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CHAPTER 11

NUTRITION OF HEVEA

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Judicious nutrient management has long been recognised as the surest means of sustaining high levels of productivity and rubber is no exception to this. Nutrient demands of Hevea were generally believed to be modest mainly because of the fact that earlier plantations were mostly in newly cleared forest soils, rich in plant nutrients. Moreover, rubber plantations present almost a closed ecosystem, in a near steady state, during their life span. Nutrient management has gained greater importance in recent years because of two reasons: firstly, Hevea plantations are no longer raised in virgin forests and secondly, most of the plantations are either in the second or third cycle of replantation. Even though nutrients removed through the crop are negligible, large amounts of mineral elements are locked up in the process of biomass accumulation and are lost through timber during replanting. Gradual depletion of mineral resources through cycles of re-plantation warrants appropriate nutrient management. Of late, more and more marginal and depleted soils are being brought under rubber cultivation to meet the increasing demand and under such situations proper soil and nutrient management is essential to sustain productivity at economic levels.

Response of a perennial crop like rubber to nutrition is influenced by the nutrient supplying capacity of the soil on the one hand and factors like clonal variation, stage of growth, intensity of exploitation and ground cover management on the other. A wealth of information has emerged on this aspect from extensive studies conducted in almost all rubber growing countries, the major contribution being from Malaysia. General fertilizer schedules for local conditions have been perfected. In this chapter, an attempt is made to review studies on nutrition conducted in the major rubber producing countries.

SOILSUNDER HEVEA

Hevea, a native of Amazon tropical forests, can grow on a wide range of soils, but deep well drained soils of pH below 6.5 and free from underlying sheet rocks are well suited for its performance as a commercially viable plantation crop (Pushpadas and Karthikakutty Amma, 1980). However, as opined by Webster (1989) most of the plantations in Africa and Asia are located in areas chosen solely on grounds of availability and convenience. Nevertheless, such areas satisfied most of the minimum requirements of soil conditions except in situations where the planters were forced to accept marginal sites.

Soils under Hevea, in general, have developed either under warm *humid equatorial monsoon climate with a little or no dry spell or under* tropical wet-dry monsoon climate with variable duration of dry season, extending from three to five months. The Indonesian archipelago, Malaysia and southern part of Sri Lanka fall under the former climatic zone while India, northern part of Sri Lanka, Burma, Thailand, Vietnam and the Philippines archipelago and southern part of Indonesia fall under the latter (Pushpadas and Karthikakutty Amma, 1980). In Brazil, the soils are mostly red yellow podsols or latosols, formed under warm humid equatorial climate. The alternating wet and dry monsoon climate prevailing in most of the rubber growing countries including India favour high degree of laterization.

The soils under rubber in Malaysia have originated mainly from igneous, metamorphic, argillaceous and arenaceous sedimentary rocks. Of the seventeen series, seven have shales as parent rocks. The other parent rocks are granite, granodiorite, basalt, andesite, rhyolites/volcanic tuff, dacite, quartzite/shale and sandstone (Chan et al. 1977). Considerable areas also represent soils originated from marine sediments and volcanic ashes as in the case of Indonesia. The major rock types in the traditional rubber growing regions in India are charnockite, pyroxene, gneiss, khondalite etc., of the precambian metamorphic complex and the soils are laterites, lateritic and red soils in catenary sequence with laterites (Krishnakumar, 1989). The parent rocks in North East India are however sandstone and shales.

Influence of soil properties on crop performance

The rubber tree can withstand soil physical conditions ranging from stiff clayey with impeded drainage to well drained sandy loam. However, its performance is affected by adverse soil conditions. Physical, chemical, physico-chemical and physiographic features of soil also influence the growth and productivity of rubber to a considerable extent.

Physiographic features: Physiographic features such as degree of slope, aspect, soil depth, rockiness etc., have been reported to have profound influence on growth and yield of rubber (Chan et al. 1972). Soil depth is considered to be an important parameter influencing growth and yield of this perennial crop. Shallow soils restrict development of tap root affecting anchorage of trees. Deep soils with large quantities of clay, which serves as a reservoir of moisture, help to tide over drought situations. A minimum depth of 100 cm has been considered essential for successful rubber cultivation (Pushpadas and Karthikakutty Amma, 1980). Intervening hard pans, if present, should be well below 1.5 m. So also, it is not desirable to have underlying sheet rocks in the profile within a depth of 2 m. Depth of more than 125 cm increases growth, yield and leaf nutrient content (Chan et al. 1974). These authors reported that slope also affects growth of Hevea. A slope upto 26% is reported to favour growth and productivity. Nevertheless, rubber is grown satisfactorily in much steeper slopes.

Aspect is found to influence growth and performance of Hevea significantly. Aliang Jiang (1981) reported that in China, rubber trees on the leeward slopes suffered less damage due to cold. Studies on microclimatic observations conducted in China by the above author revealed that trees on south and west slopes suffer less cold damage. Aspect coupled with soil properties also influence growth of rubber trees. Either water stress or excess stagnant water in the root zone, will weaken cold hardiness of rubber trees. The authors of this chapter have observed that the initial establishment and growth of immature Hevea are better on the southern slopes than on other aspects in Tura (North East India) situated at an altitude of 600 m MSL. This observation is quite contradictory to the experience in the traditional rubber growing regions in South India experiencing warm humid climatic conditions.

Physical properties: A wide range of textures from clay to sandy loam has been reported in the soils under rubber. Soils of loamy texture are best suited for cultivation of rubber (Pushpadas and Karthikakutty Amma, 1980). However, within loams higher clay content has been reported to promote growth as well as yield. In Malaysia, lack of adequate clay has been found to affect the growth of rubber in some of the soil series due to poor nutrient retention and this has warranted rescheduling of the fertilizer application (Sivanadyan, 1972). Feeder root development has been reported to be affected by soil texture (Soong, 1971). He observed a positive correlation of root development with sand content and negative correlation with clay content in the soils of Malaysia. Though clay content in the rubber growing soils of India has been reported to be relatively high, it is moderated by the presence of high amount of sesquioxides, thus reducing the adverse effect of high clay content. Other physical parameters like bulk density and porosity also affect the growth of Hevea indirectly through their influence on soil erosion and consequent root development.

The productive potential of a soil is influenced by its moisture retention characteristics and rubber being a rainfed crop, this factor assumes greater importance. A wide range of available water content has been reported from soils under Hevea in Malaysia and India (Soong and Lau, 1977; Krishnakumar et al. 1990). The amount of moisture retained at various tensions was also found to vary depending on the nature and content of clay. At field capacity (-0.033 MPa) 19.5 to 37.8% soil moisture was found to be retained in the surface soils of the west coast of India (Krishnakumar, 1989). In these soils, 75% of moisture was desorbed at -0.5 MPa and hence this tension can be considered critical as far as soil moisture availability in rubber growing soils is concerned. The Kaoline-ironoxide aggregates present in the high clay tropical soils tend to hold more moisture at lower tensions behaving like sands, and at the same time these aggregates behave like clays at higher tensions, enabling retention of sizeable quantity of water. In the latter case the aggregate size becomes irrelevant because it is the micropores within aggregates that get drained.

Ground covers help in improving soil physical properties. Aggregation of soil particles under both natural and legume covers was found to be better when compared to soils under clean cultivation. Between the legume and natural covers, the former influences soil physical properties more favourably than the latter (Duley, 1952; Bremner, 1956; Cornfield, 1955 and Watson, 1957). A better soil structure in terms of mean weight diameter, rate of infiltration and percentage of water stable aggregates, has been reported in India, when rubber is grown in association with legume cover than with natural cover (Krishnakumar, 1989).

In denuded forests as well as in areas subjected to continuous shifting cultivation the soil physical properties have been found to be improved considerably once a rubber plantation is established. Twenty years after planting of rubber the moisture retained at field capacity was significantly higher vis-a-vis the moisture retained in an adjacent field under continuous shifting cultivation (Krishnakumar et al. 1990a).

Physico-chemical properties: The minerology of clays present in the soils largely influences their physical and physico-chemical behaviour. Cations such as calcium, magnesium and potassium play an important role in the nutrition of rubber and dynamics of these mineral elements is governed by the type of clay minerals. Rubber growing soils of Malaysia are rich in Kaolinite (1:1 layer silicate clays). Of the 23 soil series, 14 series have been reported to have kaolinite content of more than 50% and other seven series have 20-50% (Chan et al. 1977). Illite also has been reported to be present in all the above soil series. In the clay fraction of soils of basaltic origin from eastern and south eastern Nigeria, kaolinite was identified to be the dominant clay mineral (Eshett and Omutei, 1989). Eshett and Omutei (1989) reported the presence of hematite, lepidocrocite, mica, smectite and goethite in the soils of south eastern Nigeria. The clay fraction in the soils under Hevea in India is also dominated by kaolinite. The presence of the oxides of iron and aluminium in the clay fraction leads to poor release of nutrients through mineral weathering to meet the demand of rubber for rapid growth and high yield (Eshett and Omutei, 1989). This situation warrants judicious fertilizer application and proper establishment of leguminous ground covers. Appreciable amount of illite, mostly of degraded nature, has been identified in the soils along the west coast of India. Soils with appreciable amount of this mineral would render potassium unavailable by fixation. Inconsistent response to potassium observed by Ananth et al. (1966) in immature phase and by Potty et al. (1976) in mature areas could be attributed to the diverse minerology of soil clay fractions especially of illite group. The range of aluminium in some of the soils is so high that it could lead to toxicity problems. The optimal pH for rubber is reported to be in the range of 4 to 6.5. The possibility of aluminium toxicity in the above range is very remote. Even though Hevea is reported to tolerate a pH range of 3.8 to 7.0, the extremes could affect its growth and productivity. In soils with pH less than 4, it is not the low pH per se but the toxicity or deficiency of mineral elements that often limits crop production (Marscher Horst, 1986).

Rubber is grown in soils with a wide range of CEC. While CEC of 2.05 to 15.96 m eq $100g^{-1}$ is reported in Malaysia, it ranges from 3.55 to 18.02 meq 100 g^{-1} in soils under Hevea in India. In the soils of basaltic origin in Nigeria the CEC is relatively low (Eshett and Omueti, 1989). Soils in the rubber growing countries, in general, have been found to be low in exchangeable bases especially in the upper horizons and this could be attributed to leaching appreciable quantities of metallic cations down the profile due to high rainfall. Next to calcium, aluminium is found to be the dominant cation of the exchangeable elements. In soils with a pH value of less than 5, preponderance of exchangeable aluminium is generally observed. A drop in aluminium to calcium ratio in the soils adversely affects the growth in most of the crops. Presence of organic matter also is known to reduce the toxic effect of aluminium by chelation (Mutatkar and Pritchelt, 1967). In the case of rubber soils, maintenance of a relatively higher organic matter status through organic matter recycling, coupled with calcium enrichment indirectly by the addition of rock phosphate, could lead to a favourable condition to alleviate the toxic effect of aluminium through chelation and optimum calcium to aluminium ratio. Moreover, the rubber tree itself most probably has a certain degree of aluminium tolerance (Krishnakumar, 1989).

Fertility status: In general, soils under Hevea have been found to be rich in organic matter compared to other agricultural soils in the same region. The organic matter distribution down the profile shows an enrichment in the surface horizons and a decline in the sub-surface horizons. This high accumulation of organic matter in the top soil is due to maintenance of a luxurient leguminous ground cover which adds about six tonnes of organic matter per hectare during the pre-tapping phase of rubber. The organic matter enrichment, however, depends upon the nature of the ground cover. The most commonly grown, Pueraria phaseoloides, has been reported to add about 3.0 tonnes of organic matter during the first four years whereas Mucuna bracteata, a species introduced from the north eastern parts of India, adds 5.6 tonnes during the same period (Kothandaraman et al. 1990). Addition of litter through annual leaf fall also helps build up of organic matter. On an average, about six tonnes of organic matter is added every year through annual leaf fall. The slow pace of oxidation inside the closed canopy of rubber plantations helps to maintain the high organic matter status. The cultural operations with nearly zero tillage also favour stabilisation of organic matter at a relatively high level. Since most soils under Hevea have an abundance of aluminium, the organic matter is complexed with this element, thereby leading to a reduction in decomposition. Interaction of oxides/allophane with the organic matter in the tropical soils again render the organic matter relatively resistant to mineralisation. Extreme phosphorus deficiency consequent to the presence of higher amount of soluble aluminium inhibits microbial growth and these factors also result in low mineralisation of organic matter (Munevar and Wollum, 1977). A range of organic carbon content from 1.11 to 3.76% has been reported in the soil under Hevea in India. A comparable range has also been reported from Malaysia. The C/N ratio was around 10 in the rubber growing soils of India suggesting the stable nature of organic matter in these soils. However, in the rubber growing soils of north east India, an extreme deficiency of organic matter has been encountered consequent to the traditional practice of shifting cultivation (Krishnakumar and Potty, 1989). Planting of rubber has been reported to enrich organic matter status in depleted soils. Studying the influence of rubber plantation on the eco-system of north east India, Krishnakumar et al. (1990b) reported an increase of 0.6% in the organic matter content of soils in a 10 year old rubber plantation compared to a 'jhume' cultivated field in the same location.

An available nitrogen content of 11.6 to 38.8 ppm has been reported in the soils under Hevea in India (Krishnakumar, 1989). The organic carbon content has a positive correlation with available nitrogen. Rao et al. (1990) reported a low rate of nitrification in soils under rubber plantations of north east India where low temperatures prevail for nearly four months.

In general, rubber growing soils are rich in iron and aluminium which render phosphorus sparingly available. A wide-spread deficiency of available phosphorus and potassium in soils under Hevea in the traditional rubber growing regions in India has been reported by George (1961b). Extreme deficiency of available soil phosphorus has also been reported in soils of non-traditional rubber growing regions in north east India.

The available calcium content, generally in the lower range, varied widely in the profiles studied in the west coast of India. Rubber trees appear to have a degree of adaptability to low calcium environment. The influence of calcium is however vital mainly because of its role in alleviating aluminium toxicity thereby resulting in increased availability of phosphorus and potassium. The ratio of calcium to total cation should be around 0.15 for the roots to grow uninhibited. Al/Ca molar activity ratios also influence root development and growth in acid soils. A ratio of 0.02 is considered to be the upper limit beyond which growth will be affected (Marschner Horst, 1987).

The available magnesium content exhibits varied distribution in soils under Hevea in various countries. In India, even within the traditional rubber growing region, distinct delineation has been attempted with respect to available magnesium content (Pushpadas and Ahmed, 1980) and the variation has been attributed to the parent material.

Pedogenesis and classification

Based on the cation exchange capacity, Al_2O_3, SiO_2 / R_2O_3 ratio, nature of the underlying rocks and also the clay mineral assemblage, Krishnakumar (1989) suggested a probable pedogenesis of the soils under Hevea in the west coast of India. He suggested a weathering sequence where a rapid leaching of silica takes place as a consequence of alkaline hydrolysis of the parent rocks of mixed chemical composition, resulting in a higher iron and aluminium content. Since iron could get transformed into oxides more rapidly than aluminium, there is more iron in the sesquioxides and a good quantity of it also appears as free iron oxides. Aluminium released due to hydrolytic decomposition reacts with silica to form mostly kaoline and other layer silicates. A part of unreacted aluminium crystallises as gibbsite, creating a kaoline-gibbsite system that is stable in the prevailing acid conditions. Presence of aluminium in the exchange sites indicates intense tropical weathering. An oxide mixed minerology of the soil is therefore a logical outcome. A lower SiO_2/R_2O_3 ratio encountered suggests a highly weathered condition of the soil. R_2O_3 is dominated by iron and this has resulted in relatively higher SiO_2/R_2O_3 ratios.

International system of soil classification had been attempted to characterise rubber growing soils. The soils in Malaysia have been classified upto series level under the orders Entisols, Inceptisols, Ultisols and Oxisols (Chan, 1977). A soil suitability classification scheme also has been suggested by him wherein five classes (I to V) have been described on the basis of limitation to rubber cultivation. Separate classification systems have been adopted by different countries. Da Costa (1968) developed a system in Brazil for the local red-yellow podzols and latosols. Similarly the Commission for Technical Cooperation in Africa (CCTA) have published a soil map of Africa following French and Belgian systems (d'Hoore, 1964). The classification systems developed by FAO and UNESCO 1974) also are being followed in some countries. A land capability classification has been suggested for rubber by Sys (1975) as per FAO guidelines. Broadly classifying the soils under Hevea in India, Krishnakumar (1989) ascribed three large groups in the major rubber growing belt viz: Paleudalfs (Kanyakumari and Calicut region and Goa); Paleudlts (Central Kerala) and Paleustalfs (Karnataka).

Differential performance of clones in different series has been observed in Malaysia and specific recommendations for different series with respect to clones have been evolved. For instance, Chan and Pushparajah (1972) showed that RRIM 600 gave the highest yield in Holirood and Munchung series but its performance was inferior in Rengam series. Thus an understanding of the taxonomic unit would help in offering proper recommendation with respect to the clone to be planted. In view of this an environmax approach has been evolved in Malaysia, wherein clonal recommendations are made considering the constraints existing in a particular environment. A detailed account of the soil capability and clonal effects, soil-clone interaction and the environmax approach for rubber has been given by Watson (1989).

Response to nutrients

Though the need for manuring rubber has long been recognised this aspect has not received the required attention compared to other agricultural and commercial plantation crops. Nutritional studies on rubber received low priority as the crop was normally treated as a forest species.

Moreover, the initial plantations were on rich newly cleared forest soils. Nevertheless, manurial trials on rubber, started in the early 1900s in Malaysia and Indonesia confirmed good response of the tree to the application of fertilizers (Penders, 1940). The effect of various nutrient elements on the growth of Hevea was also established from the studies conducted in Malaysia (Bollejones, 1954). The mineral composition of Hevea was reported to be influenced by soil fertility status (Dijkman, 1951).

The trees immobilise substantial quantities of nutrients in the trunks, branches and roots of which about half get immobilised during the pre-tapping phase. During the immature phase the nutrient requirement is estimated to be much greater than the fertilizer input. For instance, the total nitrogen immobilised during the first six years is estimated to be 728 kg ha^{-1} which works out to be on an average 120 kg ha^{-1} yr^{-1}. However, the recommended level of nitrogen application is far below this. The deficit has to be met from nutrient reserves of the soil. The resultant nutrient depletion leaves the soil less fertile and this situation can be overcome only by ensuring establishment and maintenance of a luxurient leguminous ground cover which will gradually release substantial quantities of nutrients once the canopy of rubber closes. Full compensation of the nutrients immobilised by the growing trees may lead to the development of heavy crown rendering them vulnerable to the risk of wind damage. However, adoption of cultural practices such as branch induction could be beneficial to a certain extent (Watson, 1989).

Nutrition during immature phase

Most of the earlier studies were confined to the pre-tapping phase. Studies in Indonesia indicated that the effect of fertilizers was the highest in the pre-tapping stage and the trees attained tapping girth two to three years earlier with proper fertilizer application (Dijkman, 1951). Owen et al. (1957), reviewing the results of 17 trials conducted in Malaysia, found only negligible response to applied nitrogen during early immaturity phase and the response was evident from the sixth year only. On the other hand, hand, significant effect of phosphorus was obtained at fifth, sixth and seventh year after commencement of manuring programme. No significant response to potassium was obtained in most of the trials. The higher level of soil fertility in the newly created plantations could be the main reason for the lack of response in the early stage.

In the laterite soils of South West India, rubber plants respond positively in terms of girth increment to application of phosphatic fertilizers at lower levels. A positive benefit from nitrogen manuring also has been reported. However, no significant girth increase has been shown by the application of potassium alone. The pattern of response indicated a positive interaction between nitrogen and potassium (George, 1963). Results of multi-locational trials in India at pre-tapping stage revealed that the response to applied fertilizers during the first four years of immaturity is dependent on the initial soil fertility status (Ananth et al. 1966). However, lack of response to nutrients, particularly to nitrogen and phosphorus was reported from the fifth year onwards. This was attributed to the large quantities of nutrients released by the leguminous cover. Response of rubber to fertilizer application depends on the type of ground covers also (Potty et al. 1978).

The extent of response to fertilizers depends on the type of soil as well as the clone (Bolton, 1960b; Krishnakumar and Potty, 1989). On sandy latosols in Malaysia, marked response to soluble phosphatic fertilizers, and lower response to nitrogen were reported. The effect of potassium was not significant (Bolton, 1960b). Response of Hevea to potassium has been reported to be influenced by potassium status of the soil (Pushparajah and Guha, 1969). In the highly depeleted soils of North East India, Krishnakumar and Potty (1989) observed a marked increase in the girth of plants at higher levels of nitrogen, phosphorus and potassium.

Systematic application of fertilizers throughout the pre-tapping phase leads to build up of plant nutrient reserves. Application of phosphorus at the rate of 30 kg P_2O_5 ha^{-1} increased the soil phosphorus status from *0.47 mg 100 g^{-1} to 2.43 mg 100 g^{-1} and by further raising the level to* 60 kg P_2O_5 ha^{-1} soil phosphorus increased to 6.8 mg 100 g^{-1} over a period of nine years. The nutrient concentration in leaf also registered a corresponding increase. Application of rock phosphate at the rate of 30 and 60 kg P_2O_5 ha^{-1} raised the leaf values to 0.19 and 0.22% respectively from 0.15% in the control plot. Similarly, addition of muriate of potash helped in raising the available potassium level in soil to 5.94 mg 100 g^{-1} at 20 kg K_2O ha^{-1} and to 10.93 mg 100 g^{-1} at 40 kg K_2O ha^{-1} (Krishnakumar and Potty, 1990). Application of rock phosphate increased the available calcium in soil as well as the leaf calcium level (RRII, 1988).

During the early immature phase, the nutrient demand of Hevea has been found to vary with the type of planting material. For instance, application of higher doses of fertilizers was needed when polybag plants were used (Krishnakumar and Potty, 1989).

Mature phase

Loss of nutrients such as nitrogen, phosphorus, potassium and magnesium as a result of latex extraction is negligible. Major nutrients, nitrogen, phosphorus, potassium and magnesium have positive effect on rubber yield. This could be a direct effect or mediated through their effect on growth of bark, bark renewal etc (Samsidar et al. 1975; Pushparajah, 1969). Experiments in India (George, 1962) that application of nitrogen, phosphorus and potassium could substantially increase yield. Owen et al. (1957) however, found that nitrogen had no significant influence on yield during the first four years. There was, however, evidence of response to application of phosphorus, which influenced yield significantly during the first four years. In the red loam soils of South India, Punnoose et al. (1978) reported lack of any response to major nutrients applied from the fifth year of planting upto commencement of tapping except for a marginal increase obtained by increasing potassium from 50 to 100 kg ha^{-1}. Towards the later stage of tapping however, residual effect of potassium was noticed, which could be attributed to the minerology of soil permitting fixation of potassium. Presence of appreciable amount of illite in the clay minerals lock up potassium through fixation which gets released with progress of time and results in delayed response.

Philpot and Westgarth (1953) found beneficial effect of phosphorus and potassium on the stability of latex. The positive effect due to combination of phosphorus and potassium was ascribed to a more balanced Mg/P ratio in the latex. Ram Beaux and Danjard (1963) suggested application of potassium for reducing the Mg/P ratio. Addition of potassium in Terrarosa soils of Vietnam has increased the yield by decreasing the Mg/P ratio in clone Gl 1, which has high latex magnesium (Beaufils, 1954). According to Owens (1957) if proper initial management is given, especially with respect to optimum nutrition during the pretapping phase, plantations would continue to perform well even if a period of neglect sets in. Therefore, supply of nitrogen, phosphorus and potassium during pretapping phase is highly essential. The effect of phosphorus applied during immature phase continues to the early years of tapping, as reported by Haines and Crother (1940).

Nutrient requirement with stimulation

Application of yield stimulants such as 2,4-D and 2,4,5-T (De Jonge, 1955) and Ethrel (2-chloroethyl phosphonic acid) (Abraham et al. 1968; Abraham, 1970) results in higher yield and subsequently more drainage of nutrients through latex extracted. Pushparajah (1966) and Lustinec et al. (1967) reported higher levels of extraction of major nutrients as a consequence of stimulation. Stimulation also resulted in lower potassium levels in leaves (Puddy and Warriar, 1961). Pushparajah et al. (1972) found an increase in concentration of potassium removed per unit weight of rubber in stimulated trees. Application of stimulants was reported to affect concentration of calcium and pH of the serum as well. An increase in yield by 1150 kg on stimulation resulted in increased drainage of nitrogen, phosphorus, potassium and magnesium by 14, 5, 14 and 2 kg ha^{-1} respectively respectively in clone PB 86 (Pushparajah et al. 1972). In the experiment with 2,4,5-T, it was noticed that application of potassium had beneficial effect, but nitrogen gave a negative effect over a period of six months following stimulation. The study also revealed that, where the response to fertilizer under normal exploitation system was negligible, increase in fertilizer dose with Ethrel stimulation gave higher yield in clone GT 1. While Ethrel application in unfertilized plot gave an increase of 41% in yield, it gave 50% increase with application of nitrogen. The corresponding figures for clone LCB 1320 were 49 and 127% respectively. Potassium application also improved the response of GT 1 and LCB 1320. Similar results were obtained for magnesium also. Taking into consideration the nutrients immobilised in the tree, those removed through latex, leaching losses and depletion of soil reserves, it would be established that additional quantity of nutrients are required where stimulation is practiced (Pushparajah et al. 1972). A budget for nitrogen and potassium in the case of clone RRIM 600 is given in Table 1.

TABLE 1

Budget for nitrogen and potassium required by RRIM 600 in panel C.
Adapted from Pushparajah et al. (1972).

Soil series	Added as fertilizer		Deficit: Unstimulated		Deficit: Ethrel stimulated	
	N	K	N	K	N	K
Rengam (Typic Paleudult)	46	45	-15	-5	-75	-62
Holyrood (Oxic Dystropept)	36	41	-25	-9	-85	-66
Malacca (Plinthic Haplorthox)	51	39	-10	-11	-70	-68
Munchong (Tropeptic Haplorthox)	41	36	-20	-14	-80	-71

Nutrient interactions

A highly significant correlation between magnesium and manganese concentration in *Hevea* leaves was reported by Beaufils (1955) and Bollejones (1957). A higher level of magnesium induces manganese deficiency symptoms. A wide-spread magnesium deficiency has been reported from Malaysia. However, the case is not so under Indian conditions in spite of the highly acidic nature of soils. Increased supply of manganese also could reduce magnesium concentration as reported by Bollejones (1957). An enhanced manganese content not only influences magnesium status in *Hevea* laminae but also reduces soil pH and concentration of potassium ions. The close relationship between manganese and phosphorus in the mineral nutrition of rubber also has been reported by him. Bollejones (1954) had shown that increased magnesium supply resulted in an increase in the concentration of phosphorus in the leaf. Also, in the early stages of seedling development the growth seemed to be governed more by magnesium than by phosphorus.

Moisture relations

A low soil moisture level has been reported to reduce uptake of potassium and phosphorus and leads to absorption of more calcium and magnesium (Talha et al. 1979). In areas with long dry spell larger quantities of exchangeable potassium are required to be added to compensate for the deficiency of moisture (Paauw, 1978). Though natural rubber producing countries are mostly in the humid tropics, there are areas where long dry spells are encountered particularly in the non-traditional rubber growing regions in India. Gander and Tanner (1976) stated that when plants were under moisture stress, uptake of nutrients usually decreased and this was particularly the case with phosphorus, potassium, calcium and magnesium. Water relations govern yield of rubber. Ionic balance, especially of the cations, is known to play a significant role in the growth of rubber. Studies conducted on the influence of soil moisture on cation uptake revealed that application of higher levels of potassium helps in maintaining higher exchangeable potassium and magnesium content in the latex. During stress period, higher potassium application was found to maintain higher water potential, longer flow and thereby higher yield (Krishnakumar, 1989).

Fertilizer recommendations

Importance of regular manuring of rubber is evident from field experiments conducted in most of the rubber growing countries. In Malaysia soil classification upto series level has been attempted long back and therefore specific fertilizer recommendations have been evolved to suit different soil series. In other countries, information available from location specific fertilizer trials have formed the basis for evolving general fertilizer schedules. In India, Nair (1956) suggested a blanket recommendation based on the soil fertility status and the observations from the fertilizer trials on rubber conducted elsewhere. Simultaneously, multi-locational field trials were started to provide necessary information to revise the recommendations for rubber at different stages of growth. These experiments also revealed that response of rubber is directly related to soil available nutrients and leaf nutrient status (Ananth et al. 1966; Potty et al. 1976). A discriminatory approach was therefore proposed as the most efficient and economic method for optimum fertilizer usage.

A general outline of the fertilizer recommendation for rubber followed by Rubber Research Institute of India in the seedling nursery, budwood nursery, polybag nursery, immature phase and mature phase is given in Table 2. Through the fertilizer trials conducted at different agroclimatic regions and for different clones, this general fertilizer recommendation will be updated from time to time to suit the agroclimatic and soil conditions and the clonal characters.

For the north eastern India separate fertilizer recommendation was evolved by Krishnakumar and Potty (1989) considering the physico-chemical characteristics of the soil. Pushparajah and Low (1977) have given the detailed fertilizer schedule followed in Malaysia for immature rubber. Pushparajah (1983) compared the fertilizer recommendation for immature rubber between countries. In Malaysia based on the parent material, nature of the soil, clonal characters, management etc. modified fertilizer schedule was evolved separately for estate sector and small holders (Watson, 1989).

Method and time of fertilizer application

The application of fertilizer is to be undertaken taking into consideration the stage of growth of plant, ground cover management, soil, climatic factors and type of fertilizer. During the initial phase, growth is active and hence split applications are desirable. Similarly on soils of light texture also, higher frequency is warranted. The type of fertilizer also decides the method of application. In Malaysia split application is recommended in series with light textured soils and also in heavy textured soils with high rainfall (Pushparajah et al. 1974).

For mature rubber fertilizers are to be applied in rectangular or square patches in between four trees and are to be gently forked in. In slopy areas, where cover crop has not completely died out or wherever

TABLE 2

General fertilizer recommendations for rubber

Stage	Fertilizer (quantity and time)				
1. Seeedling nursery	Organic manure 2 tonnes ha^{-1} basally. 700 kg P_2O_5 ha^{-1} and rock phosphate as basal dressing. Rock phosphate needs to be applied once in three years if the bed is in continuous use. 10:10:4:1.5 NPKMg mixture 2.5 tonnes ha^{-1} as basal dose 6-8 weeks after planting. 550 kg ha^{-1} urea top dressing 6-8 weeks after basal dressing.				
2. Budwood nursery	30 g of P_2O_5 as rock phosphate basal dose 250 g $plant^{-1}$ 10:10:4:1.5 NPKMg mixture in two doses of 125 g each and from 2nd year onwards 125 g $plant^{-1}$ 2-3 months after cutting back.				
3. Polybag nursery	10:10:4:1.5 NPKMg mixture 10-30 g $plant^{-1}$ depending on the age.				
4. Immature rubber*		N	P_2O_5	K_2O	MgO
		($kg\ ha^{-1}$)			
	1st year	10	10(5)	4	1.5
	2nd year	40	40(20)	50	40.0
	3rd year	50	50	20	7.5
	4th year	40	40	16	6.0
5. Mature rubber		30	30	30	--

Figure in parentheses are the water solube form of phosphorus.

* From 5th year onwards the recommendation for mature rubber is followed in areas where good leguminous ground cover is maintained. If not 60:40:20 $N:P_2O_5:K_2O$ ha^{-1} is recommended.

** In Mg rich areas no MgO is recommended.

bench terracing is practised, broadcasting in inter-row space can be resorted to (Pushpadas and Ahmed, 1980). If the fertilizer mixture contains urea, it is essential that the mixture be forked in to prevent losses.

Fertilizers can also be applied as foliar sprays. Wherever a quick result is needed as for correcting a deficiency this method can be practised. Spraying urea, zinc sulphate, ammonium phosphate etc. under certain conditions yield good results.

Fertilizer has to be applied when the soil moisture is optimum. Periods of heavy rainfall and dry spells have to be avoided. In India the recommended time of manuring is during the premonsoon period, ie. April/May and postmonsoon period, ie. September.

Discriminatory fertilizer usage

The concept of discriminatory fertilizer recommendation envisages supply of adequate quantity of nutrients to the plants taking into consideration the nutrient reserves and the available nutrient content in the soil, plant nutrient status, site characteristics and other specific parameters. This practice has been widely accepted and extensively used in Malaysia (Chang and Teoh, 1982) and in India.

The differential response of *Hevea* to fertilizers has already been established based on long term field trials. The difference in response of rubber to fertilizer application among different soil types have also been observed (Silva, 1976). Hence, correlation of results of field experiments with data from soil and leaf analyses only would help to overcome this difficulty. Relationship between soil and leaf nutrient levels also has been confirmed by Owen (1953) and Lau et al. (1977). Critical soil nutrient content for *Hevea* in some soil series also has been reported by Guha (1969). Various improvisations in the diagnostic techniques of soil analysis paved the way for more authentic soil nutrient assessment methods (Singh and Talibudin, 1969; Singh, 1970). Soil analysis is influenced by many site specific factors that have to be accounted for before offering any fertilizer recommendation.

The assessment of nutrient requirement through leaf analysis was reported by Shorrocks (1961; 1962a,b; 1965a,b; Chapman, 1941; Beaufils, 1955). The analytical values, however, largely depend on sampling (Chang and Teoh, 1982). The critical leaf nutrient content for *Hevea* in shade leaves, as reported by Watson (1989), is reproduced in Table 3.

TABLE 3

Range of leaf nutrient content at optimum age in shade leaves (%)

Nutrient	Clonal group*	Low	Medium	High	Very high
N	1	<3.21	3.21-3.50	3.51-3.70	> 3.70
	2	<3.31	3.31-3.70	3.71-3.90	> 3.90
	3	<2.91	2.91-3.20	3.21-3.40	> 3.40
K	I	<1.26	1.26-1.50	1.51-1.65	> 1.65
	II	<1.36	1.36-1.65	1.66-1.85	> 1.85
P		<0.20	0.20-0.25	0.26-0.27	> 0.27
Mg		<0.21	0.21-0.25	0.26-0.29	> 0.29
Mn (ppm)		<45	45-150	> 150	

* For N: Group 1 clones are all clones except those in group 2 and 3.
Group 2 clones are RRIM 600 and GT 1.
Group 3 clones are all wind-susceptible clones.
eg. RRIM 501, RRIM 513, RRIM 605, RRIM 623, etc.

For K: Group I are all clones except those in group II.
Group II are RRIM 600, PB 86, PB 5/51.

Low: Well below optimum, tending to visual deficiency.

Medium : Suboptimal.

High and very high: Levels above which responses are unlikely.

Voluminous work has been conducted in Sri Lanka in refining the sampling of leaf and analytical methods (Silva, 1976). In India, leaf sampling season starts from August and extends upto October, for the routine analysis for offering fertilizer recommendations. The critical levels fixed for soil and leaf for discriminatory fertilizer recommendations are given in Table 4.

Watson (1989) has summarised the usefulness of leaf nutrient content as an indicator of fertilizer requirement. While dealing with commercial experience in the field of leaf analysis for diagonising nutritional requirement of Hevea, Chang and Teoh (1982) reported much variation in nutrient concentrations particularly for nitrogen and phosphorus, with age of the plant.

TABLE 4

Soil fertility standard and critical leaf nutrient levels.
(Adapted from Pushpadas and Ahmed, 1980).

Nutrient	Standard		
	Low	Medium	High
Soil			
Organic carbon (used as a measure of available nitrogen) (%)	<0.75	0.75-1.50	>1.50
Available phosphorus (mg 100 g^{-1})	<1.00	1.00-2.50	>2.50
Available potassium (mg 100 g^{-1})	<5.00	5.00-12.50	>12.50
Available magnesium (mg 100 g^{-1})	<1.00	1.00-2.50	>2.50
Leaf			
Nitrogen %	<3.00	3.00-3.50	>3.50
Phosphorus %	<0.20	0.20-0.25	>0.25
Potassium %	<1.00	1.00-1.50	>1.50
Magnesium %	<0.20	0.20-0.25	>0.25

Beaufils (1954, 1957) studied the possibility of using nutrient ratio in leaf and latex as a guide to evolve fertilizer recommendation. The work was mainly based on the studies in the rubber growing soils of Vietnam and Cambodia. This system was further studied under different situations (Fallows, 1961) and it was found that the Beaufils system was not readily applicable in Malaysia.

Role of mineral nutrients and deficiency symptoms

Hevea grows well on a wide variety of tropical soils and responds to any deficiency or excess of nutrients. The studies conducted by Bollejones (1954) and Shorrocks (1965) confirmed the essentiality of nutrients in the growth of rubber. The characteristic leaf deficiency symptoms shown by both rubber and cover plants are illustrated in the book 'Mineral Deficiencies in Hevea and Associated Cover Plants' (Shorrocks, 1964). Mineral deficiencies, apart from their influence on the growth of rubber plants and yield, have been reported to affect the ultrastructure and stability of latex (Gomez, 1978).

In India deficiency symptoms are generally observed for N, K and Mg. Micronutrient deficiencies are seldom encountered. Zinc deficiency symptoms are noticed in the seedling nursery plants and also in the early immature phase in the main field, quite often as a result of heavy application of phosphatic fertilizers. The symptoms of zinc deficiency are usually transient.

Nitrogen: The characteristic yellowing is first observed in the lower whorls and as the intensity of deficiency increases it affects the younger leaves. Symptom appears in sun leaves in mature plantations and results in overall retardation of growth.

Phosphorus: In seedlings the typical symptoms are yellowish-brown discolouration of the upper surface and purpling of the undersides of upper and middle leaves. Acute deficiency results in the laminae bending upwards and tips becoming scorched. Deficiency in the mature phase does not produce any visual symptoms, and is detected only by leaf analysis. It results in retardation of growth and affects stability of latex.

Potassium: Development of marginal and tip chlorosis followed by necrosis is the characteristic symptom of K deficiency. On young unbranched trees the symptoms will appear first on the older whorls of the plant. In mature plantations K deficiency is revealed by the appearance of a butter yellow colour over the canopy. Leaf size also will be reduced considerably.

Magnesium: The early stage of magnesium deficiency is a pale green interveinal mottling which changes into bright yellow and spreads towards the margin. In the case of severe deficiency, yellowing is often followed by *interveinal and marginal scorch of leaves (brown necrotic patches).* In the young unbranched trees the symptoms are usually seen in the lower storeys. In mature trees symptoms appear in fully exposed sun leaves.

Zinc: The leaves of the upper stories of the tree become reduced in breadth, relative to length, with wavy undulating margins. Chlorosis of the leaves also is noticed with the mid-rib and main veins remaining dark green in colour. In young unbranched trees, the symptoms are seen in the top storeys resulting in death of apical meristem and development of auxillary meristems.

Calcium: Deficiency of calcium is first manifested as a scorching of the tip or margin of leaf. Since the element is immobile in young trees, deficiency symptoms are first noticed in the younger leaves and under severe deficiency, the point may die back. The deficiency symptom is generally seen on shade leaves in mature trees. Calcium also plays an immense role in the stability and flow of latex.

Manganese: In sand culture, manganese deficiency causes the laminae of middle and upper whorls to develop a diffuse pale yellow green interveinal region. Veins remain markedly white but are surrounded by green strips of tissue and thus could be distinguished from the uniform pale green interveinal region (Bollejones, 1954). The deficiency symptoms in unbranched trees first appear in the lower leaves and could extend to all leaves in acute cases. The deficiency appears in the shaded leaves in the initial phase in mature trees but could spread to exposed branches (Watson, 1989).

Boron: Deficiency of boron in young plants appears with young leaves surrounding the growing point of the plants being killed and turning black at the tips. In the initial phase boron deficient plants showed a darker green foliage. Shedding of the youngest laminae before the expanded one accompanied by a pale yellow diffuse chlorosis of the topmost expanded laminae also were manifested when boron deficiency was induced in plants. In young plants, as a result of the deficiency, the terminal leaf whorls are produced without discrete internodes giving a bottle brush effect. Death of apical meristems have also been observed simultaneously leading to development of auxillary meristems.

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