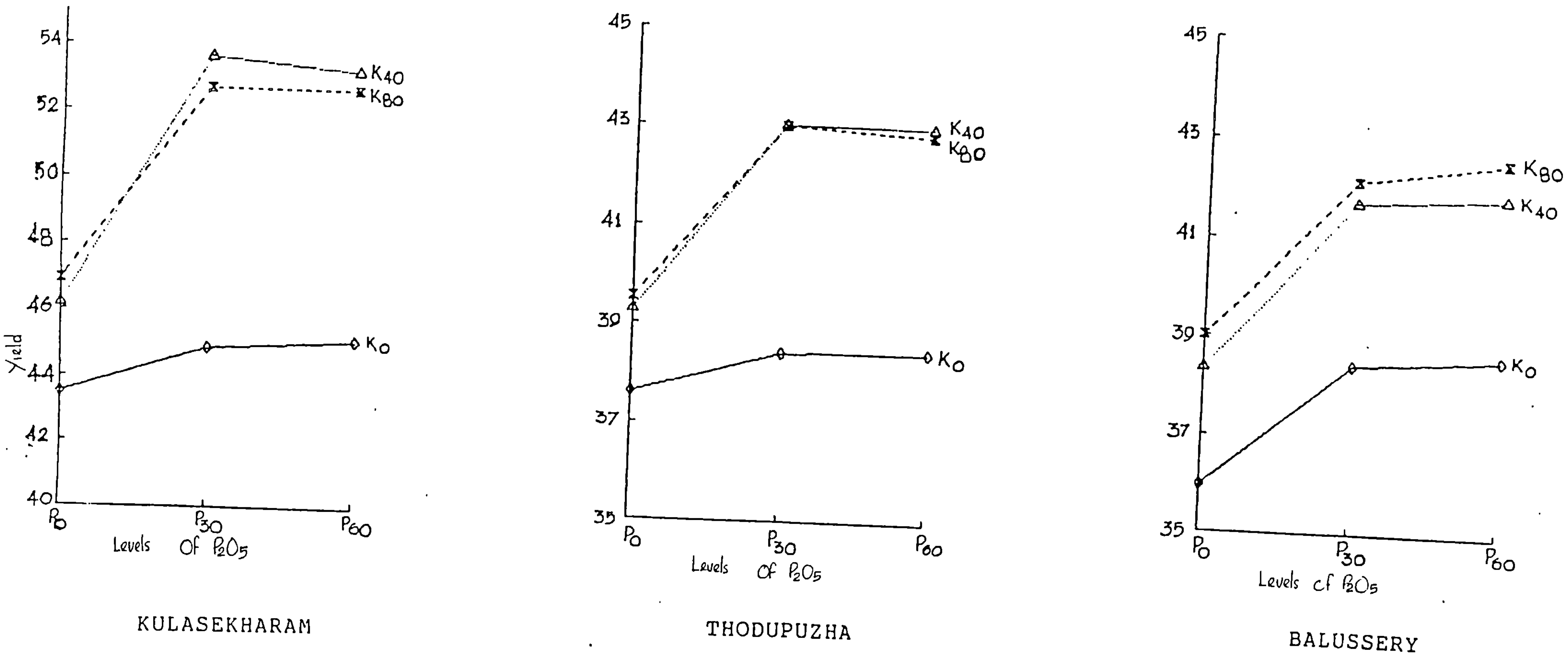
In the experiment at Balussery, at the N_0 level, application of K at 40 and 80 kg levels resulted in progressive significant increases in yield (Table 18). However, the yields obtained at N_0K_{40} and N_0K_{80} were small compared to the combinations involving higher levels of N and K (Fig. 15). With the N_{40} and N_{80} levels, application of K at 40 kg level resulted in significant increase in yield. But increasing the level of K to 80 kg did not result in a further significant increase in yield. At all the levels of K, application of N at 40 kg significantly increased the yield. Increasing the level of N to 80 kg did not affect the yield with K_0 and K_{80} levels, but with the K_{40} level there was a reduction. It can be seen that the level of soil N (Table 2) in this location was relatively high and this could be the reason why the N_{80} level was not useful and even depressed yield probably by creating an imbalance in the tree (Rubber Research Institute of Malaya 1969a and Guha et al. 1971). In the case of the main effects (Table 16) the 40 kg level of N was sufficient while the 80 kg level of K gave the best yield. However the superiority of the 80 kg level of K is not clearly manifested in the NK interaction effects. Though in the absence of N, the 80 kg level of K gave a significant increase, at the 80 kg level of N the increase in yield by raising the level of K from 40 to 80 kg just missed statistical significance. With the 40 kg level of N, application of 40 and 80 kg doses of K did not give a difference. In this way eventhough the main effect of 80 kg K was significant its intraction with the 40 and 80 kg levels of N came out unimportant. The best interaction was a combination of 40 kg each of N and K which was on par with $N_{40}K_{80}$ and $N_{80}K_{80}$. Reports of the Rubber Research Institute of Ceylon (1966), Pushparajah (1977) and Sivanadyan (1983) indicated NK interactions.

4.1.3.2.3 Interaction PK

At Kulasekharam, increasing the level of P from P_0 to P_{30} resulted in a significant increase in yield at all the levels of K application (Table 19). However,further increasing the level of P to 60 kg did not significantly affect the yield (Fig. 16). Application of K at 40 kg significantly increased the yield over the K_0 level with all the levels of P. Further increasing the level of K to 80 kg did not affect the yield at the P_0 and P_{60} levels while at the P_{30} level there was a reduction. The best interaction was $P_{30}K_{40}$ and increasing the level of P above this was not beneficial while increasing the level of either K alone or both K and P jointly resulted in significant reduction in yield. This interaction is reflected in the main effect of P and K also (Table 16) where the optimum levels of P and K were found to be 30 and 40 kg respectively.

In the experimental site at Thodupuzha application of P at 30 kg level significantly increased the yield over the P_0 level at all the levels of K application (Table 19). Further increasing the level of P to 60 kg did not affect the yield (Fig. 16). Similarly increasing the level of K from K_0 to K_{40} significantly increased the yield at all the levels of P. Further increase in the level of K to 80 kg did not result in a significant increase in yield with P_{30} and P_{60} levels eventhough at P_0 there was an increase. The interaction $P_{30}K_{40}$ gave the highest yield which was not significantly different from the

FIG. 16 EFFECT OF PK INTERACTION ON YIELD (g tree^{-1} tap^{-1})-



yields obtained at combinations of still higher levels of both nutrients.

At Balussery, the performance of P at all the levels of K was the same as at Thodupuzha (Table 19). Application of K at 40 kg gave a significant increase in yield over K_0 with all levels of P (Fig.16). Further increasing the level of K to 80 kg did not significantly increase the yield at P_{30} level which appears to be the optimum level for P as seen from the main effect of P (Table 16). However, with P_0 and P_{60} there was an increase for the 80 kg level of K. This increase at K_{80} has been reflected in the main effect of K (Table 16) also. The interaction $P_{60}k_{80}$ gave the highest yield which was significantly better than $P_{30}K_{40}$. However, the interaction $P_{60}K_{80}$ was on par with $P_{30}K_{80}$ and $P_{30}K_{40}$ was on par with $P_{60}K_{40}$. Interaction effects of PK were reported by Owen et al. (1957), Rubber Research Institute of Malaya (1965b) and Yogaratnam and Weerasuriya (1984).

4.1.3.2.4 Interaction NMg

In the experiment at Kulasekharam application of N at 40 kg has substantially increased the yield at both levels of Mg (Table 20). Further increasing the level of N to 80 kg did not appreciably increase the yield eventhough it was statistically significant (Fig. 17). Application of Mg has not influenced the yield much, probably because the soil contained fairly high levels of Mg (Table 2) and this might be due to less leaching loss of Mg from soil under the relatively low rainfall condition

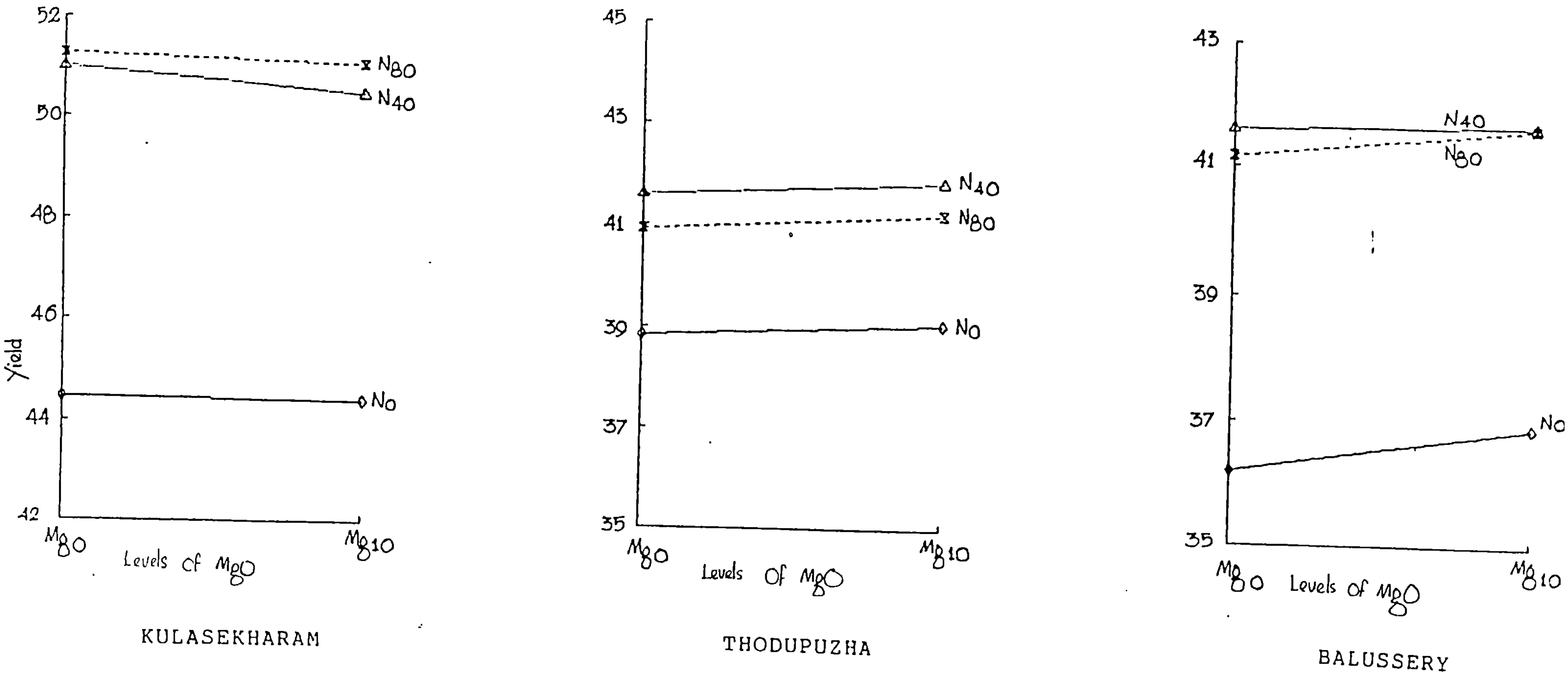
Table 19 Effect of PK interaction on yield (g $tree^{-1} tap^{-1}$)

Levels of P_2O_5	*Levels of K_2O*			*For PK combinations*	
	K_0	K_{40}	K_{80}	SE	CD
Kulasekharam					
P_0	43.49	46.20	46.96		
P_{30}	44.88	53.64	52.71	0.279	0.817
P_{60}	45.13	53.25	52.68		
Thodupuzha					
P_0	37.62	39.28	39.54		
P_{30}	38.44	43.03	43.01	0.079	0.232
P_{60}	38.48	43.01	42.86		
Balussery					
P_0	35.96	38.34	39.00		
P_{30}	38.43	41.73	42.17	0.174	0.510
P_{60}	38.62	41.90	42.61		

Table 20 Effect of **NMg** interaction on yield (g $tree^{-1} tap^{-1}$)

Levels of N	Levels of MgO		For NMg combinations	
	Mg_0	Mg_{10}	SE	CD
Kulasekharam				
N_0	44.47	44.42		
N_{40}	50.98	50.47	0.074	0.215
N_{80}	51.24	51.06		
Thodupuzha				
N_0	38.83	39.09		
N_{40}	41.58	41.86	0.006	0.016
N_{80}	40.90	41.23		
Balussery				
N_0	36.18	36.90		
N_{40}	41.61	41.68	0.042	0.123
N_{80}	41.16	41.64		

FIG.17 EFFECT OF NMg INTERACTION ON YIELD (g $tree^{-1}$ tap^{-1})-



existing here. The effect of Mg showed a negative influence on yield and at N_{40} it even gave a significant reduction. This could be the result of the destabilising effect of Mg on latex (Rubber Research Institute of Malaya, 1969a and 1969b). In the main effect of Mg (Table 16) its application significantly depressed the yield. It is clear from the interaction table that this negative effect of Mg is the result of its negative interaction with the 40 kg level of N.

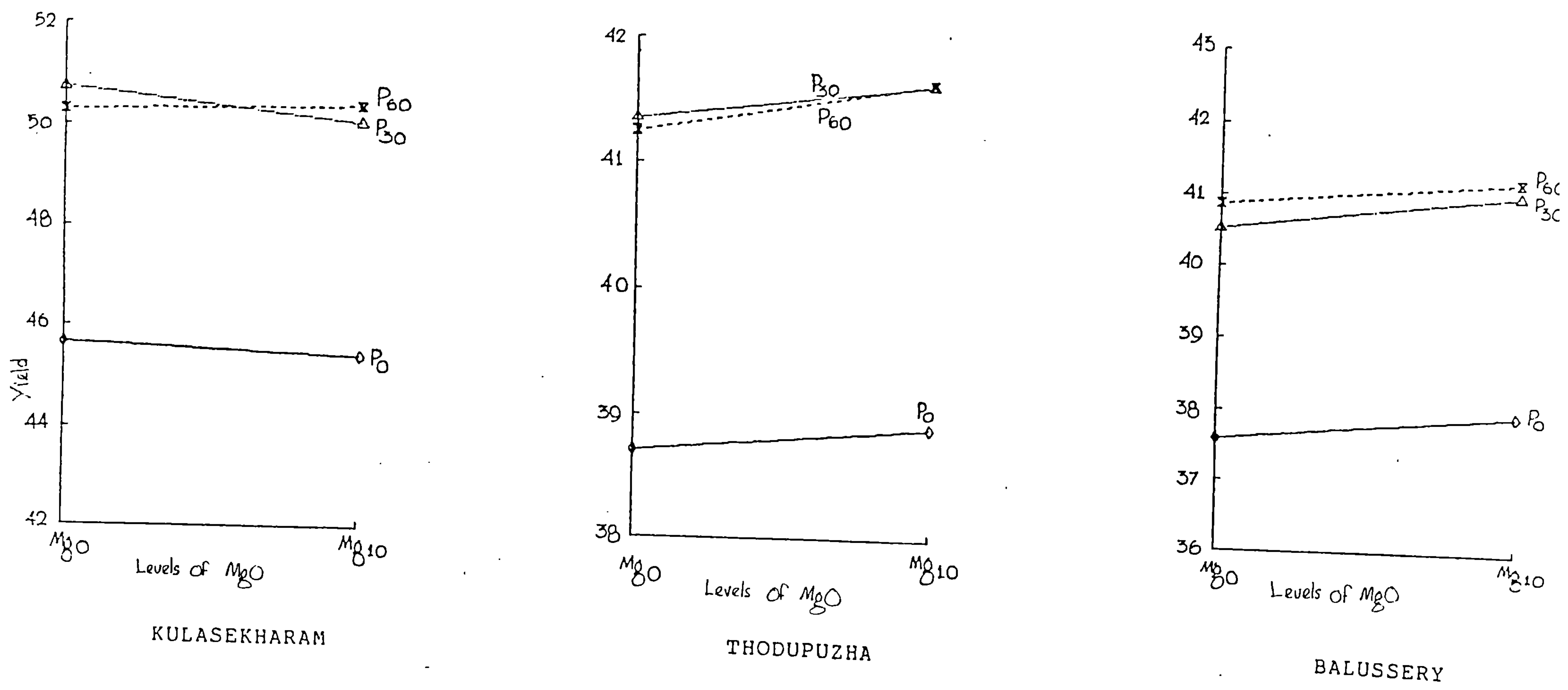
At Thodupuzha, application of N at 40 kg level significantly increased the yield both in the presence and absence of Mg (Table 20) and beyond 40 kg N there was a decrease. The interaction $N_{40}Mg_{10}$ gave the highest yield (Fig. 17).

At Balussery also application of N at 40 kg significantly increased the yield at both levels of Mg (Table 20). Further increasing the dose of N was not beneficial in the presence of Mg while in the absence of Mg there was a decrease (Fig. 17). The interaction N_{40} Mg_{10} gave the highest yield eventhough it was not significantly different from N_{40} Mg_0.

4.1.3.2.5 Interaction PMg

At Kulasekharam there was significant increase in yield with P_{30} compared to P_0 at both the levels of Mg (Table 21). Increasing the level of P to 60 kg resulted in significant but small changes in yield with the two levels of Mg (Fig. 18). At the P_{30} level, application of Mg significantly reduced the yield.

FIG. 18 EFFECT OF PMg INTERACTION ON YIELD (g tree^{-1} tap^{-1})



In general it is seen that the interaction of P with Mg was not very decisive and in fact there was only a negative effect. The highest yield was given by P_{30} in the absence of Mg.

In the experiment at Thodupuzha the main effect of P at 30 kg level was more pronounced and Mg had a significant influence on yield at every level of P applied thereby justifying the application of Mg in this location (Table 21). The combination P_{30} Mg_{10} was found to be sufficient for optimum yield (Fig. 18).

At Balussery also similar results were obtained justifying the need for Mg application (Table 21). The increase in yield from P_0 to P_{30} was significant and marked while further increase from P_{30} to P_{60} though statistically significant was small at both levels of Mg (Fig. 18). The interaction P_{60} Mg_{10} gave the highest yield which was significantly higher than the $P_{30}Mg_{10}$ combination. However the increase from $P_{30}Mg_{10}$ to $P_{60}Mg_{10}$ was small. Significant PMg interactions were reported by Mathew et al. (1989).

4.1.3.2.6 Interaction KMg

In the case of the experiment at Kulasekharam application of K at 40 kg gave appreciable increase in yield irrespective of the level of Mg (Table 22). Further increase in the level of K did not have much influence (Fig. 19). This was true with the main effect of K also (Table 16) where beyond K_{40} there was no further increase in yield. Application of Mg had a negative

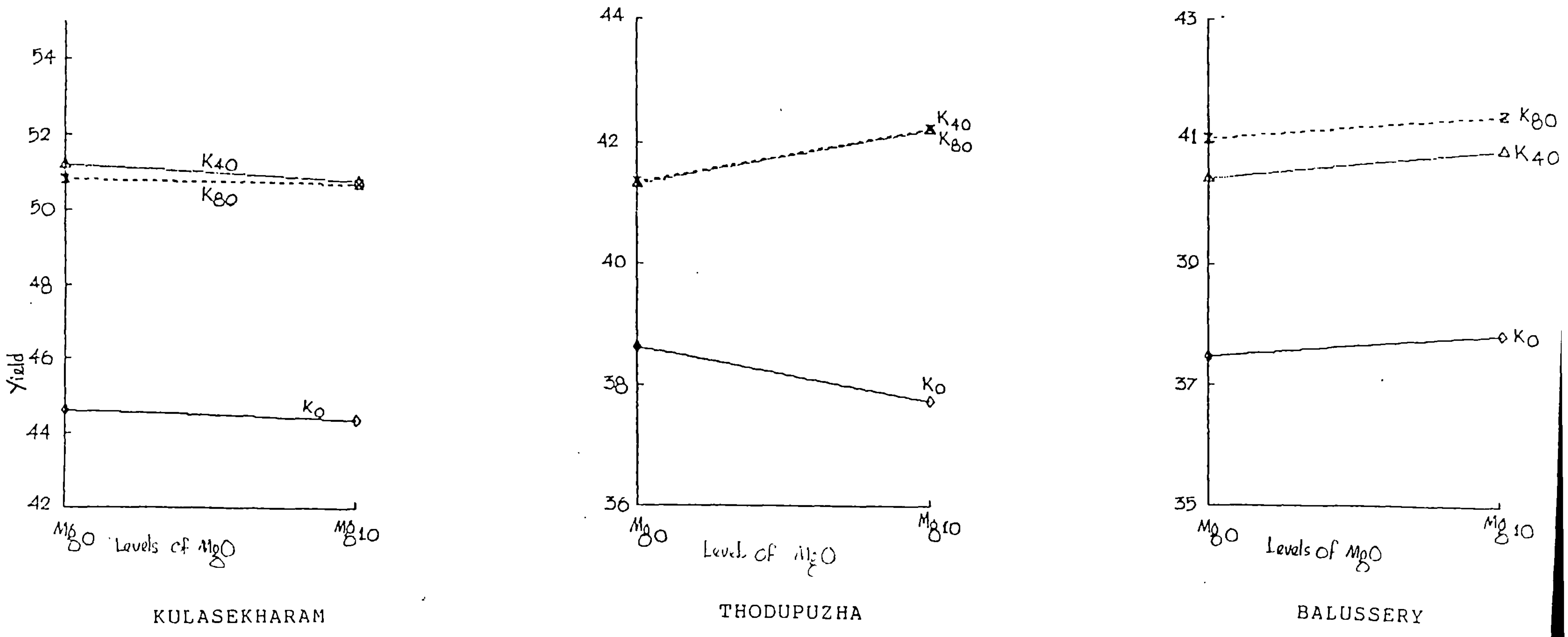
Table 21 Effect of PMg interaction on yield (g $tree^{-1} tap^{-1}$)

Levels of P_2O_5	Levels of Mg_O		For PMg combinations	
	Mg_0	Mg_{10}	SE	CD
Kulasekharam				
P_0	45.65	45.44		
P_{30}	50.73	50.09	0.074	0.215
P_{60}	50.29	50.42		
Thodupuzha				
P_0	38.71	38.91		
P_{30}	41.35	41.63	0.006	0.016
P_{60}	41.25	41.64		
Balussery				
P_0	37.58	37.96		
P_{30}	40.52	41.04	0.042	0.123
P_{60}	40.86	41.22		

Table 22 Effect of KMg interaction on yield (g $tree^{-1} tap^{-1}$)

Levels of K_2O	Levels of Mg_O		For KMg combinations	
	Mg_0	Mg_{10}	SE	CD
Kulasekharam				
K_0	44.62	44.38		
K_{40}	51.23	50.82	0.074	0.215
K_{80}	50.83	50.74		
Thodupuzha				
K_0	38.63	37.73		
K_{40}	41.33	42.22	0.006	0.016
K_{80}	41.36	42.24		
Balussery				
K_0	37.47	37.86		
K_{40}	40.42	40.90	0.042	0.123
K_{80}	41.06	41.46		

FIG.19 EFFECT OF KMg INTERACTION ON YIELD (g tree^{-1} tap^{-1})-



effect at every level of K which was significant at K_0 and K_{40}. The interaction $K_{40}Mg_0$ gave the highest yield which was significantly better than all other combinations involving different levels of K and Mg.

At Thodupuzha application of Mg has given a beneficial effect which was pronounced at K_{40} and K_{80} levels (Table 22 and Fig. 19). At Balussery an uniform beneficial effect was noticed by application of Mg at all the levels of K (Table 22 and Fig. 19).

The main effect of Mg is reflected in the interaction effects also in all the locations and there is no need to apply Mg at Kulasekharam and at the other two location it is necessary. This may be attributed to the influence of climate mainly rainfall which is probably responsible for the differential response to Mg.

4.1.4 Chemical analysis

4.1.4.1 Effect of nutrients on soil nutrient contents

The effect of applied nutrients on soil organic carbon and available P,K,Ca and Mg are presented and discussed.

4.1.4.1.1 Effect of nutrients on organic carbon

The results obtained for the three locations are presented in Table 23. Application of N at both 40 and 80 kg levels has significantly increased the organic carbon content over the N_0

level in all the three locations during all the years. The N_{80} level gave the highest organic carbon content and was superior to the N_{40} level. The effect of P was not very conspicuous. At Kulasekharam application of P at 60 kg significantly improved the organic carbon content, while the 30 kg was on par with P_0. The effect of P was not significant at Thodupuzha. However, the P_{30} and P_{60} treatments gave numerically higher values than the P_0 treatment. At Balussery the effect of P was significant. The P_{60} level gave the highest value during all the years. During 1989, both P_{60} and P_{30} were superior to P_0, but the former two levels were on par. In 1990, P_{60} was superior to both P_{30} and P_0, but the latter levels were on par. The P_{30} and P_0 levels were on par during 1991 also while P_{60} level was superior to P_{30} level.

In the case of K, its application at both 40 and 80 kg levels had a significant effect in increasing the organic carbon content at Kulasekharam during 1990. The 80 kg level gave the highest value which was on par with the 40 kg level. During 1989 and 1991 though the effect of K was not significant a similar trend was noticed. Application of K did not significantly affect the organic carbon content during any of the years at Thodupuzha and Balussery. However during 1989 and 1990 the K_{40} and K_{80} treatments gave numerically higher values than K_0 in these locations.

Table 23 Effect of nutrients on soil organic carbon (per cent)

Treatments Nutrients	Kulasekharam			Thodupuzha			Balussery		
kg ha^{-1}	1989	1990	1991	1989	1990	1991	1989	1990	1991
N_0	0.92	0.91	0.93	1.00	1.00	1.02	1.03	1.04	1.04
N_{40}	1.01	1.02	1.04	1.13	1.15	1.18	1.14	1.16	1.19
N_{80}	1.12	1.10	1.12	1.22	1.23	1.26	1.27	1.30	1.32
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}
P_0	1.00	0.99	1.00	1.11	1.12	1.14	1.13	1.16	1.18
P_{30}	1.02	0.99	1.02	1.13	1.13	1.16	1.15	1.16	1.17
P_{60}	1.03	1.05	1.06	1.11	1.13	1.15	1.16	1.18	1.20
F-ratio	NS	S^{**}	S^{**}	NS	NS	NS	S^{**}	S^{*}	S^{*}
K_0	1.00	0.99	1.02	1.11	1.12	1.15	1.14	1.16	1.18
K_{40}	1.01	1.02	1.03	1.12	1.13	1.16	1.16	1.17	1.20
K_{80}	1.03	1.02	1.04	1.12	1.13	1.14	1.14	1.16	1.17
F-ratio	NS	S^{*}	NS	NS	NS	NS	NS	NS	NS
SE(N,P,K)	0.01	0.01	0.01	0.008	0.006	0.006	0.006	0.006	0.007
CD(N,P,K)	0.03	0.02	0.03	0.024	0.019	0.019	0.019	0.019	0.021
Mg_0	1.02	1.01	1.02	1.12	1.12	1.14	1.14	1.16	1.18
Mg_{10}	1.01	1.01	1.04	1.12	1.14	1.16	1.15	1.17	1.19
F-ratio	NS	NS	NS	NS	S^{*}	NS	NS	S^{*}	S^{*}
SE(Mg)	0.01	0.01	0.01	0.007	0.005	0.004	0.003	0.003	0.003
CD(Mg)	-	-	-	-	0.014	-	-	0.009	0.009

S^{*} : Singnificant at P=0.05 level

S^{**} : Significant at P= 0.01 level

NS : Not Significant

The effects of Mg was significant only during 1990 at Thodupuzha and during 1990 and 1991 at Balussery where its application significantly improved the organic carbon contents. A similar trend was noticed in all other cases except at Kulasekharam in 1989.

An examination of Table 23 indicates that there was generally a small but gradual build up of organic carbon in the three location with time.

It is seen that addition of all the nutrients helped in the enrichment of soil organic carbon. When mineral nutrients are in adequate supply in soil there will be better conservation of organic carbon of soil (Stevenson, 1964 and Brady, 1988). The gradual build up of organic carbon in the soil could be the result of continuous addition of leaf litter from the trees. The effect of N on the organic carbon status is well known. In rubber soil it is all the more enhanced. Hence, it is not discussed in detail. Reports of the Rubber Research Institute of Malaysia (1976) indicated that application of fertilizers, especially N increased the level of organic carbon in the soil.

4.1.4.1.2 **Effect of nutrients on available P**

The available P content in the different locations is given in Table 24. The effect of N application on the available P content of soil was significant only at Balussery in the year 1990, where the N_{80} level gave higher P content over the N_{40} and

N_0 levels. The two latter levels were on par. In all the remaining cases, the effect of N was not significant and the trend also was inconsistent. There was progressive significant increase in the P content of soil with incremental doses of P application in all the locations during the entire period. There was also substantial increases in P content with each level of P application. The highest content of soil P was given by the P_{60} level.

The response to application of K was inconsistent. At Kulasekharam the K_{80} level was on par with K_0 in 1989 and both these levels were superior to K_{40}. In 1990 and 1991 there was no significant difference among the different levels of K. In 1990 numerically the highest P content was obtained at K_0 level, while in 1991 the highest content was obtained at the K_{80} level. Significant differences were noticed among the levels of K at Thodupuzha during all the three years. In 1989 and 1990 the K_{80} level was on par with K_0 and in 1991 the K_0 level was superior to both K_{40} and K_{80} levels. At Balussery application of K at K_{40} level gave significantly higher P content compared to K_{80} and K_0 levels in 1989 and 1991. In 1990 also K_{40} level gave numerically the highest P content eventhough the differences among the levels of K were not significant.

The effect of application of Mg also was inconsistent on the P content of soil in the different locations. At Kulasekharam there was no significant effect from Mg application

Table 24 Effect of nutrients on soil available P (kg ha^{-1})

Treatments	Kulasekharam			Thodupuzha			Balussery		
Nutrients kg ha^{-1}	1989	1990	1991	1989	1990	1991	1989	1990	1991
N_0	20.26	30.18	33.07	19.49	26.85	47.06	38.65	50.01	56.69
N_{40}	20.20	30.15	32.66	19.66	26.76	47.41	38.33	49.65	56.37
N_{80}	20.44	29.92	32.84	19.49	26.69	46.62	38.99	50.85	55.94
F-ratio	NS	NS	NS	NS	NS	NS	NS	S^*	NS
P_0	16.16	16.73	16.84	14.59	17.54	20.15	24.43	25.91	24.79
P_{30}	20.29	32.65	36.07	20.43	28.22	54.66	41.09	54.29	60.26
P_{60}	24.46	40.87	45.67	23.63	34.54	66.27	50.46	70.31	83.96
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}
K_0	20.41	30.41	32.74	19.86	26.99	48.23	38.22	50.42	56.14
K_{40}	19.93	29.76	32.86	18.88	26.36	46.49	39.40	50.46	57.65
K_{80}	20.56	30.09	32.98	19.90	26.94	46.36	38.35	49.63	55.22
F-ratio	S^{**}	NS	NS	S^{**}	S^{**}	S^{**}	S^{**}	NS	S^{**}
SE(N,P,K)	0.13	0.18	0.26	0.131	0.146	0.234	0.257	0.280	0.268
CD(N,P,K)	0.38	0.53	0.76	0.385	0.427	0.686	0.753	0.821	0.786
Mg_0	20.45	29.87	32.68	19.46	26.62	47.46	38.76	50.40	55.56
Mg_{10}	20.15	30.30	33.04	19.64	26.92	46.60	38.56	49.94	57.11
F-ratio	NS	NS	NS	NS	S^{**}	S^{**}	NS	NS	S^{**}
SE(Mg)	0.13	0.18	0.31	0.111	0.047	0.164	0.259	0.204	0.310
CD(Mg)	–	–	–	–	0.136	0.477	–	–	0.90

S^* : Significant at P=0.05 level

S^{**} : Significant at P= 0.01 level

NS : Not Significant

during the entire period. In 1990 and 1991 numerically higher means were given by Mg application, while the reverse trend was noticed in 1989. The effect of application of Mg was significant in 1990 and 1991 at Thodupuzha. In 1990, there was a significant increase in P content from Mg application while there was a significant reduction in 1991. In 1989, Mg application did not affect the P content. At Balussery, application of Mg gave a significant increases in P content only in 1991 and during the previous years the effect was not significant and even a reverse trend was noticed.

The increase in the available P content of soil with application of P was notable. It is only a direct effect of application of P fertilizer. Similar increases in P content of soil were reported by Bolton (1960) and Pushpadas et al. (1972) in rubber growing soils. There was also a gradual build up of available P in the different locations with time. As expected, N or K application has not influenced the P content of soil.

4.1.4.1.3 Effect of nutrients on available K

The available K contents of soil in the three locations are presented in Table 25. Application of N had significant negative effect on the available K content during all the years at Kulasekharam and Balussery and during 1990 and 1991 at Thodupuzha. There was progressive reduction in the K content with incremental doses of N application. The highest K content was noticed at N_0 and lowest at N_{80} level. At Thodupuzha during

1989 though the effect of N was not significant, numerically the highest K content was observed at N_0 and lowest content at N_{40} level.

At Kulasekharam, application of P showed a tendency to reduce the K content. During 1990 both the P_{30} and P_{60} levels significantly reduced the K content compared to P_0 where the former two levels were on par. The P_{60} level significantly depressed the K content in 1991 below the P_{30} and P_0 levels and there was no significant difference between the latter levels. The effect of P was not significant during 1989. But a similar trend as in 1990 was noticed. At Thodupuzha the effect of P was significant only in 1990 when the P_{30} level gave higher K content above the P_{60} and P_0 level, the latter levels being on par. During 1989 and 1991 also a more or less similar trend was noticed. During 1991 there was a significant reduction in the K content with application of P at both P_{30} and P_{60} levels at Balussery. The P_{30} and P_{60} levels were on par. During 1989 and 1990 the effect of P was not significant. The P_0 level gave the highest K content in 1989 while during 1990 the highest K content was obtained at P_{30} level.

Application of K at both K_{40} and K_{80} levels significantly increased the K content of soil during all the years in the three locations over the K_0 level. The highest K content was given by K_{80} level which was significantly higher than the K_{40} level. There was substantial increase in the K content with K

Table 25 Effect of nutrients on soil available K (kg ha^{-1})

Treatments Nutrients kg ha^{-1}	Kulasekharam			Thodupuzha			Balussery		
	1989	1990	1991	1989	1990	1991	1989	1990	1991
N_0	133.98	159.32	211.21	126.04	151.36	163.57	110.60	138.61	155.66
N_{40}	125.59	146.96	205.94	119.45	139.44	156.59	104.87	122.83	143.28
N_{80}	106.70	130.07	168.45	119.86	123.70	138.92	87.73	108.16	120.36
F-ratio	S^{**}	S^{**}	S^{**}	NS	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}
P_0	123.21	150.39	196.95	119.42	135.86	153.66	102.38	122.09	142.42
P_{30}	120.12	141.80	196.01	123.09	141.52	154.48	101.92	125.63	137.32
P_{60}	122.94	144.16	192.63	122.84	137.12	150.94	98.90	121.88	139.56
F-ratio	NS	S^{**}	S^{*}	NS	S^{*}	NS	NS	NS	S^{**}
K_0	91.53	100.82	122.91	89.30	105.34	117.56	91.87	87.48	104.60
K_{40}	117.00	147.91	182.27	126.12	141.09	156.91	100.97	123.96	143.91
K_{80}	157.74	187.62	280.42	149.93	168.08	184.61	110.36	158.15	170.79
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}
SE(N,P,K)	1.25	1.51	0.98	2.172	1.292	1.383	1.217	1.265	0.956
CD(N,P,K)	3.66	4.42	2.88	6.369	3.790	4.056	3.570	3.709	2.805
Mg_0	124.23	146.61	197.40	129.85	144.69	156.56	106.56	126.71	141.86
Mg_{10}	119.95	144.29	192.99	113.72	131.64	149.39	95.57	119.68	137.67
F-ratio	S^{**}	NS	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}
SE(Mg)	0.84	0.98	0.48	0.953	0.747	0.517	0.406	0.793	0.968
CD(Mg)	2.43	-	1.39	2.765	2.167	1.500	1.178	2.301	2.808

S^{*} : Significant at P = 0.05 level

S^{**} : Significant at P = 0.01 level

NS : Not Significant

application. There was a significant reduction in the K content with application of Mg in all the locations during the entire period except for Kulasekharam during 1990 where also a similar trend was observed.

It was observed that application of K significantly increased the available K content of soil. This is the direct effect of application of K fertilizer. Similar observations were reported by Pushpadas et al. (1978) Lau (1979) and Dissanayaka and Mithrasena (1986).

Application of N was found to reduce the K content of soil. Higher concentrations of NH_4^+ ions especially in the lower layers would have replaced K^+ ions from the exchange sites bringing more of K into the solution from where they were lost by leaching (Tisdale et al. 1985). Moreover, the higher growth associated with application of N would have increased the plant uptake of K thus reducing its level in the soil. Application of Mg also lead to decrease in the K content of soil. It would be possible that when Mg was added to soil it might have displaced some K^+ ions into the soil solution which in turn were lost by leaching thus lowering the K content of soil (Brady, 1988).

4.1.4.1.4 Effect of nutrients on available Ca

The results are presented in Table 26. The effect of N was significant in all the three years and in the three locations. Increasing the level of N progressively reduced the available Ca

Table 26 Effect of nutrients on soil available Ca (kg ha^{-1})

Treatments Nutrients kg ha^{-1}	Kulasekharam			Thodupuzha			Balussery		
	1989	1990	1991	1989	1990	1991	1989	1990	1991
N_0	269.35	406.30	470.57	197.18	254.31	323.37	386.00	458.69	588.52
N_{40}	240.59	363.13	431.30	178.35	229.99	287.74	365.32	433.75	550.33
N_{80}	212.06	317.58	391.45	154.88	203.66	252.95	337.36	411.11	507.76
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}
P_0	200.50	241.25	282.00	123.82	143.66	159.75	322.42	361.41	402.65
P_{30}	241.57	362.70	445.66	183.94	242.12	300.78	363.70	441.23	562.09
P_{60}	279.92	483.06	565.66	222.65	302.19	403.52	402.56	500.92	681.88
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}
K_0	243.54	365.11	428.28	174.76	228.78	288.06	364.57	433.99	552.11
K_{40}	239.37	363.37	432.04	179.07	228.84	288.43	360.56	432.85	546.03
K_{80}	239.09	358.53	433.00	176.58	230.34	287.57	363.54	436.72	548.48
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}	NS	NS	NS	S^{**}	S^{**}
SE(N,P,K)	0.63	0.88	1.02	0.585	0.536	0.624	1.254	0.786	0.575
CD(N,P,K)	1.83	2.59	2.98	1.715	1.571	1.831	3.677	2.305	1.687
Mg_0	241.71	361.55	429.87	117.66	228.76	228.24	361.79	434.90	548.61
Mg_{10}	239.63	363.12	432.34	175.95	229.88	287.79	363.99	434.14	549.13
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}	NS	NS	S^{**}	NS	NS
SE(Mg)	0.48	0.30	0.58	0.422	0.431	0.368	0.289	0.555	0.272
CD(Mg)	1.40	0.87	1.68	1.225	-	-	0.839	-	-

S^{*} : Significant at P=0.05 level

S^{**} : Significant at P=0.01 level

NS : Not Significant

content of soil. On the other hand application of P had a significant positive effect on soil Ca in all cases. There was progressive and substantial increases in the Ca content with incremental doses of application of P. The pattern of response to K application was highly inconsistent in the three locations and also over the years. For Mg, no clear trend was seen.

It is seen that application of P has significantly increased the Ca content of soil. When P was added to soil as rock phosphate it also added Ca to soil and this could be the reason why the Ca content of soil increased with addition of P. There was also a build up of Ca in soil with addition of P over the years. This could be due to the continuous applications of rock phosphate (Bolton, 1960 and Pushparajah, 1966). Application of N has increased the growth and yield of the tree and might have removed more Ca from soil,with the result the Ca content of soil was reduced.

4.1.4.1.5 Effect of nutrients on available Mg

It is noticed that application of N has significantly reduced the available Mg content of soil in the three locations during the entire period (Table 27). The Mg content decreased progressively with incremental doses of N in all cases except for 1990 at Kulasekharam and Thodupuzha where the N_{40} and N_{80} levels were on par. There was a significant increase in the Mg content with application of P in all cases except for 1989 at Balussery.

At Kulasekharam the P_{60} level was superior to P_{30} level in 1989 and 1990 while in 1991 the P_{30} level came superior to P_{60} level in increasing the Mg content of soil. At Thodupuzha the P_{60} and P_{30} levels were always on par and in 1989 and 1991 the P_{30} level was on par with P_0. The effect of P was not significant in 1989 at Balussery. During subsequent years both the P_{30} and P_{60} levels significantly increased the Mg content. The P_{30} and P_{60} levels were on par.

Application of K at both 40 and 80 kg levels had a significant negative effect on the Mg content in all the locations during the entire period. At Kulasekharam the K_{40} and K_{80} levels were on par. At K_{80} level there was a further significant reduction in Mg content compared to the K_{40} level at Thodupuzha during 1989 and 1990, while during 1991 these two levels were on par. At Balussery there was progressive reduction in the Mg content with incremental doses of K application during 1989 while there was no significant difference between the K_{40} and K_{80} levels during 1990 and 1991. Application of Mg significantly increased the soil Mg content in all the locations during the entire period.

Application of Mg has significantly increased the Mg content of soil which can be explained as the direct effect of addition of Mg fertilizer (Dissanayaka and Mithrasena, 1986). Application of N and K reduced the Mg content of soil. Higher concentration of NH_4^+ and K^+ ions might have replaced more of

Table 27 Effect of nutrients on soil available Mg (kg ha-1)

Treatments Nutrients kg ha^{-1}	Kulasekharam			Thodupuzha			Balussery		
	1989	1990	1991	1989	1990	1991	1989	1990	1991
N_0	124.15	143.42	169.13	25.21	30.04	41.34	74.94	78.04	98.89
N_{40}	118.47	129.60	148.33	20.88	26.13	36.30	64.99	71.38	91.73
N_{80}	112.04	130.15	145.26	19.43	26.46	35.41	62.99	68.47	88.80
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}
P_0	115.28	130.92	152.22	21.49	26.96	37.40	67.64	69.73	90.37
P_{30}	118.95	134.88	156.59	21.85	27.91	37.58	67.51	74.31	95.29
P_{60}	120.43	137.37	153.91	22.18	27.77	38.07	67.76	73.86	93.76
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	NS	NS	S^{**}	S^{**}
K_0	124.48	148.06	164.34	24.25	30.45	41.14	75.30	81.23	101.55
K_{40}	115.35	127.42	149.59	20.98	26.29	35.85	64.96	68.27	89.20
K_{80}	114.83	127.70	148.78	20.29	25.90	36.06	62.65	68.39	88.66
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}
SE(N,P,K)	0.424	0.410	0.517	0.135	0.118	0.189	0.21	0.47	0.53
CD(N,P,K)	1.245	1.203	1.516	0.397	0.345	0.555	0.63	1.38	1.57
Mg_0	115.63	130.37	150.73	20.08	25.77	35.78	66.61	68.75	89.19
Mg_{10}	120.81	138.41	157.75	23.60	29.32	39.59	68.66	76.51	97.09
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}
SE(Mg)	0.430	0.344	0.340	0.099	0.039	0.041	0.22	0.10	0.32
CD(Mg)	1.248	0.997	0.988	0.286	0.113	0.118	0.63	0.30	0.94

S^{**} : Significant at P=0.01 level

Mg^{++} ions from the exchange sites into the soil solution and they were subsequently lost by leaching (Tisdale *et al*. 1985). Again more of Mg was probably removed by the tree when growth and yield were improved by application of N and K.

4.1.4.2 Effect of nutrients on leaf nutrient contents

4.1.4.2.1 Effect of nutrients on leaf N content

The results obtained for the three locations are presented in Table 28. It is seen that application of N at both 40 and 80 kg levels has significantly increased the leaf N content over the N_0 level in all the three locations. The N_{80} level was superior to the N_{40} level in all the locations during the entire period except for Kulasekharam in 1991 where the former levels were on par. The N_{80} level gave the highest leaf N content in all cases. Application of P, K and Mg did not show a significant effect on the leaf N content. It can be seen that application of N has increased the soil organic carbon (Table 23) which might have lead to greater absorption of N and increased N content of leaf. Similar increases in the leaf N content of rubber from application of N fertilizers were reported by Shorrocks (1962 and 1964), Kalam *et al*. (1980) and Sivanadyan (1983).

4.1.4.2.2. Effect of nutrients on leaf P content

Application of N did not have much influence on leaf P (Table 29). In the case of P, incremental doses of its application progressively increased the P content in all the

Table 28 Effect of nutrients on leaf N (per cent)

Treatments	Kulasekharam			Thodupuzha			Balussery		
Nutrients kg ha^{-1}	1989	1990	1991	1989	1990	1991	1989	1990	1991
N_0	3.206	3.342	3.573	3.505	3.991	3.810	3.409	3.799	3.698
N_{40}	3.413	3.614	3.796	3.691	4.193	4.004	3.612	3.999	3.897
N_{80}	3.591	3.791	3.918	3.885	4.398	4.206	3.805	4.199	4.103
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}
P_0	3.372	3.553	3.770	3.670	4.170	3.974	3.589	3.994	3.891
P_{30}	3.423	3.593	3.768	3.712	4.218	4.041	3.625	4.000	3.906
P_{60}	3.416	3.600	3.750	3.699	4.195	4.006	3.612	4.003	3.900
F-ratio	NS	NS	NS	NS	NS	NS	NS	NS	NS
K_0	3.388	3.579	3.753	3.684	4.180	3.987	3.613	4.001	3.889
K_{40}	3.420	3.582	3.756	3.695	4.202	4.006	3.598	3.979	3.910
K_{80}	3.403	3.586	3.776	3.703	4.201	4.027	3.616	4.018	3.898
F-ratio	NS	NS	NS	NS	NS	NS	NS	NS	NS
SE (N,P,K)	0.05	0.06	0.07	0.05	0.04	0.03	0.05	0.03	0.04
CD (N,P,K)	0.16	0.17	0.19	0.15	0.10	0.08	0.14	0.09	0.11
Mg_0	3.401	3.592	3.772	3.705	4.204	4.010	3.616	4.002	3.900
Mg_{10}	3.406	3.572	3.753	3.683	4.184	4.003	3.601	3.996	3.898
F-ratio	NS	NS	NS	NS	NS	NS	NS	NS	NS
SE (Mg)	0.02	0.03	0.05	0.02	0.01	0.03	0.01	0.02	0.2
CD (Mg)	-	-	-	-	-	-	-	-	-

S^{**} : Significant at P = 0.01 level

NS : Not Significant

Table 29 Effect of nutrients on leaf P (per cent)

Treatments	Kulasekharam			Thodupuzha			Balussery		
Nutrients kg ha^{-1}	1989	1990	1991	1989	1990	1991	1989	1990	1991
N_0	0.225	0.240	0.257	0.278	0.300	0.330	0.270	0.350	0.351
N_{40}	0.224	0.243	0.259	0.281	0.293	0.327	0.269	0.350	0.351
N_{80}	0.237	0.244	0.260	0.279	0.291	0.350	0.263	0.350	0.351
F-ratio	S^{**}	NS	NS	NS	S^{**}	NS	S^{**}	NS	NS
P_0	0.211	0.226	0.240	0.260	0.280	0.288	0.249	0.330	0.331
P_{30}	0.230	0.241	0.258	0.279	0.293	0.349	0.263	0.350	0.351
P_{60}	0.234	0.260	0.278	0.300	0.310	0.370	0.290	0.371	0.370
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S_{**}	S^{**}	S_{**}
K_0	0.230	0.247	0.263	0.286	0.298	0.353	0.271	0.354	0.355
K_{40}	0.223	0.240	0.257	0.277	0.295	0.329	0.266	0.348	0.350
K_{80}	0.222	0.239	0.256	0.276	0.291	0.325	0.264	0.347	0.347
F-ratio	S^{**}	S^{*}	NS	S^{*}	S^{*}	NS	S^{**}	NS	S^{*}
SE (N,P,K)	0.003	0.003	0.003	0.003	0.002	0.02	0.002	0.003	0.002
CD (N,P,K)	0.008	0.008	0.009	0.009	0.005	0.05	0.005	0.009	0.007
Mg_0	0.224	0.242	0.259	0.280	0.294	0.337	0.268	0.350	0.351
Mg_{10}	0.226	0.242	0.259	0.279	0.295	0.334	0.267	0.350	0.351
F-ratio	NS	NS	NS	NS	NS	NS	NS	NS	NS
SE (Mg)	0.001	0.002	0.003	0.003	0.003	0.01	0.002	0.001	0.001
CD (Mg)	-	-	-	-	-	-	-	-	

S^{*} :Significant at P = 0.05 level S^{**} :Significant at P = 0.01 level NS :Not Significant locations during the entire period. The P_{60} level gave the highest P content in all cases which was superior to P_{30} level in all cases except at Kulasekharam in 1989 where the two levels were on par. Both the P_{60} and P_{30} levels gave significantly higher P content over the P_0 level.

The effect of K was significant in the three locations during two years each. Application of K showed a reducing effect on the P content of leaf in all cases. The effect of application of Mg was not significant in any case. In most cases Mg application showed a tendency to reduce the leaf P content.

Application of P has significantly increased the P content of leaf. It was already seen that there was significant increase in the soil P level from application of P fertilizer. The high P status of soil might have helped in better absorption of P resulting in high P contents of leaf. Shorrocks (1962), Pushpadas et al.(1978) and Yogaratnam et al.(1984) also reported that application of P improved the leaf P content of rubber.

4.1.4.2.3 Effect of nutrients on leaf K content

The effect of application of N on the leaf K content was not significant in any of the locations (Table 30). The effect of P was not significant in almost all cases. The effect of application of K on leaf K content was significant at all the locations during all the years. It is also seen that application n of Mg significantly reduced the leaf K content in all cases.

Table 30 Effect of nutrients on leaf K (per cent)

Treatments	Kullasekharam			Thodupuzha			Balussery		
Nutrients kg ha^{-1}	1989	1990	1991	1989	1990	1991	1989	1990	1991
N_0	1.440	1.524	1.621	1.521	1.565	1.621	1.523	1.821	1.865
N_{40}	1.381	1.479	1.577	1.478	1.518	1.576	1.474	1.777	1.818
N_{80}	1.376	1.473	1.576	1.473	1.507	1.568	1.474	1.771	1.816
F-ratio	NS	NS	NS	NS	NS	NS	NS	NS	NS
P_0	1.402	1.491	1.591	1.493	1.534	1.594	1.491	1.792	1.836
P_{30}	1.403	1.492	1.590	1.489	1.531	1.506	1.491	1.787	1.831
P_{60}	1.393	1.494	1.593	1.490	1.526	1.584	1.487	1.789	1.832
F-ratio	NS	NS	NS	NS	NS	S^*	NS	NS	NS
K_0	1.203	1.292	1.387	1.288	1.329	1.388	1.286	1.591	1.632
K_{40}	1.395	1.489	1.591	1.491	1.530	1.585	1.494	1.789	1.838
K_{80}	1.599	1.696	1.796	1.694	1.731	1.791	1.690	1.989	2.029
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}
SE (N,P,K)	0.04	0.023	0.02	0.02	0.02	0.02	0.03	0.03	0.02
CD (N,P,K)	0.10	0.07	0.07	0.06	0.06	0.06	0.09	0.10	0.07
Mg_0	1.412	1.504	1.605	1.503	1.542	1.599	1.503	1.803	1.848
Mg_{10}	1.386	1.481	1.578	1.478	1.518	1.577	1.477	1.776	1.818
F-ratio	S^*	S^*	S^*	S^*	S^*	S^*	S^*	S^*	S^*
SE (Mg)	0.006	0.003	0.008	0.006	0.006	0.006	0.006	0.006	0.006
CD (Mg)	0.020	0.010	0.024	0.020	0.020	0.020	0.020	0.020	0.020

S^* :Significant at P = 0.05 level S^{**} :Significant at P = 0.01 level NS : Not Significant

Application of K has given higher leaf K contents in all locations as expected. Similar increases in leaf K contents of rubber with application of K fertilizer were reported by Shorrocks (1961b), Yogaratnam et al. (1984) and Yogaratnam and De Mel (1985). The reduction in leaf K content consequent to application of Mg could be the result of antagonism between K and Mg in the process of absorption (Dyck, 1939).

4.1.4.2.4 Effect of nutrients on leaf Ca

The effect of application of N on the leaf Ca content was not significant in any of the locations (Table 31). Application of P at both 60 and 30 kg levels significantly increased the leaf Ca content above the P_0 level in all the locations and during all the years. The effect of K was also not significant in most cases. There was a general reduction in the leaf Ca content with application of Mg. The significant increase in the leaf Ca content with application of P could be the result of addition of rock phosphate which also contains Ca. This is in agreement with the reports of Shorrocks (1961a and 1961b) and Pushparajah (1969).

4.1.4.2.5 Effect of nutrients on leaf Mg.

The effect of application of N on the Mg content of leaf was not significant in most cases (Table 32). The effect of application of P was not significant. There was also not much effect of applied K on leaf Mg content. With application of Mg a

Table 31 ***Effect of nutrients on leaf Ca (per cent)***

Treatments	Kulasekharam			Thodupuzha			Balussery		
Nutrients kg ha^{-1}	1989	1990	1991	1989	1990	1991	1989	1990	1991
N_0	0.857	0.650	0.821	0.951	0.855	0.904	0.854	0.949	0.901
N_{40}	0.866	0.654	0.830	0.957	0.850	0.904	0.853	0.953	0.902
N_{80}	0.878	0.655	0.838	0.964	0.854	0.900	0.856	0.952	0.903
F-ratio	NS	NS	NS	NS	NS	NS	NS	NS	NS
P_0	0.796	0.608	0.759	0.893	0.807	0.842	0.792	0.889	0.845
P_{30}	0.868	0.660	0.840	0.970	0.851	0.901	0.854	0.955	0.897
P_{60}	0.937	0.691	0.890	1.008	0.901	0.966	0.918	1.010	0.965
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}
K_0	0.861	0.650	0.825	0.952	0.838	0.894	0.841	0.939	0.883
K_{40}	0.867	0.652	0.831	0.960	0.854	0.900	0.849	0.949	0.902
K_{80}	0.874	0.657	0.833	0.960	0.866	0.915	0.873	0.967	0.921
F-ratio	NS	NS	NS	NS	NS	NS	NS	NS	S^{*}
SE (N,P,K)	0.024	0.012	0.015	0.016	0.013	0.017	0.013	0.013	0.011
CD (N,P,K)	0.072	0.036	0.045	0.046	0.039	0.049	0.039	0.037	0.032
Mg_0	0.874	0.656	0.834	0.964	0.856	0.907	0.858	0.954	0.906
Mg_{10}	0.860	0.650	0.825	0.951	0.850	0.898	0.851	0.949	0.899
F-ratio	NS	NS	NS	S^{*}	NS	NS	NS	NS	S^{*}
SE (Mg)	0.009	0.005	0.004	0.005	0.004	0.012	0.008	0.009	0.003
CD (Mg)	-	-	-	-	-	-	-	-	-

S^{*} :Significant at P = 0.05 level S^{**} :Significant at P = 0.01 level NS : Not Significant

Table 32 Effect of nutrients on leaf Mg (per cent)

Treatments	Kulasekharam			Thodupuzha			Balussery		
Nutrients kg ha^{-1}	1989	1990	1991	1989	1990	1991	1989	1990	1991
N_0	0.356	0.390	0.408	0.339	0.389	0.377	0.326	0.373	0.384
N_{40}	0.344	0.376	0.395	0.325	0.375	0.364	0.314	0.366	0.376
N_{80}	0.342	0.374	0.392	0.311	0.371	0.362	0.311	0.364	0.374
F-ratio	NS	S^*	NS	NS	NS	NS	NS	NS	S^*
P_0	0.347	0.381	0.399	0.328	0.378	0.370	0.317	0.367	0.379
P_{30}	0.347	0.381	0.398	0.325	0.378	0.367	0.317	0.368	0.378
P_{60}	0.348	0.379	0.397	0.321	0.379	0.366	0.317	0.368	0.377
F-ratio	NS	NS	NS	NS	NS	NS	NS	NS	NS
K_0	0.359	0.391	0.410	0.333	0.389	0.380	0.328	0.373	0.385
K_{40}	0.344	0.378	0.394	0.324	0.375	0.363	0.313	0.366	0.375
K_{80}	0.340	0.371	0.390	0.317	0.371	0.360	0.310	0.364	0.374
F-ratio	S^*	S^*	S^*	NS	NS	S^*	NS	NS	S^*
SE (N,P,K)	0.006	0.004	0.005	0.02	0.01	0.01	0.01	0.003	0.004
CD (N,P,K)	0.018	0.010	0.020	-	-	0.02	-	-	0.010
Mg_0	0.326	0.361	0.378	0.305	0.358	0.349	0.298	0.357	0.368
Mg_{10}	0.369	0.399	0.418	0.345	0.399	0.386	0.336	0.378	0.388
F-ratio	S^{**}	S^{**}	S^{**}	S^*	S^{**}	S^*	S^*	S^*	S^{**}
SE (Mg)	0.005	0.004	0.004	0.01	0.004	0.01	0.01	0.003	0.002
CD (Mg)	0.010	0.010	0.010	0.04	0.010	0.02	0.02	0.010	0.005

S^* : Significant at P=0.05 level S^{**} : Significant at P = 0.01 level NS : Not Significant

significant increase in leaf Mg was noticed in all the three locations during all the years. The increase in the leaf Mg content with application of Mg could be its direct effect. It is seen that the application of Mg has increased its content in the soil (Table 27) which might have resulted in higher absorption and higher leaf contents. Increases in the leaf Mg content of rubber with application of Mg fertilizers were also reported by Sivanandyan (1983), Yogaratnam et al. (1984) and Yogaratnam and Weerasuriya (1984).

4.1.4.3 Effect of nutrients on latex nutrient contents

4.1.4.3.1 Effect of nutrients on latex N content

It is observed from Tables 33, 34 and 35 that application of N at both 40 and 80 kg levels significantly increased the N content of latex over the N_0 level in all the three locations. The N_{80} level gave the highest N content which was significantly higher than that given by N_{40} level in all the locations. The effect of application of P and K on latex N was not consistent in the different locations. Application of Mg had a positive effect on N content of latex in all locations which became significant at Balussery.

4.1.4.3.2 Effect of nutrients on latex P content

The effect of N on the latex P content was not conspicuous (Tables 33, 34 and 35). Application of both P and K had a significant and positive effect on the latex P content in all the three locations. The effect of Mg was not significant in any of the locations.

4.1.4.3.3 Effect of nutrients on latex K content

The results are presented in Tables 33, 34 and 35. Application of N at both 40 and 80 kg level significantly increased the latex K content over the N_0 level in the three locations. There was not much effect of P in the different locations whereas application of K significantly increased the latex K content at both 40 and 80 kg levels in all the locations over the K_0 level. The latex K content was significantly reduced by application of Mg in all the locations.

4.1.4.3.4 Effect of nutrients on latex Ca content

The effect of N and Mg on the latex Ca content was not significant in any of the locations (Tables 33, 34 and 35). Application of P has significantly increased the latex Ca content and it was maximum at P_{60} level. The application of K had a significant negative effect on the latex Ca content in all the locations.

4.1.4.3.5 Effect of nutrients on latex Mg content

It is seen from Tables 33, 34 and 35 that application of N and Mg has significantly increased the latex Mg content and the N_{80} and Mg 10 levels gave the highest values. On the contrary,

Table 33 Effect of applied nutrients on latex nutrient contents (ppm)-Kulasekharam

Treatments Nutrients kg ha^{-1}	N	P	K	Ca	Mg
N_0	5714	1424	5588	19.58	1135
N_{40}	6228	1426	5683	19.44	1185
N_{80}	6691	1415	5799	19.75	1239
F-ratio	S^{**}	NS	S^{**}	NS	S^{**}
P_0	6152	1132	5728	13.64	1213
P_{30}	6237	1423	5723	19.64	1180
P_{60}	6239	1694	5713	25.50	1104
F-ratio	S^{**}	S^{**}	NS	S^{**}	S^{**}
K_0	6240	1320	5337	21.36	1162
K_{40}	6184	1423	5697	19.25	1168
K_{80}	6205	1507	6130	18.17	1168
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}	NS
SE(N,P,K)	8.53	3.60	8.881	0.185	3.076
CD(N,P,K)	25.01	10.55	26.048	0.543	9.024
Mg_0	6207	1411	5753	19.76	1146
Mg_{10}	6212	1422	5690	19.43	1187
F-ratio	NS	NS	S^{**}	NS	S^{**}
SE(Mg)	6.23	4.47	3.136	0.162	1.956
CD(Mg)	-	-	9.100	-	5.675

S^{*} : Significant at P = 0.05 level

S^{**} : Significant at P = 0.01 level

NS : Not significant

Table 34 Effect of applied nutrients on latex nutrient contents (ppm)-Thodupuzha

Treatments Nutrients kg ha^{-1}	N	P	K	Ca	Mg
N_0	5443	3003	8662	24.56	1136
N_{40}	5904	3004	8999	24.58	1190
N_{80}	6431	3008	9184	24.50	1283
F-ratio	S^{**}	NS	S^{**}	NS	S^{**}
P_0	5960	2706	8947	16.36	1233
P_{30}	5902	3008	8992	24.64	1183
P_{60}	5886	3302	8999	32.64	1141
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}	S^{**}
K_0	5918	2908	7972	27.50	1187
K_{40}	5876	3004	9111	24.14	1187
K_{80}	5954	3105	9855	22.00	1184
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}	NS
SE(N,P,K)	19.318	2.387	13.926	0.126	2.393
CD(N,P,K)	56.660	7.001	40.847	0.368	7.019
Mg_0	5903	3005	9011	24.35	1168
Mg_{10}	5926	3006	8948	24.74	1204
F-ratio	NS	NS	S^{**}	NS	S^{**}
SE(Mg)	10.834	7.019	10.091	0.173	0.222
CD(Mg)	-	-	29.285	-	0.645

S^{*} : Significant at P = 0.05 level

S^{**} : Significant at P = 0.01 level

NS : Not significant.

Table 35 Effect of applied nutrients on latex nutrient contents (ppm)-Balussery.

Treatments Nutrients kg ha^{-1}	N	P	K	Ca	Mg
N_0	6053	2404	6209	14.69	727
N_{40}	6571	2404	6387	14.64	754
N_{80}	6983	2405	6563	14.83	831
F-ratio	S^{**}	NS	S^{**}	NS	S^{**}
P_0	6503	2111	6393	10.75	867
P_{30}	6531	2404	6423	14.56	728
P_{60}	6535	2701	6425	18.86	718
F-ratio	S^{**}	S^{**}	NS	S^{**}	S^{**}
K_0	6489	2303	5781	15.81	773
K_{40}	6506	2407	6428	14.67	767
K_{80}	6575	2506	7031	13.69	773
F-ratio	S^{**}	S^{**}	S^{**}	S^{**}	NS
SE(N,P,K)	8.715	1.741	9.913	0.144	2.269
CD(N,P,K)	25.563	5.106	29.075	0.422	6.654
Mg_0	6510	2406	6440	14.65	752
Mg_{10}	6536	2405	6387	14.80	790
F-ratio	S^{**}	NS	S^{**}	NS	S^{**}
SE(Mg)	6.663	7.441	2.780	0.136	0.613
CD(Mg)	19.342	-	8.066	-	1.779

S^{*} : Significant at P = 0.05 level

S^{**} : Significant at P = 0.01 level

NS : Not significant.

the effect of application of P on latex Mg content was negative and significant in all the locations. There was no clear trend noticed for application of K.

It is noticed that application of N has increased the latex N content in all cases. As more N was absorbed more of it has been channeled into the latex. Shorrocks (1961b), Collier and Lowe (1969) and Pushparajah et al.(1975) also observed increased N content of latex from application of N fertilizers.

The P content of latex was increased with application of P. This may be explained as the direct effect of applied P which has been reflected in the P content of leaf also (Table 29). Similar results were reported by Shorrocks (1961b) and Collier and Lowe (1969). It is seen that application of K also has increased the latex P content. The K content of latex also was increased with application of K. Pushparajah (1969) and Pushparajah et al. (1975) also obtained similar results.

The K content of latex was increased by application of K. Application of K has improved the general K status of the tree and thereby its content in latex also has increased. Similar results were reported by Shorrocks (1961b), Pushparajah (1969) and Pushparajah et al. (1975). Application of N also has increased the K content of latex. Similar increase in the latex K content with application of N was reported by Pushparajah et al. (1975). The decrease in the K content of latex with application of Mg could be the result of antagonism between these elements (Pushparajah et al. 1975).

The Ca content of latex was increased with application of P. This could be the direct contribution of Ca which is also contained in rock phosphate the carrier of P. Pushparajah *et al.* (1975) also observed increase in latex Ca content from application of P through rock phosphate. The latex Ca content was reduced by application of K. With application of K, more of K ions get into the latex system which discourages the entry of Ca ions into latex. Similar results were also observed by Pushparajah *et al.* (1975)

The increase in the Mg content of latex with application of Mg could be the result of migration of Mg into the latex which is adequately present in the tree. Beaufils, (1954), Bolton and Shorrocks (1961) and Pushparajah *et al.* (1975) also obtained higher Mg content of latex with application of Mg. Increases in the latex Mg content with application of N were also reported by Collier and Lowe (1969) and Pushparajah *et al.* (1975). It is seen that the latex Mg was reduced by application of P. Collier and Lowe (1969) also observed reduction in the Mg content of latex with application of P as rock phosphate.

4.2. Correlation studies

In order to explain the relationship between some of the important characters connected with growth and yield, correlation studies were attempted. The correlations have been worked out on all possible relationships. However only the important and relevant correlations are presented and discussed in the text.

4.2.1 Correlation between yield and growth characters

Table 36 indicates that yield was correlated with both girth increment and rate of bark renewal. It may be remembered that the yield as well as the above growth characters were positively influenced by application of the various nutrients. The increase in yield might have been the result of enhanced growth of the tree. However the girth, virgin bark thickness and weight of leaf litter were not correlated with the yield. The virgin bark thickness is a clonal character and this may be the reason for not getting a correlation with yield.

4.2.2 Correlation of yield with latex flow characteristics

Table 37 indicates that the initial flow rate was significantly and positively correlated with yield. This shows that the initial flow rate which represents the initial five minutes' yield just after tapping has a contribution to the final yield. Similar correlations were also reported by Narayanan and Abraham (1976) and Samsidar BTE Hamzah and Gomez (1982). The correlation between the total volume of latex and yield was significant and positive. This needs no further explanation since yield is very much dependent on the total volume of latex obtained.

The plugging index gave a significant, but negative

Table 36 Correlation between yield and growth characters

Character	Correlation coefficient (
Girth	-0.0764
Girth increment	0.7267**
Virgin bark thickness	0.1786
Rate of bark renewal	0.5796**
Weight of leaf litter	0.1495

** Significant at P= 0.01 level

Table 37 Correlation between yield and latex flow characteristics

Character	Correlation coefficient (r)
Initial flow rate	0.5684**
Total volume	0.9454**
Plugging index	-0.2435**
Dry rubber content	0.6407**

** Singnificant at P=0.01 level

correlation with yield. The plugging index is actually an index of the duration of latex flow after tapping is done and has a negative relationship. A higher plugging index or in other words a shorter duration of flow is likely to give a lower yield. Yeang and Paranjyothy (1982) also reported that yield was negatively correlated with plugging index. There was a positive and significant correlation between yield and the dry rubber content of latex. This was expected since the total volume of latex multiplied by the dry rubber content of latex gives the yield. Yeang and Pranjothy (1982) and Mo Shanwen et al. (1988) also reported positive correlation between yield and the dry rubber content of latex.

It was thus indicated that the total volume of latex has the maximum relationship with yield followed by the dry rubber content of latex.

4.2.3 Correlation of yield with nutrient contents in soil, leaf and latex

Table 38 indicates that yield was significantly and positively correlated with soil and leaf N contents. The correlation with latex just missed significance though it also showed a positive trend. These correlations could be due to the beneficial effect of N in increasing the yield. It may be noted that the application of N has significantly increased the yield (Table 16) as well as N contents of leaf (Table 28). This could be another reason for the correlations obtained above. Table 42 shows that the N contents of soil and leaf were positively correlated with the total volume and dry rubber content of latex. This further supports the correlation obtained between yield and N content of soil and leaf.

The correlation between yield and P contents of soil and latex were significant and positive. However, the correlation between yield and leaf P was not significant. It is indicated from Table 42 that the total volume and dry rubber content of latex were positively correlated with the P contents of soil and latex. The favourable effects of P on the yield of rubber is also reflected in these correlations. The correlation obtained for yield with the K contents of soil, leaf and latex were significant and positive. These correlations could be due to the beneficial effects of K on yield. There was significant and positive correlation between yield and Ca content of soil and leaf. This could be the result of the beneficial effect of Ca nutrition on yield.

Significant and negative correlations were obtained between yield and Mg content of soil and leaf. Application of Mg has increased the yield at Thodupuzha (Table 16) the data from where were used for these correlation studies. The soil and leaf Mg contents were also improved by application of Mg (Table 27 and 32). But the correlation obtained for yield with soil and leaf Mg was negative. This could be due to the effect of high Mg on pre coagulation of latex (Yip, 1990).

Table 38 Correlation of yield with soil, leaf and latex nutrient contents

Character	Correlation coeffieients (r)		
	Soil	Leaf	Latex
N	0.3653**	0.3225**	0.1889
P	0.3491**	0.0841	0.5576**
K	0.3897**	0.5508**	0.7067**
Ca	0.3115**	0.5213**	0.1522
Mg	-0.5697**	-0.3096**	-0.0236

Table 39 Correlation between yield and sums of soil, leaf and latex nutrients

Character	Correlation coefficients (r)
soil N + leaf N	0.3230**
soil P + leaf P	0.0906**
soil K + leaf K	0.5501**
soil Ca + leaf Ca	0.5093**
soil Mg + leaf Mg	-0.3120**
leaf N + latex N	0.3002**
leaf P + latex P	0.4088**
leaf K + latex K	0.6165**
leaf Ca + latex Ca	0.5169**
leaf Mg + latex Mg	-0.3041**
soil N + leaf N + latex N	0.3007**
soil P + leaf P + latex P	0.4086**
soil K + leaf K + latex K	0.6158**
soil Ca + leaf Ca + latex Ca	0.5052**
soil Mg + leaf Mg + latex Mg	-0.3067**

** Significant at P=0.01 level

The reports of Shorrocks (1962), Pushparajah (1969) and Pushpadas et al. (1978) also indicated positive correlation between yield and nutrient contents of soil and leaf. Negative relations of Mg were also reported by Yip (1990).

The above correlations indicate that for the diagnosis of N requirement of rubber, the soil N is the best indicator which influences yields. For P and K, their contents in latex give the best clue. In the case of diagnosis of Ca requirement, the leaf Ca content is the best indicator.

4.2.4 Correlation between yield and soil + leaf nutrients, leaf + latex nutrients and soil + leaf + latex nutrients

Correlations determined between yield and the sums of soil and leaf nutrients, leaf and latex nutrients and soil, leaf and latex nutrients are presented in Table 39. A joint examination of Tables 38 and 39 indicates that the combined correlations were never stronger than the highest single correlations of soil, leaf or latex in the case of individual nutrients. The intention of this correlation analysis was to know whether there was a combined effect of the nutrients in soil, leaf and latex. But is was noticed that such an effect was not pronounced.

4.2.5 Correlation between yield and cation concentration in soil, leaf and latex

It is seen that the K content and K+Ca content of latex gave best correlation with yield (Table 40). The general indication is that the K + Ca combination is important and hence we have to ensure a safe level of K and Ca in the tree.

Previous literature on this line indicated the possibility of a strong relationship between yield and cation concentrations in oil palm (Ollagnier et al. 1970 and Nair, 1981) and coconut. The intention of studying the above correlations was to ascertain if there was a similar relationship existing between the cation concentrations and yield in rubber.

4.2.6 Correlation between girth increment and nutrient contents of soil, leaf and latex

Table 41 indicates that the N contents of soil, leaf and latex were positively correlated with girth increment and the correlation was significant. It has already been noticed that application of N increased the girth increment as well as the N contents in leaf and latex as seen from Tables 3, 28 and 34 respectively. Application of N has enhanced the girth increment because of the effect of this nutrient on vegetative characters. This is evidenced by the correlation obtained between girth increment and N contents of leaf and latex obtained here. Probably the increased N content in the tree might have helped in enhancing the girth increment.

The girth increment was also correlated with the P content of soil and latex. This could be due to the favourable effect of applied P on these characters. In the case of K, the correlation was significant only with its content in latex. Potassium plays a

Table 40 Correlation between yield and cation concentrations of soil, leaf and latex

Cations	Correlation coeffieient (r)		
	Soil	leaf	latex
K	0.3897**	0.5508**	0.7067**
Ca	0.3115**	0.5213**	0.1522
Mg	-0.5697**	-0.3096**	-0.0236
K+Ca	0.4266**	0.6219**	0.7098**
K+Mg	0.3386**	0.5264**	0.6914**
Ca+Mg	0.2793**	0.3182**	-0.0096
K+Ca+Mg	0.4004**	0.6029**	0.6945**

Table 41 Correlation between girth increment and nutrient contents in soil, leaf and latex

Nutrient	Correlation coefficient (r)		
	Soil	Leaf	Latex
N	0.7190**	0.6908**	0.5691**
P	0.3342**	0.0804	0.4048**
K	-0.0413	0.1370	0.4469**
Ca	0.1537	0.3687**	0.2338**

** Significant at P= 0.01 level

very important role in phloem transport (Sutcliff and Baker 1974) and this could be the reason for obtaining a high correlation with latex K. There was positive correlation between girth increment and Ca contents of leaf and latex. Calcium is very important for growth as it is a constituent of the cell wall (Sutcliff and Baker, 1974). Similar correlation between girth increment and soil N and P were reported by Pushparajah et al (1983) and correlation between girth increment and leaf N by Sivanandyan (1983) and Weerasuriya and Yogaratnam (1988).

4.2.7 Correlation of latex flow characters with nutrient contents in soil, leaf and latex

4.2.7.1 Total volume

Table 42 indicates that the total volume was correlated to the N status of soil and leaf. The application of N had increased the total volume of latex as well as the leaf N as seen from Tables 14 and 28 respectively. This indicates that correlation obtained above could be due to the direct effect of N in increasing the total volume of latex. The positive and significant correlation obtained for soil and latex P could similarly be due to the positive effect of P in increasing the total volume.

The total volume also had significant and positive correlation with the K status of soil, leaf and latex. Application of K had positive effect on the total volume as well as the soil, leaf and latex K contents as visible from Tables

25, 30 and 34 respectively. This supports the view that the correlation obtained above is the result of the effect of K in increasing the total volume of latex. The soil and leaf Ca also had significant and positive correlation with the total volume which shows that Ca also has contributed to increasing the total volume.

4.2.7.2 Plugging index

It is seen from Table 42 that the correlations of plugging index with the N contents of soil, leaf and latex were significant and negative. The effect of applied N on plugging index also was negative (Table 14). As plugging index has a negative relation with yield (Yip and Gomez, 1975) the effect of N in increasing the yield is brought out in these significant correlations. This further supports the positive response in yield obtained to application of N (Table 16).

Similar negative and significant correlations were also obtained for plugging index with soil, leaf and latex K contents. Application of K also had a negative effect on plugging index like N (Table 14). The yield also was significantly increased by application of K (Table 16). This positive effect of K on yield is supported by the correlation obtained above.

The correlations of plugging index with soil, leaf and latex Ca contents were positive and significant. This could be the direct effect of Ca at high levels on increasing the plugging index (Yeang and Paranjothy, 1982).

Table 42 Correlation of latex flow characters with soil, leaf and latex nutrient contents

Character	Initial flow rate	Total volume	Plugging index	Dry rubber content
Soil N	-0.1634	0.3129**	-0.4957**	0.3854**
Soil P	0.5831**	0.2682**	0.4427**	0.3560**
Soil K	0.2145*	0.4442**	-0.1905*	0.0909
Soil Ca	0.6683**	0.2405**	0.5695**	0.2661**
Leaf N	-0.1749	0.2664**	-0.4604**	0.4056**
Leaf P	0.4843**	0.0444	0.5359**	0.1357
Leaf K	0.2160*	0.5602**	-0.2944**	0.2780**
Leaf Ca	0.5924**	0.4515**	0.2724**	0.4121**
Latex N	-0.2698**	0.1480	-0.4535**	0.2984**
Latex P	0.6232**	0.4753**	0.2884**	0.4528**
Latex K	0.1610	0.6853**	-0.4773**	0.4705**
Latex Ca	0.4846**	0.0697	0.5176**	0.2462**

* Significant at P=0.05 level; ** Significant at P=0.01 level

4.2.7.3 Dry rubber content of latex

Table 42 indicates that the N content in soil, leaf and latex were significantly correlated with the dry rubber content of latex. The correlation obtained was positive. It can be seen from Tables 14, 28 and 34 that the application of N has significantly increased the dry rubber content of latex and the N contents in leaf and latex respectively. This may probably explain the correlations obtained above. The yield also was increased by the application of N (Table 16). The dry rubber content of latex has a role in increasing the yield since the dry rubber content multiplied by the total volume of latex gives the yield. This, to a certain extent justifies the increase in yield with application of N.

The correlation of the dry rubber content with soil and latex P were significant and positive. The dry rubber content as well as the P status of soil and latex were improved by application of P as seen from Tables 14, 24 and 34 respectively. This could be the possible reason for the correlations obtained above. The increase in yield with application of P is also to some extent explained by these correlations.

It is observed that the correlations of the dry rubber content of latex with leaf and latex K contents were significant and positive. Application of K has significantly increased the dry rubber content and the K contents of leaf and latex as seen from Tables 14, 30 and 34 respectively. This positive effect of applied K might have helped in getting the above correlations. The correlations of the dry rubber content with the K contents of leaf and latex obtained above explains to a certain extent the increase in yield with application of K (Table 16).

There was significant and positive correlation between the dry rubber content and the Ca contents of soil, leaf and latex. This shows that Ca also has contributed to increasing the yield through its effect on the dry rubber content of latex.

4.2.8 Correlation between latex flow characteristics and cation concentrations in soil, leaf and latex

An examination of Table 43 indicates that the initial flow rate was mostly influenced by the Ca contents of soil, leaf and latex. For the total volume of latex,the K contents of soil, leaf and latex were important. In the case of plugging index there was highly strong positive correlation for soil and leaf Mg and a lesser but significant correlation for soil and leaf Ca. The correlation of latex Ca also was highly significant and positive. This shows that they have a negative relation with yield. It was earlier noticed that Ca contents in soil and leaf and K + Ca contents in latex were very much favourable for yield. But the correlations obtained here reveals that beyond a certain level, Ca will act as a limiting factor for yield through its effect on increasing the plugging index. The correlation between

Table 43 Correlation of latex flow characteristics and cation concentrations of soil, leaf and latex

Cations	Correlation coefficient (r)			
	Initial flow rate	Total volume	Plugging index	Dry rubber content
Soil K	0.2145*	0.4442**	-0.1905*	0.0909
Soil Ca	0.6683**	0.2405**	0.5695**	0.2661**
Soil Mg	0.1941*	-0.5723**	0.7668**	0.2928**
Soil K + Ca	0.6630**	0.3876**	0.4134**	0.2663**
Soil K + Mg	0.2426**	0.3944**	-0.1114	0.0613
Soil Ca + Mg	0.6700**	0.2090*	0.6010**	0.2482*
Soil K + Ca + Mg	0.6692**	0.3614**	0.4454**	0.2527**
Leaf K	0.2160*	0.5602**	-0.2944**	0.2780**
Leaf Ca	0.5924**	0.4515**	0.2724**	0.4121**
Leaf Mg	0.3160**	-0.3299**	0.6900**	-0.1097
Leaf K + Ca	0.3310**	0.6148**	-0.2086*	0.3472**
Leaf K + Mg	0.2703**	0.5332**	-0.2048*	0.2726**
Leaf Ca + Mg	0.7164**	0.2427**	0.6187**	0.3234**
Leaf K + Ca + Mg	0.3852**	0.5930**	-0.1240	0.3447**
Latex K	0.1610	0.6853**	-0.4773**	0.4705**
Latex Ca	0.4846**	0.0679	0.5176**	0.2462**
Latex Mg	-0.4055**	-0.0261	-0.4624**	0.1400
Latex K + Ca	0.1656	0.6876**	-0.4740**	0.4737**
Latex K + Mg	0.1212	0.6701**	-0.5104**	0.4744**
Latex Ca + Mg	-0.3747**	-0.0206	-0.4307**	0.1700
Latex K + Ca + Mg	0.1257	0.6724**	-0.5073**	0.4778**

[illegible] 0.05 level, ** Significant at P=0.[illegible] level plugging index and K was negative. This shows that K had a positive relation with yield. The correlation of latex K was highest, followed by leaf K.

In the case of dry rubber content of latex, eventhough the correlations obtained for soil nutrients were not as strong as those obtained for leaf nutrients, good correlations were obtained for Ca and K + Ca of soil. The contents of K and K + Ca of latex showed very strong correlations with the dry rubber content of latex.

4.2.9 Correlation between nutrient contents in soil, leaf and latex

Table 44 indicates that the correlations between soil and leaf contents, soil and latex contents and leaf and latex contents of N,P,K and Ca were positive and significant. This indicates that the nutrients applied to soil were reflected in leaf and latex. So the applied nutrients were most efficiently utilized. Therefore soil application is a very satisfactory method of fertilizer application in rubber. Correlations between soil and leaf nutrients were reported by Guha and Yeow (1966).

4.3 Net profits

Analysis of variance was done for the net profits taking into account only the cost of produce and prices of fertilizers and the treatment means are presented in Table 45.

Table 44 Correlation between soil, leaf and latex nutrients

	Correlation coeffieient (r)		
Nutrient	soil and leaf	soil and latex	leaf and latex
N	0.9279**	0.8903**	0.9071**
P	0.7167**	0.8884**	0.6772**
K	0.8392**	0.7038**	0.8944**
Ca	0.8830**	0.8809**	0.7856**

** Significant at P=0.01 level

In the case of N its application at 40 kg ha^{-1} gave the highest net profit in all the locations. At Thodupuzha and Balussery increasing the level of N to 80 kg significantly reduced the net profit while at Kulasekharam the reduction in net profit at 80 kg was not significant. It may be remembered that in the case of mean yield (Table 16) at Kulasekharam the 40 and 80 kg levels were on par and the 80 kg was numerically superior to the 40 kg level. But in the economic analysis, the 40 kg gave numerically higher profit. This is due to the additional cost involved at the 80 kg level of N application.

At Thodupuzha the highest mean yield was given by the N_{40} level and there was a significant reduction at the N_{80} level. This is reflected in the net profit analysis also. At Balussery, the N_{40} level gave the highest mean yield and the N_{80} level was on par with the N_{40} level. In the economic analysis also the N_{40} level gave the highest net profit. But at the N_{80} level there was a significant reduction in the net profit. This could be due to the additional cost involved for the extra 40 kg N at the N_{80} level.

Application of P at 30 kg level gave the highest net profit at Kulasekharam and Thodupuzha. At Thodupuzha, the P_{60} level significantly reduced the net profit compared to P_{30} level while at Kulasekharam the reduction in profit at P_{60} was not significant. At Balussery the P_{60} level gave the highest net profit which was on par with the P_{30} level.

Table 45 Net Profit (Rs.)

Treatments Nutrients (Kg ha^{-1})	Kulasekharam	Thodupuzha	Balussery
N_0	16041	11911	10125
N_{40}	21051	13933	14091
N_{80}	20850	13220	13515
F-ratio	S^{**}	S^{**}	S^{**}
P_0	16723	11773	10961
P_{30}	20686	13676	13351
P_{60}	20532	13616	13420
F-ratio	S^{**}	S^{**}	S^{**}
K_0	16184	11276	11136
K_{40}	20889	13973	13220
K_{80}	20869	13816	13376
F-ratio	S^{**}	S^{**}	S^{**}
SE (N.P.K)	125	16	55
CD (N.P.K)	367	45	162
Mg_0	19403	13003	12392
Mg_{10}	19225	13103	12585
F-ratio	NS	S^{**}	NS
SE (Mg)	83	5	31
CD (Mg)	-	14	-

S^{**} : significant at $P = 0.01$ level NS: not significant

In the case of mean yield (Table 16) at Kulasekharam the P_{30} level gave the highest yield which was on par with the P_{60} level. The same pattern was obtained for the net profits also. At Thodupuzha also the P_{30} level gave the highest yield which was on par with the P_{60} level. But in the case of net profits there was a significant reduction at the P_{60} level. This could be due to the extra cost involved for the additional 30 kg P at the P_{60} level. At Balussery the P_{60} level gave the highest yield which was on par with the P_{30} level. The same result was obtained for the net profits also.

At Kulasekharam and Thodupuzha the highest net profits were given by the K_{40} level which was on par with the K_{80} level. At Balussery K_{80} level gave the highest net profit which was on par with the K_{40} level.

In the case of mean yield (Table 16) at Kulasekharam the K_{40} level gave the highest yield which was on par with the K_{80} level. The same pattern was obtained for the net profit also. At Thodupuzha the K_{80} level gave the highest yield which was on par with the K_{40} level. In the case of net profit the highest value was registered by the K_{40} level which was not significantly different from that given by the K_{80} level. This numerical inferiority of the K_{80} level in the case of net profit could be due to the extra cost involved at the 80 kg level compared to the 40 kg.

At Balussery the K_{80} level gave the highest mean yield which was significantly higher than that given by the K_{40} level. In the case of net profit, though the N_{80} level gave the highest profit it was not significantly higher than the N_{40} level. The additional cost of extra 40 kg K involved at the N_{80} level might have made it on par with the N_{40} level in the economic analysis.

At Kulasekharam and Balussery application of Mg did not significantly affect the net profit, though at Kulasekharam there was a numerical reduction and at Balussery there was a numerical increase in the net profits with application of Mg. At Thodupuzha the net profit was significantly increased by application of Mg.

An overall evaluation of the economic analysis indicated that 40 kg N, 30 kg P_2O_5 and 40 kg K_2O were the optimum doses of N,P, and K in all the three locations. Application of Mg was profitable only at Thodupuzha. It also revealed that increasing the dose of N above 40 kg at Thodupuzha and Balussery and increasing the level of P above 30 kg at Thodupuzha were deterimental as far as net profit was concerned.

The bebefit cost ratios worked out for the three locations are given in Tables 46,47 and 48. The highest ratios were obtained for the treatment combination of 40 kg N, 30 kg P_2O_5 and 40 kg K_2O ha^{-1} in all the locations. So, it is further confirmed that 40 kg N, 30 kg P_2O_5 and 40 kg K_2O are the optimum doses for maximum returns in the three agroclimatic regions studied.

Table 46 Effect of nutrients on B:C ratio-Kulasekharam

Treatment combination N:P:K (kg ha^{-1})	Yield (kg ha^{-1})	Gross returns (B) (Rs.)	Gross expenditure(C) (Rs.)	B:C ratio
0: 0: 0	1813	36260	20789	1.744
0: 0: 40	1746	34910	20779	1.680
0: 0: 80	1845	36900	21018	1.756
0: 30: 0	1798	35960	20877	1.722
0: 30:40	1917	39330	21145	1.813
0: 30:80	1924	38485	21247	1.811
0: 60:0	1807	36100	21000	1.719
0: 60:40	1943	38850	21294	1.824
0: 60:80	1903	38055	21325	1.785
40: 0: 0	1810	36195	20995	1.724
40: 0:40	2003	39310	21375	1.839
40: 0:80	2016	40310	21484	1.876
40: 30:0	1902	38035	21243	1.790
40:30:40	2437	48735	22136	2.203
40:30:80	2347	46940	22091	2.125
40:60: 0	1930	38605	21396	1.804
40:60:40	2380	47605	22161	2.148
40:60:80	2350	47005	22206	2.117
80: 0: 0	1958	37160	21277	1.746
80: 0:40	1968	39350	21532	1.828
80: 0:80	2057	41130	21755	1.891
80:30: 0	1955	39090	21532	1.815
80:30:40	2405	48095	22298	2.157
80:30:80	2371	47410	22336	2.123
80:60: 0	1950	39005	21636	1.803
80:60:40	2387	47735	22380	2.133
80:60:80	2385	47695	22468	2.123
MgO-nil (mean)	2053	41060	21490	1.911
MgO-10 (mean)	2036	40720	21604	1.885

Table 47 Effect of nutrients on B:C ratio-Thodupuzha

Treatment combination N:P:K ($kg\ ha^{-1}$)	Yield ($kg\ ha^{-1}$)	Gross returns (B) (Rs.)	Gross expenditure(C) (Rs.)	B:C ratio
0: 0: 0	1578	31560	20437	1.544
0: 0: 40	1599	31985	20559	1.556
0: 0: 80	1589	31770	20633	1.540
0: 30: 0	1582	31630	20553	1.539
0: 30:40	1697	33935	20816	1.630
0: 30:80	1703	33300	20914	1.592
0: 60:0	1592	31840	20678	1.540
0: 60:40	1696	33920	20924	1.621
0: 60:80	1689	33780	21004	1.608
40: 0: 0	1578	31555	20647	1.528
40: 0:40	1715	34025	20943	1.625
40: 0:80	1719	34380	21039	1.634
40: 30:0	1649	32975	20863	1.581
40:30:40	1876	37520	21294	1.762
40:30:80	1867	37330	21370	1.747
40:60: 0	1653	33050	20979	1.575
40:60:40	1870	37395	21395	1.748
40:60:80	1858	37165	21468	1.731
80: 0: 0	1585	31690	20867	1.519
80: 0:40	1648	32955	21052	1.565
80: 0:80	1669	33385	21174	1.577
80:30: 0	1613	32265	21020	1.535
80:30:40	1849	36980	21464	1.723
80:30:80	1850	37000	21555	1.717
80:60: 0	1604	32075	21116	1.519
80:60:40	1854	37070	21581	1.718
80:60:80	1853	37060	21670	1.710
MgO-nil (mean)	1698	33960	20957	1.621
MgO-10 (mean)	1711	34220	21117	1.621

Table 48 Effect of nutrients on B:C ratio-Balussery

Treatment combination N:P:K (kg ha^{-1})	Yield (kg ha^{-1})	Gross returns (B) (Rs.)	Gross expenditure(C) (Rs.)	B:C ratio
0: 0: 0	1432	28640	20218	1.417
0: 0: 40	1471	29420	20367	1.444
0: 0: 80	1528	30565	20543	1.488
0: 30: 0	1435	28705	20333	1.412
0: 30:40	1601	32020	20672	1.549
0: 30:80	1626	32515	20799	1.563
0: 60:0	1442	28830	20453	1.410
0: 60:40	1597	31930	20775	1.537
0: 60:80	1683	33655	20995	1.603
40: 0: 0	1540	30795	20590	1.496
40: 0:40	1705	34090	20927	1.629
40: 0:80	1703	34005	21015	1.618
40: 30:0	1793	35865	21080	1.701
40:30:40	1844	36875	21246	1.736
40:30:80	1843	36860	21332	1.728
40:60: 0	1712	34240	21068	1.625
40:60:40	1853	37050	21369	1.734
40:60:80	1857	37135	21465	1.730
80: 0: 0	1554	31085	20823	1.493
80: 0:40	1656	33120	21065	1.572
80: 0:80	1684	33670	21196	1.589
80:30: 0	1719	34380	21179	1.623
80:30:40	1813	36265	21410	1.694
80:30:80	1845	36895	21548	1.712
80:60: 0	1786	34815	21389	1.628
80:60:40	1831	36620	21547	1.700
80:60:80	1829	36580	21634	1.691
MgO-nil (mean)	1665	33300	20908	1.593
MgO-10 (mean)	1683	33660	21075	1.597

SUMMARY

SUMMARY

Field experiments were conducted to study the response to nutrient applications on growth characters, yield and latex flow characteristics of rubber and to study the interrelationship between soil and plant nutrients on yield. The experiments also envisaged to assess the relative response in three different locations of Kulasekharam, Thodupuzha and Balussery and to make economic analysis of the benefit of manuring.

There were three levels of 0,40 and 80 kg N ha^{-1}., 0,30 and 60 kg P_2O_5 ha^{-1} and 0,40 and 80 kg K_2O ha^{-1} and two levels of 0 and 10 kg MgO ha^{-1}. A 3^3x 2 partially confounded factorial split plot design was followed confounding NP^2K^2 in first replication and NP^2K in second replication, with the N,P,K combinations in main plots and levels of Mg in sub plots. The results of the investigations are summarized below.

1. Application of N at 80 kg gave the highest girth increment in all the three locations. In the case of P and K applications at 30 and 40 kg levels respectively were found to be sufficient. Application of Mg at 10 kg was beneficial.

2. In the case of virgin bark thickness 40 kg N, 30 kg P and 40 kg K were found to be sufficient in all the locations. Applications of Mg was not beneficial.

3. The 80 kg level of N gave the highest rate of bark renewal at Thodupuzha while at Kulasekharam and Balussery the 40 kg level was sufficient. There was response upto the 60 kg level of P at Kulasekharam and Thodupuzha while at Balussery significant response was noticed only upto the 30 kg level. In the case of K the 40 kg level was significant in all the three locations. Application of Mg did not improve the rate of bark renewal.

4. Application of N at 80 kg level gave the highest weight of leaf litter in all locations. In the case of P and K the 30 and 40 kg levels respectively were found to be sufficient. Application of Mg was beneficial only at Balussery during one year.

5. In the case of total volume of latex 40 kg N, 30 kg P and 40 kg K were found to be sufficient in all locations except Balussery where the 80 kg level of K was superior to the 40 Kg level. Application of Mg was beneficial at Balussery and was detrimental at Kulasekharam while it had no effect at Thodupuzha.

6. Application of N and K significantly reduced the plugging index at both 40 and 80 kg levels in all the locations. The plugging index was significantly increased by application of P at both 30 and 60 kg levels. Applications of Mg also significantly increased the plugging index in all the three places.

7. The highest dry rubber content of latex was given by 80 kg N at Kulasekharam while at Thodupuzha and Balussery the 40 kg levels was sufficient. In the case of P and K the 30 kg and 40 kg levels respectively were found to be optimum. Application of Mg was beneficial at Thodupuzha and Balussery while at Kulasekharam it had no effect.

8. In the case of yield of rubber 40 kg N and 30 kg P were found to be optimum in all the locations. The 40 kg level of K was sufficient at Kulasekharam and Thodupuzha while the 80 kg level gave the highest yield at Balussery. Application of Mg was beneficial at Thodupuzha and Balussery while at Kulasekharam it reduced the yield.

9. The organic carbon content of soil was significantly increased by application of N in all the locations. The available P,K and Mg contents of soil were significantly increased by the application P, K and Mg fertilizers respectively. Application of P as rock phosphate also increased the available Ca content of soil.

10. The contents of N,P,K and Mg of leaf and latex were increased by application of the respective nutrients in all the three locations. The Ca contents also were increased by application of P as rock phosphate.

11. The yield of rubber was positively correlated with girth increment and rate of bark renewal.

12. The yield was also positively correlated with the initial flow rate, total volume and dry rubber content of latex and negatively with the plugging index.

13. Yield was positively correlated with the available N,P,K and Ca contents of soil., N,K and Ca contents of leaf and P and K contents of latex. The soil and leaf Mg contents were negatively correlated with yield. The strongest correlations with yield were given by soil N, latex P and K and leaf Ca.

14. The total volume of latex was positively correlated with the available N,P,K and Ca contents of soil, N,K and Ca contents of leaf and P and K contents of latex. The dry rubber content of latex was positively correlated with the available N,P and Ca contents of soil., N,K and Ca contents of leaf and N,P,K and Ca contents of latex. The Plugging index was positively correlated with the P and Ca contents and negatively with the N and K contents of soil, leaf and latex.

15. An overall evaluation of the economic analysis indicated that 40 kg N, 30 kg P_2O_5 and 40 kg K_2O were the optimum doses in all the three locations. Application of Mg was profitable only at Thodupuzha.

Conclusion

The manurial requirement of rubber under tapping is 40 kg N, 30 kg P_2O_5 and 40 kg K_2O ha^{-1} in the three rubber growing regions studied. Application of MgO at the rate of 10 kg ha^{-1} is beneficial only at Thodupuzha region.

The specific materials for nutrient diagnosis are soil for N, latex for P and K and leaf for Ca.

REFERENCE

REFERENCES

All India Rubber Industries Association. 1992. Rubber News. 27 (1): 4.

Amin Tyasadihardja, Achmad Soedarsan and Noermandias. 1973. Full spiral tapping on young trees of clone LCB 1320. Menara Perkebunan. 41: 223-228.

Ananth, K.C. 1966. Manuring of rubber an outline. Rubb. Bd Bull. 8: 15-18.

Angkapradipta, P., Tuti-Warsito and Nurdin, M.S. 1986. Testing the N, P and K fertilizer recommendation rates for clone GT1 on latosol. Menara Perkebunan. 54:111-119.

Archer, J. 1988. Crop Nutrition and Fertilizer Use. Farming Press Ltd., Wharfedals Road, IPS Wich, Suffolk. p. 265.

*Beaufils, E.R. 1954. Contribution to the study of mineral elements in field latex. Proceedings of the Third Rubber Technology Conference, London. pp. 87-98.

Beaufils, E.R. 1957. Research for rational exploitation of the Hevea using a physiological diagnosis based on the mineral analysis of various parts of the plants. Fertilite. 3:27-38.

Bidwell, R.G.S. 1979. Plant Physiology. Macmillan Publishing Co., Inc., New York. pp. 247 - 556.

Bolton, J. 1960. The effect of fertilizers on pH and the exchangable cations of some Malayan soils. Proc. Nat. Rubb. Res. Conf., Kuala Lumpur Part II, pp. 70-80.

Bolton, J. 1964. The response of immature Hevea brasiliensis to fertilizers in Malaya. 1. Experiments on slate derived soils. J. Rubb. Res. Inst. Malaya. 18: 67-79.

Bolton, J. and Shorrocks, V. M. 1961. The effect of magnesium limestone and other fertilizers on a mature planting of Hevea brasiliensis. J. Rubb. Res. Inst. Malaya. 17 :31-39.

Brady, N.C. 1988. The Nature and Properties of Soils. Eurasia Publishing House (P) Ltd., New Delhi. pp. 137-779.

*Bray, R.H. and Kurtz, L.T., 1945. Determination of total organic and available forms of phosphates in soils. Soil Sci. 59 :39-45.

*Chapman, G.W. 1941. Leaf analysis and plant nutrition. Soil Sci. 52: 63-69.

Cochran, W.G. and Cox, G.M. (1965). Experimental Designs. Asia Publishing House, New Delhi., pp. 51-110.

Collier, H.M. and Lowe, J.H. 1969. Effect of fertilizer application on latex properties. J. Rubb. Res. Inst. Malaya. 21 : 181 -197.

De Jonge, P. 1957. Stimulation of bark renewal of Hevea and its effect on yield of latex. J. Rubb. Res. Inst. Malaya. 15: 53-71.

Dijkman, M.J. 1951. Hevea - Thirty Years of Research in the Far East. University of Miami Press, Coral cables, Florida. p. 329.

Dissanayake, D.M.A.P. and Mithrasena, U. 1986. Influence of fertilizers on growth and mineral composition of Hevea seedlings - growth in the field nursery. Jl. Rubb. Res. Inst. Sri Lanka. 65 : 32-46.

Dyck, A.W.J. 1939. The amount and distribution of some of the nutrient elements in the rubber tree. J. Rubb. Res. Inst. Malaya. 9: 6-13.

George, C.M. 1962. Mature rubber manuring : Effects of fertilizers on yield. Rubb. Bd Bull.5: 202-208.

George, C.M. 1963. A preliminary report on the permanent manurial experiment on rubber. Rubb. Bd Bull. 7 : 37-41.

George, P.J., Premakumari, D., Markose, V.C. and Panickar, A.O.N. 1980. The rubber tree (*Hevea brasiliensis* MUELL. ARG.). In: Pillay, P.N.R. (ed.). *Handbook of Natural Rubber Production in India*. Rubber Research Institute of India, Rubber Board, Kottayam. pp. 25-29.

Guha, M.M. 1975. Fertilizer response from mature rubber in Liberia. *Proc. Int. Rubb. Conf.* Kuala Lumpur, Malaysia 3 : 108-121.

Guha, M.M. and Pushparajah, E. 1966. Responses to fetilizers in relation to soil type. *Plrs'. Bull. Rubb. Res. Inst. Malaya.* 87: 178-183.

Guha, M.M., Singh, M.M. and Chan, H.Y. 1971. Use of appropriate fertilizer for rubber based on soil and leaf nutrient survey. *Q. Jl. Rubb. Res. Inst. Ceylon.* 48 : 160-167.

Guha, M.M. and Yeow, K.H. 1966. Soil and Leaf nutrient status in relation to soil type. *Plrs' Bull. Rubb. Res. Inst. Malaya.* 87 : 170-177.

Hardjono, A., Tonapa, S., Soepardi, G. and Koswara, O. 1981. The effect of N, P, K and Mg fertilizers on the growth of GTl *hevea* seedlings in the nursery on red-yellow podzolic soils in the South Surnatra. *Menara Perkebunan* 49 : 121-127.

Hesse, P.R. 1971. *A Text Book of Soil Chemical Analysis.* John Marry, London. 520 pp.

Jackson, M.L. 1973. *Soil Chemical Analysis.* Printice Hall of India Pvt., Ltd., New Delhi. 498 pp.

Jeevaratnam, A.J. 1965. *Innovation in cultivation and fertilizer practices.* Rubber Research Institute of Ceylon. 41: 23-32.

John, R.S. 1967. The Potassium status of some soils in the rubber growing areas of Ceylon. *Q. Jl. Rubb. Res. Inst. Ceylon.* 43: 19-33.

Joseph, G.M., Saraswathyamma, C.K. and George, P.J. 1980. Hevea clones. In: Handbook of Natural Rubber Production in India. Radhakrishna Pillay, P.N. (ed.). Rubber Research Institute of India, Rubber Board, India, pp. 47-59.

Kalam, M. A., Karthikakutty Amma, M., Punnoose, K.I. and Potty, S.N. 1980. Effect of fertilizer application on growth and nutrient content of some important Hevea clones. Rubb. Bd Bull. 16: 19-29.

Lau, C.H. 1979. Effect of potassium and aluminium treatments on growth and nutrient uptake of rubber seedlings and on soils. J. Rubb. Res. Inst. Malaysia. 27 : 92-103.

Lau, C.H., Pushparajah, E. and Yap, W.C. 1973. Evaluation of phosphorus indices for Hevea. Proc. Conf. on Fertility and Chemistry of Tropical Soils., Kuala Lumpur. p. 103.

Lu Xingzheng and He Xiangdong, 1982. Fertilizer application based on nutrient diagnosis of rubber trees. Chin. J. trop. Crops. 3: 27-39.

Mainstone, B. J. 1969. Residual effects of ground cover and nitrogen fertilization of Hevea prior to tapping. J. Rubb. Res. Inst. Malaya. 21: 113-125.

Mathew, M., Punnoose, K.I., Potty, S.N. and George, E.S. 1989. A study on the response in yield and growth of rubber grown in association with legume and natural ground cover during the immature phase. J. Plant Crops. 16: 433-441.

Milford, G.F.J., Paardekooper, E.C. and Ho Chai Tee. 1969. Latex vessel plugging, its importance to yield and clonal behaviour. J. Rubb. Res. Inst. Malaya. 21: 274.

Mo Shanwen, He Dingquan and Cai Chuhui. 1988. A study on the dry rubber content based adjustment of stimulating and tapping intensity Chin.J. trop. Crops. 9: 37-45.

Nair, C.K.N. 1957. Fertilizers for rubber. Rubb. Bd Bull. 4: 7-16.

Nair, M.A. 1981. Nutritional Studies on Oil Palm (Elaeis guineensis Jacq.) Ph. D. Thesis, Kerala Agricultural University.

Narayanan, R. and Abraham, P.D. 1976. Latex vessel plugging indices and their variation for clones, sites and tapping systems. J. Rubb. Res. Inst. Malaysia. 24: 248-260.

Nasution, Z.M., Lukman and Badaruddin. 1985. The effect of manuring combined with ethrel stimulant application on rubber trees of AVROS 2037 clone. Menara Perkebunan. 53: 252 - 255.

*Ollagnier, M., Ochs, R. and Martin, G. 1970. Manuring of oil palm in the world. Fertilite. 36: 3-63.

Owen, G., Westgarth, D.R. and Iyer, G.C. 1957. Manuring Hevea: Effect of fertilizers on growth and yield of mature rubber trees. J. Rubb. Res. Inst. Malaya. 15: 29-52.

*Piper, C.S. 1950. Soil and Plant Analysis. Academic Press, New York.

Paardekooper, E.C. and Samosorn, S. 1969. Clonal variation in latex flow pattern, J. Rubb. Res. Inst. Malaya. 21: 264.

Potty, S.N. Abdul Kalam, M., Punnoose, K.I. and George, C.M. 1976. Response of Hevea to fertilizer application in relation to soil fertility characteristics. Rubb. Bd Bull. 13 : 48-54.

Potty, S.N., Punnoose, K.I., Karthikakutty Amma, M. and George, C.M. 1980. Effect of fertilizers on growth, yield and nutrient status of four Hevea clones. Paper presented in International Rubber Conference, Kottayam, India. 1980.

Punnoose, K.I., Potty, S.N., Kalam, M.A., Karthikakutty Amma, M. and Mathew, M. 1978. Studies on direct and residual effect of nitrogen, phosphorus and potassium on the growth and yield of rubber in red loam soils of South India. Proceedings of the Plantation Crops Symposium I Kottayam. p. 175.

Punnoose, K.I., Potty, S.N., Mathew, M. and George, C.M. 1975. Response of Hevea brasiliensis to fertilizers in South India. Proc. Int. Rubb. Conf. Kuala Lumpur, Malaysia. pp.84-105.

Pushpadas, M.V. Potty, S.N., George, C.M. and Krishnakumari, M. 1972. Effect of long term application of NPK fertilizers on pH and Nutrient levels of soil and leaf in Hevea brasiliensis. J.Plant Crops. 1: 38-43.

Pushpadas, M.V., Subbarayalu, G. and George, C.M. 1978. Studies on correlation between nutrient levels in soil and leaf and yield of Hevea brasiliensis. Rubb. Bd Bull. 15: 11-22.

*Pushparajah, E. 1966. Studies on the effects of rock phosphate on growth and yield of Hevea brasiliensis. M. Agric. Sc. Thesis, University of Malaya.

Pushparajah, E. 1969. Response on growth and yield of Hevea brasiliensis to fertilizer application in Rengam Series soil. J. Rubb. Res. Inst. Malaya. 21:165-174.

Pushparajah, E. 1977. Nutrition and fertilizer use in Hevea and associated covers in Peninsular Malaysia - A review Jl. Rubb. Res. Inst. Sri Lanka. 54 : 270-283.

Pushparajah, E. 1981. Nitrogen cycle in rubber (Hevea) cultivation. In: Nitrogen cycling in South - east Asian wet monsoonal ecosystems. Wetselaar, R., Simpson, J.R. and Rosswall, T. (eds.) pp. 101-107.

Pushparajah, E., Chan, H.Y. and Sivanadyan, K. 1983. Recent developments for reduced fertilizer application for Hevea. Proc. Rubb. Res. Inst. Malaysia Plrs' Conf. Kuala Lumpur. pp. 313-327.

*Pushparajah, E. and Guha, M.M. 1968. Fertilizer response in Hevea brasiliensis in relation to soil type and soil and leaf nutrient status. Procedings of 9th International Conference on Soil Science, Adelaide. 4:85-98.

Pushparajah, E and Haridas, G. 1977. Developments in reduction in immaturity period of *Hevea* in Peninsular Malaysia. *Jl. Rubb. Res. Inst. Sri Lanka.* 54: 93-105.

Pushparajah, E., Mohd Noor Bin Wahab and Samuel, J.G. 1973. Response to fertilizers in replanted small holdings. *Proc. Rubb. Res. Inst. Malaysia Plrs' Conf.* Kuala Lumpur. pp. 258-266.

Pushparajah, E.,Muhmud Bin Haji Abdul Wahab and Lau, C.H. 1977. Residual effect of applied phosphates on performance of *Hevea brasiliensis* and *Pueraria phaseoloides*. *J. Rubb. Res. Inst. Malaysia.* 25: 101-108.

Pushparajah, E., Sivanadyan, K., Subramanian, A. and Tan, K.T. 1975. Influence of fertilizers on nutrient content, flow and properties of *Hevea* latex. *Proc. Int. Rubb. Conf.* Kuala Lumpur, Malaysia. 3: 122-131.

Pushparajah, E., Sivanandyan, K. and Yew, F.K. 1974. Efficient use of fertilizers. *Proc. Rubb. Res. Inst. Malaysia Plrs' Conf.* Kuala Lumpur. pp.102-114.

Pushparajah, E., Soong, N.K., Yew, F.K. and Zainol Eusof. 1976. Effect of fertilizers on soils under *Hevea* *Proc. Int. Rubb. Conf.* Kuala Lampur. 3: 37-45.

Rubber Board. 1984. Potassium requirements of rubber. *Rubb. Bd Bull.* 20 : 5-8.

Rubber Board. 1991. *Indian Rubber Statistics*. 19: 1-13.

Rubber Board 1993. *Rubber and its cultivation*. Rubber Board, Kottayam. pp.19-63.

Rubber Research Institute of Ceylon 1966. *Annual Review Rubb. Res. Inst. Ceylon*. pp. 110-131.

Rubber Research Institute of Malaya, 1940. Manuring.. *Plrs'. Bull. Rubb. Res. Inst. Malaya*. 9 :1-7.

Rubber Research Institute of Malaya. 1958. Manuring of Hevea Annual Report Rubb. Res. Inst. Malaya. p.15.

Rubber Research Institute of Malaya. 1965a. Fertilizer experiments of mature rubber. Plrs'. Bull. Rubb. Res. Inst. Malaya. 77: 36-55.

Rubber Research Institute of Malaya. 1965b. Effect of fertilizers and cover plants on early yield of young rubber. Plrs' Bull. Rubb. Res. Inst. Malaya. 77: 56-64.

Rubber Research Institute of Malaya. 1967. Economic use of fertilizers in mature rubber. Plrs'. Bull. Rubb. Res. Inst. Malaya. 93: pp.300-308.

Rubber Research Institute of Malaya. 1969a. Dicta of fertilizer usage. Plrs'. Bull. Rubb. Res. Inst. Malaya. 102: 97-98.

Rubber Research Institute of Malaya. 1969b. Magnesium: Its role in rubber cultivation. Plrs'. Bull. Rubb. Res. Inst. Malaya. 102: 99-102.

Rubber Research Institute of Malaya. 1971a. Nutrients and rubber. Plrs'. Bull. Rubb. Res. Inst. Malaya. 114: 127-128.

Rubber Research Institute of Malaya. 1971b. Potassium: Its role in rubber cultivation. Plrs' Bull. Rubb. Res. Inst. Malaya. 114: 129-135.

Rubber Research Institute of Malaya. 1971c. Nitrogen: Its role in rubber cultivation. Plrs' Bull. Rubb. Res. Inst. Malaya. 114: 250-258.

Rubber Research Institute of Malaya. 1972. Cycle of nutrients in rubber plantation. Plrs'. Bull. Rubb. Res. Inst. Malaya. 120: 73-81.

Rubber Research Institute of Malaysia. 1973 *Manual of Laboratory Methods for Chemical Analysis of Hevea brasiliensis Rubber*. Rubber Research Institute of Malaysia, Kuala Lumpus, Malaysia. 139 pp.

Rubber Research Institute of Malaysia. 1976. Influence of fertilizers and covers on fertility of soils under *Hevea*. *Plrs'. Bull. Rubb. Res. Inst. Malaysia*. 142: 8-13.

Rubber Research Institute of Malaysia. 1978. Rock phosphate sources and their potential as fertilizers in rubber cultivation. *Plrs'.Bull. Rubb. Res. Inst. Malaysia*. 157: 147-156.

Rubber Research Institute of Malaysia, 1989. RRIM planting recommendations 1989-91. *Plrs' Bull. Rubb. Res. Inst. Malaysia*. 198: 3-22.

Rubber Research Institute of Sri Lanka. 1983. *Annual Review Rubb. Res. Inst. Sri Lanka*. pp. 61-82.

Rubber Research Institute of Sri Lanka. 1986. *Annual Review Rubb. Res. Inst. Sri Lanka*. pp.51-64.

Rubber Research Institute of Sri Lanka. 1987. *Annual Review Rubb. Res. Inst. Sri Lanka*. pp. 60-73.

Rubber Research Institute of Sri Lanka. 1988. *Annual Review Rubb. Res. Inst. Sri Lanka*. pp.57-72.

Rubber Research Institute of Sri Lanka. 1989. *Annual Review Rubb. Res. Inst. Sri Lanka*. pp.39-50.

Samsidar BTE Hamzah, Abdul Aziz Mohmood, Sivanadyan, K. and Gomez J.B. 1975. Effects of mineral dificiencies on bark anatomy of *Hevea brasiliensis*. *Proc. Int. Rubb. Conf. Kuala Lumpur. Malaysia*. pp:165-180.

Samsidar BTE Hamzah and Gomez, J.B. 1982. *Some structural* factors affecting the productivity of *Hevea brasiliensis*. III. Correlation studies between structural factors and plugging. *J. Rubb. Res. Inst. Malaysia*. 30: 148-160.

Shorrocks,V.M. 1960. Leaf analysis as a guide to nutrition of *Hevea brasiliensis* l. Sampling technique with mature trees: Principles and preliminary observations on the variations in leaf nutrient composition of the tree.*J. Rubb. Res. Inst. Malaya*. 16: 1-8.

Shorrocks,V.M. 1961a. Leaf analysis as a guide to the nutrition of *Hevea brasiliensis*. I. Sampling technique with mature trees: principles and observations on the variations in leaf nutrient composition with position on the tree. *J. Rubb. Res. Inst. Malaya*. 17: 1-13.

Shorrocks,V.M. 1961 (b). Some effects of fertilizer application on the nutrient composition of leaves and latex of *Hevea brasiliensis*. *Proceedings of Natural Rubber Research Conference*, 1960, Kuala Lumpur, Malaya pp. 119-130.

Shorrocks,V.M. 1962. Leaf analysis as a guide to the nutrition of *Hevea brasiliensis*. V. A leaf sampling technique for nature trees. *J. Rubb. Res. Inst. Malaya*. 17: 167-190.

Shorrocks,V.M. 1964. Effect of time of fertilizer application on leaf nutrient composition *J. Rubb. Res. Inst. Malaya*. 18: 276 - 278.

Shorrocks,V.M. 1965(a) Leaf analysis as a guide to the nutrition of *Hevea brasiliensis*. VI. Variation in leaf nutrient composition with age of leaf and with time. *J. Rubb. Res. Inst. Malaya*. 19: 1-8.

Shorrocks,V.M. 1965(b). Mineral nutrition, growth and nutrient cycle of *Hevea Brasiliensis* I. Growth and nutrient content. *J. Rubb. Res. Inst. Malaya*. 19: 32-47.

Shorrocks,V.M. 1965(c). Magnesium limestone, Kieserite and ground serpentine as magnesium fertilizer *J. Rubb. Res. Inst. Malaya*. 19: 9-16.

Sivanadyan, K. 1983. Manuring of mature *Hevea*: Recent evidences and a possible new outlook. *Proc. Rubb. Res. Inst.* Malayasia Plrs' Conf. Kuala Lumpur. pp 286 - 312.

Sivanadyan, K. and Gandimathi, H. 1985. Influence of nitrogen fertilization on various aspects of tree development in *Hevea brasiliensis*. *Proc. Int. Rubb. Conf.* Kuala Lumpur, Malaysia. pp.

Southorn, W.A. and Edwin, E.E. 1968. Latex flow studies II. Influence of lutoids on the stability and flow of *Hevea* latex. *J. Rubb. Res. Inst. Malaya*. 20: 187 - 200.

Stevenson, I.L. 1964. Biochemistry of soil. In: *Chemistry of the Soil*. Bear, F.E. (ed.). Oxford and IBH Publishing Co., Calcutta. pp. 242-287.

Subbiah, B.V. and Asija, L.L. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Curr. Sci.* 25: 259 - 260.

Sutcliff, J. F and Baker, D.A 1974. *Plants and Mineral Salts*. Oxford and IBH Publications, New Delhi pp. 11 - 25.

Tisdale, S.L., Nelson, W.L. and Beaton, J.D 1985. *Soil Fertility and Fertilizers* Macmillan Publishing Company, New York. pp.249-349.

*Walkley, A.J. and Black, I.A. 1934. Estimation of soil organic carbon by the chromic acid titration method *Soil Sci.* 37: 29 - 38.

Weerasuriya, S.M. and Yogaratnam, N. 1988. Effect of potassium and magnesium on growth of young *Hevea brasiliensis* *Jl. Rubb. Res. Inst. Sri Lanka*. 68: 1-8.

Wycherley, P.R. 1977. Energy flow and dry matter accumulation in relation to selection and exploitation. *Jl. Rubb. Res. Inst. Sri Lanka*. 54: 207 - 220.

Xu Nengkun, Xiao Zhaomin, Liang Fulu and Liang Xiujin. 1986. Effect of mineral fertilizers on nutrient composition, mineral deficiency and growth of young rubber trees on three types of soils in West Guangdong. *Chin. J. trop. Crops*. 7: 47-55.

Yeang, H.Y and Paranjothy, K. 1982. Some primary determinants of seasonal yield variation in clone RRIM 623. J. Rubb. Res. Inst. Malaysia. 30: 131-147.

Yew, F.K. and Pushparajah, E. 1984. Plant tissues as indicators of soil nutrient availability for Hevea: Glass house evaluation. J. Rubb. Res. Inst. Malaysia. 32: 171 - 181.

Yip, E. 1990. Clonal characterisation of latex and rubber properties. J. nat. Rubb. Res. 5: 52 - 80.

Yip, E. and Chin, H.C. 1977. Latex flow studies: Distribution of metallic iron between phases of Hevea latex and the effects of yield stimulation on the distribution. J. Rubb. Res. Inst. Malaysia. 25: 31 - 49.

Yip, E. and Gomez, J.B. 1975. Stability of fresh Hevea latex in relation to latex vessel plugging. Proc. Int. Rubb. Conf. Kula Lumpur. pp. 203 - 224.

Yogaratnam, N. and De Mel, J.G. 1985. Effect of fertilization on leaf composition of NPK in some Hevea cultivars. Jl. Rubber. Res. Inst. Sri Lanka. 63: 15-24.

Yogaratnam, N., Silva, F.P.W. and Weerasuryia, S.M 1984. Recent developments in the nutrition of Hevea in Sri Lanka. Proceedings of International Rubber Conference "75 years of Rubber Research Sri Lanka," 1984, Colombo, 1: 207 - 247.

Yogaratnam, N. and Weerasuriya, S.M. 1984. Fertilizer responses in mature Hevea under Sri Lanka condition. J. Rubb. Res. Inst. Sri Lanka. 62: 19-39.

* Originals not seen

APPENDICES

APPENDIX - I

WEATHER DATA DURING THE PERIOD OF THE EXPERIMENT AND MEANS OF PREVIOUS 25 YEARS (1964-1988) AT KULASEKHARAM

Months	Total rainfall (mm)				Number of rainy days			
	1964-88 (average)	1989	1990	1991	1964-88 (average)	1989	1990	1991
January	30	6	8	32	4	2	3	4
February	37	28	46	54	4	3	3	3
March	84	124	79	47	5	3	5	4
April	176	165	92	176	8	8	8	9
May	228	115	387	111	11	9	17	14
June	320	483	238	780	20	22	16	28
July	194	271	149	150	13	14	12	12
August	88	78	21	54	6	6	2	3
September	182	252	33	138	7	13	3	9
October	316	288	463	248	17	21	21	19
November	271	236	447	264	12	12	12	14
December	84	28	33	30	2	1	2	2
Total	2010	2074	1996	2084	109	114	104	121

APPENDIX - II

WEATHER DATA DURING THE PERIOD OF THE EXPERIMENT AND MEANS OF PREVIOUS 25 YEARS (1964-1988) AT KULASEKHARAM (Continued)

Months	Maximum temperature (monthly mean)				Minimum temperature (monthly mean)				Average relative humudity (per cent)			
	1964-88 (average)	1989	1990	1991	1964-88 (average)	1989	1990	1991	1964-88 (average)	1989	1990	1991
January	31.4	31.9	32.3	31.8	18.5	18.2	17.9	18.2	68.0	69.5	67.0	68.5
February	33.5	33.6	34.1	33.8	19.8	18.5	18.2	19.2	69.5	71.0	69.0	70.0
March	34.1	34.0	34.3	34.2	22.3	21.8	21.3	22.0	73.0	73.0	73.5	73.5
April	34.6	34.2	34.0	33.8	23.2	23.2	23.7	23.6	77.0	76.5	79.5	76.5
May	31.2	31.0	31.2	31.6	23.1	23.1	23.4	22.9	80.5	79.5	82.5	79.5
June	30.2	30.6	29.8	30.8	23.2	23.4	23.5	23.4	86.0	86.0	85.5	87.0
July	29.8	30.2	29.6	29.8	22.9	23.0	22.7	22.5	85.0	86.0	86.0	85.5
August	30.1	30.3	30.2	30.5	23.4	23.2	23.7	23.4	83.0	84.0	81.5	83.5
September	31.9	32.4	32.6	32.3	22.2	22.1	21.9	22.3	81.5	82.0	85.5	82.0
October	31.8	32.0	31.6	32.1	22.0	21.8	21.9	22.2	83.5	84.0	85.0	85.0
November	30.7	31.0	30.4	30.6	22.4	22.6	22.2	22.5	82.5	81.0	84.5	83.0
December	31.3	31.6	31.4	31.1	21.3	21.7	21.2	20.9	72.0	75.0	75.0	75.5

APPENDIX - III

WEATHER DATA DURING THE PERIOD OF THE EXPERIMENT AND THE MEANS OF PREVIOUS 25 YEARS (1964 - 1988) AT THODUPUZHA

Months	Total rainfall (mm)				Number of rainy days			
	1964-88 (average)	1989	1990	1991	1964-88 (average)	1989	1990	1991
January	18	4	14	18	3	2	2	3
February	42	12	10	21	5	3	2	3
March	86	48	40	70	6	6	5	6
April	260	124	159	210	12	7	8	10
May	308	275	310	286	18	12	15	9
June	695	918	868	910	26	25	24	24
July	803	812	974	927	27	24	28	28
August	558	512	460	410	21	20	18	16
September	395	418	427	480	17	18	16	18
October	425	348	430	378	18	16	14	14
November	248	314	270	296	10	12	10	11
December	84	98	89	78	5	6	6	5
Total	3922	3883	4051	4084	168	151	148	147

APPENDIX - IV

WEATHER DATA DURING THE PERIOD OF THE EXPERIMENT AND MEANS OF PREVIOUS 25 YEARS (1964-1988) AT THODUPUZHA (Continued)

Months	Maximum temperature (monthly mean)				Minimum temperature (monthly mean)				Average relative humudity (per cent)			
	1964-88 (average)	1989	1990	1991	1964-88 (average)	1989	1990	1991	1964-88 (average)	1989	1990	1991
January	33.5	33.6	33.8	32.2	20.2	20.7	19.8	19.9	67.5	69.5	67.5	69.5
February	35.6	36.7	35.7	36.0	22.1	23.0	20.7	21.3	71.0	71.0	71.0	70.0
March	35.8	36.0	36.7	35.5	24.0	24.5	23.5	23.9	73.0	74.5	72.0	73.0
April	35.3	35.3	36.2	34.8	24.4	23.1	25.0	24.0	76.0	77.5	77.5	77.0
May	33.0	32.9	32.6	33.7	24.6	23.9	24.1	25.3	79.0	80.5	79.0	81.0
June	29.7	29.2	29.5	30.5	23.2	23.0	23.4	23.4	87.0	88.5	89.5	89.5
July	29.4	28.9	28.5	29.7	22.8	22.9	22.9	23.1	90.0	89.5	90.0	90.0
August	30.4	30.2	30.5	30.7	24.0	22.8	23.2	23.6	88.5	89.0	89.0	88.5
September	31.3	31.0	31.5	31.1	23.2	23.0	23.2	23.4	83.5	83.0	82.0	82.5
October	32.4	31.3	32.8	33.0	23.5	23.2	23.7	23.3	81.5	82.5	81.5	80.5
November	32.4	32.6	32.1	32.3	22.2	21.9	22.0	22.6	76.0	75.0	75.0	76.0
December	33.1	34.1	32.8	33.2	20.3	20.7	20.1	20.5	69.0	68.0	67.5	68.5

APPENDIX - V

WEATHER DATA DURING THE PERIOD OF THE EXPERIMENT AND THE MEANS OF PREVIOUS 25 YEARS (1964-1988) AT BALUSSERY

Months	Total rainfall (mm)				Number of rainy days			
	1964-88 (average)	1989	1990	1991	1964-88 (average)	1989	1990	1991
January	10	-	45	-	2	-	4	-
February	11	-	-	-	2	-	-	-
March	29	11	-	8	3	3	-	2
April	129	70	30	115	10	10	4	9
May	327	136	619	96	17	15	23	9
June	1021	1044	648	1409	28	30	28	30
July	1176	791	917	1154	29	22	31	30
August	710	462	605	500	26	27	29	26
September	362	285	135	106	10	17	6	7
October	416	535	518	624	18	23	20	18
November	259	207	67	178	8	8	9	10
December	48	4	4	-	2	2	1	-
Total	4499	3545	3588	4190	155	157	155	141

APPENDIX - VI

WEATHER DATA DURING THE PERIOD OF THE EXPERIMENT AND MEANS OF PREVIOUS 25 YEARS (1964-1988) AT BALUSSERY (Continued)

Months	Maximum temperature (monthly mean)				Minimum temperature (monthly mean)				Average relative humudity (per cent)			
	1964-88 (average)	1989	1990	1991	1964-88 (average)	1989	1990	1991	1964-88 (average)	1989	1990	1991
January	31.7	31.8	31.5	31.6	22.0	21.8	21.6	21.4	69.0	69.0	68.5	69.5
February	31.9	32.0	31.7	31.8	23.1	21.9	22.6	22.8	71.0	69.5	70.0	71.0
March	32.6	32.7	32.4	32.5	24.7	24.8	24.5	24.6	71.5	71.0	71.5	71.5
April	32.9	33.0	32.5	32.8	25.8	25.7	25.4	25.5	73.0	73.5	73.0	72.5
May	32.5	32.6	32.8	32.9	25.6	25.4	25.7	25.6	78.5	77.5	78.5	77.0
June	29.5	30.0	30.0	30.2	23.8	23.6	23.4	23.1	87.5	87.5	88.5	90.0
July	28.2	28.7	29.0	29.1	23.3	23.1	23.4	23.7	90.5	90.0	89.5	90.5
August	28.7	29.0	28.9	29.3	23.6	23.5	23.7	23.4	89.0	89.0	89.5	89.5
September	29.5	29.4	29.5	29.6	23.7	23.6	23.2	23.5	85.0	85.0	86.0	85.5
October	30.4	30.0	30.1	30.4	23.8	23.9	23.6	23.7	81.8	80.5	82.5	82.0
November	31.1	31.2	31.0	31.4	23.4	23.2	23.6	23.2	76.0	77.0	77.0	76.5
December	31.6	31.5	31.0	31.4	22.2	22.6	22.1	22.0	69.5	69.5	68.5	70.0

PLATE-I VIEW OF A RUBBER PLANTATION

PLATE-II TRUNK OF A TREE SHOWING TAPPING PANEL