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Chapter 11

Soils and nutrition

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1. INTRODUCTION

In the beginning rubber plantations were raised mostly in newly cleared forests, rich in plant nutrients. Over a period of time the situation changed. Newly-cleared forest areas became unavailable and rubber cultivation had to be taken up on denuded and less fertile crop lands. Even though removal of nutrients through crop is less in rubber compared to that in other crops, large quantities of nutrients get locked up in the biomass of the trees and are lost permanently from the soil system with the removal of timber at the time of replanting. Most of the plantations in India are now in the second or third replanting cycle (Krishnakumar and Potty, 1992; Karthikakuttyamma, 1997) and majority of these are to be replanted again with rubber. Therefore, to ensure optimum growth and yield and to protect sustainability of the system, maintenance of soil fertility through regular application of fertilizers is very important.

2. SOILS

2.1 Composition

The four major components of soil are inorganic or mineral materials, organic matter, water and air. The solid mineral particles comprise about 45 per cent of total soil volume and the organic matter, five per cent, the balance being pore spaces occupied by air and water. The proportion of air and water in soil is subject to rapid and wide fluctuations. At optimum moisture level for plant growth, the pore space is divided more or less equally between air and water.

The inorganic portion of soil, quite variable in size and composition, is composed of small rock fragments and mineral particles of various kinds and sizes. Rock fragments are comparatively larger in size. Some stone and gravel pieces may be as large as small rock fragments. Sands are somewhat smaller in size (0.02 - 2.0 mm diameter) and can be seen easily with naked eye. The sand particles do not stick together and feel gritty when rubbed between fingers. Still smaller in size are the silt particles (0.002 - 0.02 mm) which are powdery when dry and even when wet are not sticky. The smallest mineral particles are the clays (<0.002 mm) which form a sticky mass when wet and aggregate into hard clods when dry. The smallest clay particles have colloidal properties and can be seen only with the aid of an electron microscope. Clay acts as a storehouse for both water and nutrients.

Soil minerals are grouped into primary and secondary minerals. Primary minerals (quartz, micas, feldspars) are prominent in sand and silt fractions. The secondary minerals (silicate clays, iron oxides) tend to dominate in clays. X-ray diffraction pattern backed by differential thermal analysis data shows that the predominant clay mineral is kaolinite followed by degraded illite. Presence of degraded illite calls for attention since this will exert profound influence on potassium nutrition (Krishnakumar, 1989).

2.2 Physical properties

The important physical properties of soil which affect plant growth are texture, structure, depth and drainage. In general, physical properties are much more important, as they are not easily amenable to manipulations while most of the chemical properties can be corrected by the application of fertilizers and soil amendments.

2.2.1 Texture

Soil texture is a measure of the proportion of the different-sized particles in the soil. Terms such as sandy loam, silty clay, clay loam, *etc.* are used to denote soil texture.

A soil is termed clay if it contains 40 per cent or more of clay and sandy if it contains more than 70 per cent of sand. Loam has more or less even distribution of sand, silt and clay.

Rubber is found to grow on soils of varied texture but those with loamy texture are best-suited as they have average water holding and percolating capacities. Finer-textured subsoil can be useful in preventing leaching of nutrients and in retaining moisture at a suitable depth. Texture of the rubber growing soils in Kerala varies from sandy loam to clay, the predominant textural class being clay and sandy clay loam (Krishnakumar, 1989).

2.2.2 Structure

The arrangement of sand, silt and clay particles within the soil is termed as soil structure. Soil structure highly influences water and air movement in the soil. The soil particles are found together in aggregates. Arrangement, size and stability of the soil aggregates or peds are indicated through structure. These aggregates vary from granules to plates, prisms and columns. Granular or crumb structure is the most ideal for cultivation. In the tropics, maintenance of granular or crumb structure is difficult as the granules or crumbs on the surface breaks down owing to the impact of rain. The fine materials thus formed clog the larger pores forming a surface skin largely impermeable to water.

Structure is one of the soil properties which can be improved by management practices. In rubber plantations, maintenance of a good granular or crumb structure can be achieved by growing a protective leguminous cover crop. Organic matter added to the soil also aids in aggregate formation. Establishment of leguminous ground covers in rubber plantations helps aggregation of large size fractions like sand. The better aggregation compared to natural cover, is due to high microbial activity in the legume root rhizosphere. A relatively high rate of infiltration is also noticeable in soils under legume cover (Krishnakumar, 1989).

2.2.3 Depth

Soils for rubber cultivation should have a minimum depth of 1 m without any intervening hard pan or impenetrable layer. Water table should also be well below 1 m so that at least 1 m of soil with good aeration, essential for root penetration, is available. Good soil depth helps the plant to tide over drought season more efficiently as moisture stored in the lower depths will become available to the roots during drought situation. Yield of rubber is found to be very much reduced in shallow soils as compared to soils having adequate depth (Dijkman, 1951). Moreover, shallow soil or soil with high water table does not ensure proper anchorage of the tree which therefore becomes susceptible to wind damage by uprooting.

2.2.4 Drainage

Well-drained soils are essential for optimum growth and yield of rubber plants. In marshy areas, owing to poor physical properties and waterlogged condition, growth of rubber is always found to be very poor. Soil drainage is affected by topography, intensity and duration of rainfall, soil physical characteristics and ground cover condition. In rubber plantations on level land, drainage can be facilitated by providing open drains. In hilly areas, the ravines and depressions which form natural waterways can be utilized with the adoption of proper methods for reducing stream velocity. Drainage of excess water considerably improves the physical structure of waterlogged soils and ensures better aeration of soil. Tap roots penetrate deep into the soil while lateral roots spread into less deeper strata. Drainage ensures better anchorage because of the formation of well-developed root system. Absorption of water and nutrients depends on proper aeration of soil, which in turn is improved by good drainage. Drainage also increases activity of beneficial soil microflora.

2.3 Chemical properties

The important chemical properties of soils are soil reaction (pH), organic matter content and fertility status. The organic matter content and fertility status can be improved by proper management of the soil which include growing of leguminous cover crop, application of manures and fertilizers and adoption of soil and water conservation measures.

2.3.1 Soil reaction

The pH is a measure of acidity or alkalinity and is expressed on a 0 - 14 scale. A pH of seven indicates neutrality, while pH below seven indicates acidity and that above seven alkalinity. The optimal pH of soil for rubber cultivation lies in the range of 4.0 to 6.5 but the crop can tolerate a pH range of 3.8 to 8.0. Young seedlings tend to be more sensitive to low pH than mature trees. Soil pH above 8.0 causes growth retardation. Most of the soils in the humid tropics are acidic in reaction.

2.3.2 Organic matter

Soil contains an accumulation of partially disintegrated and decomposed plant and animal residues and other organic compounds synthesized by the soil microbes as decay occurs. Organic matter after decomposition, attains a more or less stable form called humus which is dark coloured, amorphous and colloidal in nature. Humus is very similar to clay in physico-chemical properties. It carries negative electric charges on its surface which attract and hold ions like potassium (K), calcium (Ca) and magnesium (Mg). Humus acts as a cementing material and assists greatly in granulating clay particles to form stable crumbs. It facilitates movement of water in the soil and improves aeration. The organic matter content of well-drained soils varies from 1.0 to 6.0 per cent and the level requires maintenance by regular application of plant and animal residues to soil. The capacity of the soil to retain moisture and nutrients is also increased by addition of organic matter.

2.3.3 Cation exchange capacity

Every soil has certain ability to hold cations on its negatively-charged sites. The total of all such sites (of both mineral and organic constituents) in a soil is known as its cation exchange capacity (CEC). It is expressed as C mol per kg (previously in milli-equivalents per 100 g of soil). The CEC can vary from less than 5.0 to 40.0 depending upon the amount and type of clay, the organic matter content and pH.

2.3.4 Fertility status

Soil fertility indicates the inherent capacity of a soil to supply plant nutrients. Nutrient needs of the rubber are less than those of other plantation crops like coffee, cocoa or oil palm. Rubber, therefore, can be grown on soils poor in nutrient content but of good physical properties. Any deficiency in the fertility can be supplemented by proper manuring and good agromanagement practices.

In general, the organic carbon (OC) status is high in the rubber growing soils due to the cultivation of leguminous cover crops in the immature phase and annual addition of leaf litter and other crop residues in the mature phase. Majority of the rubber growing soils are deficient in phosphorus (P) and potassium (K). The available P status is low due to the high P fixation in these soils. In general, the available K status is also low in most of the conventional rubber growing regions (Joseph *et al.*, 1990; Karthikakuttyamma *et al.*, 1991). The available magnesium (Mg) status is high in the northern districts of Kerala, Karnataka, Goa and Maharashtra regions and Kanyakumari district in Tamil Nadu and low in the southern districts of Kerala (Karthikakuttyamma *et al.*, 1991). In north-eastern India, OC status is low due to the traditional practice of shifting cultivation ('jhumming'). The P and K status ranges from low to medium and Mg status is high (Krishnakumar and Potty, 1989). Generally, in the acidic pH range, availability of micro-nutrients iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) will be more and the chances of deficiency, rare.

2.4 Soils under rubber in India

2.4.1 Soils of traditional areas

The rubber tree can grow on a wide range of soils. However, deep well-drained soils of pH below 6.5, free from underlying sheet rocks are best-suited. Soils under rubber, in general, have developed under warm humid equatorial monsoon or tropical wet and dry monsoon climates with variable duration of dry season extending from three to five months. The soils of the rubber tract in India are highly weathered and are mostly laterite and lateritic. Red and alluvial soils are also seen in some areas.

The major geological formations and their chronological succession are crystalline rocks of Archean age, sedimentary rocks of Tertiary age, laterites capping the crystalline and sedimentary rocks, and Recent and Subrecent sediments. The crystalline rocks chiefly comprise charnockites, khondalites, granites and gneissic granites and basic dykes. Charnockites are the most extensive and prominent rocks among the crystalline rock types of Kerala. Charnockites are encountered in the districts of Pathanamthitta (northern part), Kottayam, Ernakulam, Trichur, Palghat, Malappuram, Calicut, Wynad, Cannanore and Kasaragod. Khondalites occur in the southern parts of Kerala in the districts of Pathanamthitta, Quilon and Trivandrum and in Kanyakumari district of Tamil Nadu.

As per the recent studies, the majority of the soils in the traditional rubber growing tract are red ferruginous soils. The rubber growing soils of Kerala and Tamil Nadu have been characterized and 62 soil series identified and mapped. Out of the 62 soil series identified, 51 are under the order Ultisols, 9 under Inceptisols and 2 under Entisols (NBSS & LUP, 1999).

Laterite soils are formed under conditions of abundant rainfall and high temperature of the tropics and are characterized by the presence of a hard laterite horizon in the profile. Their subsurface layers are commonly red or yellow in colour due to the accumulation of free iron oxides. Lateritic soils have an underdeveloped laterite horizon. High amounts of iron and aluminium oxides present in these soils make P unavailable to plants. The presence of these oxides and the kaolinitic nature of clay impart good physical properties to these soils. Thus, though these soils are poor in plant nutrient contents, the physical condition of the soil is well suited for rubber cultivation. These soils are friable and have good aggregate stability which facilitate good aeration and free drainage. These soils are acidic in reaction with pH ranging from 4.5 to 6.0.

Red soils are derived from granite, gneiss and other allied rocks of micaceous type. They are less weathered when compared to laterite soils and the texture varies from loam to silty clay loam or clay loam. The cellular concretions of iron, characteristic of laterite soils, are absent in red soils. These soils are acidic (pH 5.0 to 6.5), deficient in organic matter and low in all the major plant nutrients but more fertile than laterite soils. Typical red soils are found in Kanyakumari district and part of Trivandrum district where rainfall is less intense. The physical properties of these soils are also well suited for cultivation of rubber.

Alluvial soils are the youngest geological formations and are laid down by materials carried through rivers. They are found in river banks, valleys and deltas. The rubber-cultivated area under this type of soil is limited.

Laterite is the main soil type found in South West Karnataka (Perur and Mithyantha, 1972). The soils of this region are formed from Dharwar schist of peninsular gneiss formed under high temperature and high rainfall conditions. They are old soils and are at the last stage of weathering. Surface soil (0 - 30 cm) generally indicates acidic reaction (pH 5.4) and medium OC content. Available P, K and Mg contents fall under low, medium and high ranges respectively.

2.4.2 Soils of non-traditional areas

Soils under rubber plantings in the non-traditional areas show wide variations in origin and physical and chemical characteristics. In some of the states in the north-eastern region, the soils have been studied in detail (Bhattacharya *et al.*, 1996) but a critical assessment in relation to rubber cultivation is lacking.

2.4.2.1 North-eastern region

Parent material of soils in Tripura is generally sedimentary in nature. Major soils under rubber in Tripura are Ultisols and Alfisols (Bhattacharya *et al.*, 1996). These soils are acidic in reaction (pH 4.5) and the OC content is low (0.72%). Available P, K and Mg contents in the surface layer are 0.32, 4.5 and 4.93 mg per 100 g soil respectively.

Soils under rubber in Assam are red soils of both laterized and non-laterized nature (Bora and Das, 1972). These soils are acidic in reaction (pH 4.6) and the OC content is 0.9 per cent. Available P, K and Mg contents of the surface layer are 0.27, 5.98 and 8.3 mg per 100 g soil respectively.

Non-laterized red soils are encountered in Meghalaya (Bora and Das, 1972). These soils are also acidic in reaction (pH 4.9) and the OC content is 0.98 per cent.

In Mizoram, the soils under experimental rubber cultivation are grey-coloured and derived from shales. These soils are loose and prone to landslides.

The soils in Nagarkata (West Bengal) region are formed mainly by deposits brought down by rivers from mountain regions of the Himalayas. These soils are relatively shallow, light textured and highly porous. They are highly acidic because of the leaching of bases.

2.4.2.2 Konkan region

Soils in the Konkan region (Dapchari, Maharashtra) are mainly laterites (Govindarajan and Rao, 1978). Other soils like non-lateritic and red to reddish brown soils are also encountered (Vaidya and Joshi, 1972). The soils are mainly derived from Basalt. In the surface layer, OC content is 1.71 per cent and the available nutrients P, K and Mg are 0.13, 10.0 and 7.5 mg per 100 g soil, respectively. At 30 to 60 cm the corresponding values are 1.66, trace, 10.0 and 9.13. In both the layers the pH is 5.9.

2.4.2.3 Eastern region

The main soil types encountered in Sukma (Madhya Pradesh) are red and yellow soils (Khanna and Motiramani, 1972). Parent materials are quartzite, sandstone and shales. The soil is acidic in reaction (pH 5.3) and low in OC content (0.53%). Available P, K and Mg are 0.20, 4.25 and 4.62 mg per 100 g soil respectively. These soils exhibit considerable shrinkage and cracking on drying.

Two types of laterites, namely, laterite murrum and laterite rock, are encountered in Dhenkanal (Orissa) area (Raychaudhari and Mukherjee, 1942). Major parent materials are sandstone and conglomerate (Sahu, 1972). The soil is acidic in reaction (pH 5.9) and the OC content is 1.7 per cent. Available P, K and Mg are 0.13, 10.0 and 7.5 mg per 100 g soil respectively.

2.5 Impact of rubber cultivation on soil properties

Soils under the third cycle of rubber planting and those in adjacent virgin forests did not reveal much difference in their morphological features. Soils from rubber plantation do not show any structural degradation or textural changes. However, the moisture holding capacity of forest soil is higher than that under rubber plantation (Karthikakuttyamma, 1997).

Rubber cultivation necessitates intense management of nutrients with every cycle of replanting. Though rubber plantation maintained high range of OC according to fertility standards, significant reduction occurs with replanting in OC content and total N and K. Compared to soils from virgin forests, soils under rubber show an increase in P level probably due to application of P and its slow utilization. The levels of cationic nutrients like K, Ca and Mg are comparatively lower in rubber soils. There is a decrease in soil pH and an increase in total Fe, Al and sesquioxides. The nutrient removal from rubber plantations is estimated to be 755, 833, 1260 and 945 kg per ha N, K, Ca and Mg respectively during every replanting cycle (Karthikakuttyamma, 1997).

3. PLANT NUTRITION

There are at least 16 elements which are essential for the growth and development of all plants. The essential elements are carbon (C), hydrogen (H), oxygen (O), nitrogen

(N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo) and chlorine (Cl). The nutrients which are required in large amounts are called primary, major or macro-nutrients and those required in small amounts are called micronutrients or minor elements or trace elements. Primary elements are N, P and K which are mainly supplied through fertilizers and secondary elements are S, Ca and Mg. In addition to these essential elements, sodium (Na), silicon (Si) and cobalt (Co) have been identified as beneficial elements. These beneficial elements, even though not essential, are found to stimulate growth in certain plant species, under certain conditions.

Plants obtain C, H and O from air and water and the rest of the nutrients from soils, fertilizers and manures. Nitrogen from the air is fixed by legume plants through the symbiotic association with bacteria colonized in their root nodules. Carbon and O from the air enter the leaves as carbon dioxide (CO_2) and major portion of H is obtained from water. The essential nutrient elements and the forms in which they are absorbed by plants are given in Table 1.

Table 1. Essential elements, their ionic forms for plant absorption and concentration in plant dry matter

Element	Ionic form	Approximate concentration
Nitrogen	NO_3^-, NH_4^+	Trace - 5.0%
Phosphorus	$H_2PO_4^-$, HPO_4^{2-}	0.1 - 0.4%
Potassium	K^+	1.0 - 5.0%
Calcium	Ca^{2+}	0.2 - 1.0%
Magnesium	Mg^{2+}	0.1 - 0.4%
Sulphur	SO_4^{2-}	0.1 - 0.4%
Iron	Fe^{2+}	50 - 250 ppm
Manganese	Mn^{2+}	20 - 500 ppm
Zinc	Zn^{2+}	25 - 150 ppm
Copper	Cu^{2+}	5 - 20 ppm
Boron	$H_2BO_3^-$, H_3BO_3	6 - 60 ppm
Molybdenum	MoO_4^{2-}	below 1.0 ppm
Chlorine	Cl^-	0.2 - 2.0%

3.1 Nutrients and their deficiency symptoms

Using the very simple raw materials like carbon dioxide, air and water and energy from sunlight, plants produce a variety of compounds like carbohydrates, proteins, fats, vitamins, essential oil, rubber, medicines, fibers, *etc.* Carbon, H and O make up 94 per cent of a plants' dry matter and all the other elements add up to 6.0 per cent. Nitrogen, P and S are constituents of proteins and nucleic acids. Other mineral elements such as Mg and micronutrients are constituents of organic structures, mainly of enzyme molecules, where they are directly or indirectly involved in the catalytic function of the enzyme. Potassium and Cl are the only mineral nutrients that are not constituents of organic molecules in plants. They function mainly in osmoregulation, maintenance of electrochemical equilibria in cells and regulation of enzyme activities.

3.1.1 Nitrogen

Nitrogen is a constituent of chlorophyll and all proteins. Being the building blocks of proteins, it is required for vigorous growth. Plants deficient in N are stunted in growth and leaves become yellow in colour (Plate 23. a). The yellow colouring first appear on older leaves and in the case of severe deficiency, leaves turn brown and fall off. Rubber yield gets reduced.

In young unbranched trees the symptoms are first observed in older leaves in the lower storeys and when the deficiency becomes severe, upper storeys are also affected. In mature trees, as a result of retarded growth, the crown becomes small and the deficiency symptoms are seen mostly on leaves exposed to the sun.

3.1.2 Phosphorus

Phosphorus is involved in energy transfer in plant metabolism and is termed as the energy currency in plant system. Phosphorus is essential for growth, cell division, root growth and seed and fruit development. It is a constituent of several compounds like nucleic acids, phytin, oils and fats. The deficiency of P retards shoot growth and root development and also delays fruit ripening. The deficiency symptoms usually start on older leaves. A bluish-green to red colour develops which in severe cases of deficiency changes to bronze or red colour (Plate 23. b).

In rubber, P deficiency is seldom manifested in the field. Deficiency can be confirmed only by leaf analysis. Bronzing on the underside of the leaf and die-back of the leaf tip are the specific deficiency symptoms. In young unbranched trees, the symptoms are first found in leaves in the middle and upper storeys and considerable defoliation may also occur.

3.1.3 Potassium

Potassium is the most abundant cation in the cytoplasm and is required for pH stabilization and osmoregulation. Potassium is involved in the water regulation of the plants and is required for enzyme activation and membrane transport process. There are about 50 enzymes which depend on or are stimulated by K.

Yellowing or chlorosis of the margin and tip of the leaves followed by necrosis is the characteristic symptoms of K deficiency (Plate 23. c). On young unbranched trees, the symptom appears first on the older flushes of leaves, and extends to the mid-storeys in advanced stages of deficiency. In old branched trees, the symptom appears on leaves exposed to sunlight. In mature plantation, K deficiency is revealed by the appearance of butter yellow colour all over the canopy. The yellow colour may not be clearly visible from inside the plantation. Leaf size is reduced considerably. The symptoms seldom appear before August.

3.1.4 Calcium

A high proportion of Ca in plant tissue is located in cell walls and has essential structural functions in the regulation of membrane permeability and strengthening of cell walls. It is involved in cell division, growth, root lengthening and activation of enzymes. Calcium deficiency is seen first on growing tips and the young leaves. Root growth is hindered under Ca deficiency .

In rubber, the first symptom of Ca deficiency is the development of tip or marginal scorch, usually white to slightly brownish (Plate 23. d). In young unbranched trees, symptoms usually appear on upper storey or younger leaves, and in severe cases die-back may occur. In mature trees, deficiency symptoms are expressed on shade leaves in lower canopy and not on leaves exposed to full sunlight.

3.1.5 Magnesium

Magnesium occupies the central position of chlorophyll and hence it is vital for photosynthesis. Magnesium aids in the formation of sugars, proteins, oils and fats. It is specific activator of several enzymes. In rubber, high levels of Mg in latex results in latex instability. The balance between Mg and P in latex is important and an optimal Mg : P ratio of 0.7 to 1.3 has been suggested for latex.

The early stages of Mg deficiency is a pale green mottling in between the lateral veins which changes into bright yellow and spread towards the margins often giving a herringbone pattern (Plate 24. a). In the case of severe deficiency, yellowing is often followed by interveinal and marginal scorch (brown necrotic patches) of leaves. When the deficiency is extremely severe, there may be considerable defoliation and marked reduction in tree girth and leaf size.

In young unbranched trees, the symptoms are usually seen on older or lower storeys of leaves. In mature trees, the symptoms usually appear in leaves exposed to full sunlight. Usually Mg deficiency symptoms are manifested in highly-leached sandy soil low in Mg, in clones with high Mg requirement and in areas with high N and K application.

3.1.6 Sulphur

Sulphur is a constituent of amino acids, cystine and methionine and hence essential for the synthesis of proteins. Sulphur is involved in the formation of chlorophyll and activation of several enzymes. It is a part of the vitamins biotin and thiamin.

Sulphur deficiency symptoms in many ways resemble those of N. It starts with the appearance of pale yellow or light green leaves. This is followed by reduction in leaf size, resulting in the cupping of the leaf (Plate 24. b). Unlike N deficiency, S deficiency symptoms appear first on the younger leaves and are present even after N application. Plants deficient in S are small and spindly with short and slender stalks and growth becomes retarded.

3.1.7 Micronutrients

The micronutrients include elements like Zn, B, Mn, Mo, Cu, Fe, *etc.* Among these, Zn deficiency alone is reported occasionally.

3.1.7.1 Zinc

Zinc is directly or indirectly required by several enzyme systems and involved in protein and auxin synthesis and seed production.

Zinc deficiency is commonly reported in the case of young plants in the nursery or in the main field. The characteristic symptom is that the leaf lamina becomes very much reduced in breadth relative to its length (Plate 24. c). Frequently, the laminae become twisted and the margins appear wavy or undulating. There is also a general yellowing of the leaf with the midrib and main veins remaining dark green in colour.

In young unbranched trees the symptoms are found on top storeys. Death of apical meristem occurs under conditions of severe Zn deficiency and side shoots may develop from axillary meristems. In old branched trees, deficiency may be detected on the basis of analysis of leaves exposed to full sunlight.

3.1.7.2 Boron

Boron is required for important functions like cell differentiation and development, germination and growth of pollen grains, translocation of sugars, lignin synthesis, *etc.* in plants.

Boron-deficient leaves are distorted and reduced in size and somewhat brittle. There is no loss of colour (Plate 24. d). In young unbranched trees, the first sign of boron deficiency is found in the younger, upper storeys on the plant. The individual storeys cannot be distinguished because of the absence of distinct internodes, giving a bottle-brush appearance. In mature trees, deficiency may be detected by analysis of leaves in the shade.

In India, deficiency symptoms are commonly observed for N, P, K and Mg. Calcium and S deficiencies are very rare. Among micronutrients, only Zn deficiency is manifested in nurseries where rock phosphate has been added continuously. Zinc deficiency symptoms have also been reported in field plantings of two to three years age from North Kerala and Karnataka where pH of the soil is high. The deficiency is transient and gets corrected in due course when the root system gets ramified.

3.2 Nutrient management

In the immature phase of rubber, proper manuring is essential for good growth and early tappability. In general, the soils under rubber are found to be rich in organic matter. Leguminous cover crops normally established in the immature phase of rubber, add about 6 t of organic matter and 230 to 350 kg of fixed N per ha (Watson, 1957; Kothandaraman *et al.*, 1989). In mature rubber, approximately 6 t of dry matter per ha is added every year through annual leaf fall, the range being 2.9 to 7.7 t (Shorrocks, 1965) and is comparable to 8.3 t under forests (Sivanadayan and Moris, 1992). The slow pace of oxidation inside the closed canopy of rubber plantation helps to maintain high organic matter status. The cultural operations with nearly zero tillage favour stabilization of organic matter at a high level (Krishnakumar and Potty, 1992). Though continuous growing of rubber reduces OC status, compared to adjacent natural forest, the plantations still maintain high range of OC (Karthikakuttyamma, 1997). In poor soils, girth and girth increment of rubber show positive response to N and P fertilizer application (Punnoose *et al.*, 1976).

Good management in the immature phase of rubber plantation improves the soil fertility status and reduces the fertilizer requirement in the mature phase especially in the initial years of tapping (Punnoose *et al.*, 1976). However, the response to applied fertilizers in mature rubber through yield increase, is little or difficult to establish and differ widely with the nature of the soil and agromanagement practices (Pushpadas *et al.*, 1973; 1978).

The current approach for nutrient management is to monitor leaf nutrient status and follow discriminatory fertilizer recommendations. The combination of soil testing and leaf analysis provides a better basis for offering fertilizer recommendation than resorting to one method alone.

Nutrients influence flow and properties of latex. The concentration of Mg in the latex is inversely related to latex stability and considerable variations in Mg content between clones have been reported. High P content and low Mg/P and (Mg + Ca)/P ratios are associated with good latex stability. High Mg in latex leads to poor latex stability resulting in precoagulation on the tapping cut leading to reduction in latex flow and yield (Shorrocks, 1964).

3.2.1 Soil testing

Soil testing is a comparatively rapid and inexpensive procedure for obtaining information on nutrient availability in soils. Various methods are adopted for determining availability such as the estimation of individual nutrients through various extractants or solvents like dilute acids or alkalies. One of the serious limitations of soil testing is that it fails to give information on the rate at which the nutrients become available to plants. Routine soil testing does not take into account the availability of organic forms of nutrients. Occasionally soil analysis may reflect poor status of nutrients in the soil while the plant may be well supplied with these nutrients, as a result of the influence of past manuring. In routine soil testing, pH, OC, available P, K, and Mg are estimated. Organic carbon is estimated as a measure of the nitrogen status of the soil (Jackson, 1973).

3.2.1.1 Soil sampling

It is important that the soil samples collected should be a true representative of the area. Samples should be collected only after two to three months of manuring. If there is uniformity in the nature of the soil, lie of the land, manurial history, age of the trees and growth of rubber and cover crop, two composite samples of soil from 0 to 30 and 30 to 60 cm depths would be adequate for an area up to 20 ha.

For collecting soil samples, 5 to 20 spots (depending on the total area to be sampled) are selected at random and 60 cm deep pits are dug (Plate 25. a). In slopes, care has to be taken to locate more pits along the slopes where variations in soil properties are likely to occur. Road margins, labour line sites, areas close to cattle shed or compost pile, old bunds, marshy spots, vicinity of trees or stumps or other non-representative locations are to be avoided. After removing the surface litter and mulch, a thin vertical section of soil is cut from the top to a depth of 30 cm using a sharp-edged tool such as chisel (Plate 25. b). Another cut at a depth of 30 to 60 cm (Plate 25. c) may be made and pool all samples of 0 to 30 cm and 30 to 60 cm separately. If the composite sample is large, reduce the quantity by quartering. For quartering, the well-mixed soil is spread into a thin layered square on a polythene sheet or paper and divided into four equal squares. The soil in the diagonally opposite squares is discarded (Plate 25. d) and the process is repeated until about 250 to 500 g of soil is obtained. The samples are dried in shade and packed in clean cloth bags. Manure contaminated gunny or alkathene bags should not be used. Each sample is properly labelled giving details of block sampled, depth of sampling and the label is kept in the bag. Pencil or ball point pen shall be used for labelling.

3.2.2 Plant analysis

Plant analysis is based on the principle that plant behaviour is related to the concentration of nutrient in the tissues. Leaf is the seat of active growth process and in perennial crops, leaf analysis is the most accepted procedure for assessing the nutritional status. Leaf samples are analysed for total N, P, K, Ca and Mg. A known quantity of powdered leaf sample is digested and from the digest, N is estimated following Kjeldahls' procedure (Karthikakuttyamma, 1989). A known quantity of powdered leaf sample is ashed in muffle furnace and acid extracted. From the extract, P is estimated by colorimetry, K by flame photometry, Ca and Mg by atomic absorption spectrophotometry. Leaf analytical values give information on the total quantity of each nutrient in the leaf and the balance among different nutrients. The concentration of leaf nutrient is affected by the sampling technique, time of sampling, age and position of the leaf, *etc*. In rubber, the leaf nutrient content varies significantly depending on the position in the canopy, age of the leaf, season and the clone (Shorrocks, 1965; Abraham *et al*., 1997).

3.2.2.1 Leaf sampling

Leaf samples are collected from August to October. During this period leaves would be six to eight months old. However, recent studies have revealed that the leaf sampling period can be 220 to 310 days after the leaf emergence (Abraham *et al*., 1997). Depending on the area to be sampled, 10 to 30 trees are selected at random (10 trees up to 5 ha, 30 trees for 20 ha and proportionate number of trees for areas between 5 and 20 ha). In the case of branched immature trees and trees under tapping, four basal leaves are collected from the terminal whorl of low branches in shade from each of the selected tree (Plate 26. a-c). New flushes and leaves infected by *Oidium* and other diseases are unsuitable for sampling. Leaves formed after the onset of southwest monsoon are also not suitable. In the case of unbranched young trees, plants without new flushes are chosen and four basal leaves from the topmost whorl are collected. Leaflets are detached from the petiole using a sharp knife or blade. If 30 trees are selected, only the middle leaflet from each leaf is taken. If 15, the two leaflets on either side and if 10, all the three leaflets are collected. About 120 leaflets should be available in one composite sample (Plate 26. d).

The leaf samples shall reach the laboratory within 24 h. If this is not possible, the samples shall be packed and kept in a refrigerator and brought the next day itself. Alternatively, each leaflet can be pressed on the upper side with hot iron, at the cotton range, and brought to the laboratory at the earliest possible (Krishnakumari *et al*., 1978). Case history in the prescribed proforma of the area represented shall accompany each sample.

3.2.3 When to undertake soil and leaf analyses?

3.2.3.1 In field plantings

Soil may be analysed before starting rubber cultivation to ascertain soil fertility and the fertilizer schedule to be adopted during the initial four years can be determined. However, if at any stage during the first three years of immaturity the growth of plants is found to be unsatisfactory and some nutritional problems are suspected, leaf samples may be collected and analysed for ascertaining whether any change in the manuring schedule is necessary.

During the fourth year of the planting, soil and leaf samples may be analysed and fertilizer recommendation for the fifth year obtained. Subsequently, leaf sample may be analysed every year. Soil samples need be analysed only once in three years.

In plantations, where soil and leaf analyses are not regularly carried out and problems like wind damage, panel coagulation or late dripping arise, it is appropriate to adopt discriminatory fertilizer use immediately.

3.2.3.2 In seedling and budwood nurseries

Before the establishment of nursery, soil may be analysed for assessing nutrient status and to determine the fertilizer schedule to be adopted initially. Subsequently, in the case of seedling nursery, composite soil samples may be drawn every alternate year from the nursery beds after removal of plants from the nursery, for determining the fertilizer schedule for the ensuing years.

In the case of budwood nursery, analysis of soil for determining fertilizer schedule need be done only once in three or four years. If the growth of the plants in the nursery is unsatisfactory and nutrient deficiency or imbalance is suspected, leaf samples may be collected from such plants and analysed. Samples may be collected from seedling nursery at the time of budding and from budwood nursery eight months after cutting back.

3.2.4 Integrated approaches

Integrated nutrient management approach aims at achieving optimum performance of crops by providing adequate supply of nutrients as well as maintenance of proper balance among the nutrients and has become popular among rubber growers.

3.2.4.1 Discriminatory fertilizer usage

Manuring after assessing the nutritional requirements of plants is referred to as discriminatory fertilizer usage. In laboratories, this is accomplished by soil/leaf analysis data and case history of the area. Discriminatory fertilizer usage has many advantages compared to general fertilizer recommendation. Very often adoption of this method results in saving of fertilizers and ensures optimum growth and yield. Adequate supply of nutrients and maintenance of proper balance in the ratio of different nutrients are important. Only leaf analysis can help in correcting any deficiency or imbalance in the nutrient status of the rubber tree. The method also minimizes or corrects problems like wind damage, panel coagulation and late dripping. It improves the quality of the latex by preventing precoagulation of field latex and reduces instability of preserved latex that occur mainly due to high Mg content or improper ratio of Mg to P.

Discriminatory fertilizer usage helps in making different fertilizer prescriptions to suit variations in clones, exploitation systems, soil conditions, *etc.* In some parts of Palghat district, Konkan area of Maharashtra and the Andaman and Nicobar Islands, the soil has neutral to alkaline reaction. Under such situations, fertilizers containing calcium can be avoided and a higher dose of K than recommended for other areas is warranted. In these areas, use of rock phosphate can be avoided and soluble phosphatic fertilizers like ammonium phosphate (20 - 20) can be given. These discriminations are possible only on the basis of soil and leaf analyses.

3.2.4.2 DRIS

For further improvement of the foliar diagnosis, the Diagnosis and Recommendation Integrated System (DRIS) approach developed by Beaufils (1973), is being attempted. DRIS is a comprehensive system which involves calibration of plant tissue composition, environmental parameters and management practices as a function of plant performance, yield and quality. By identifying the nutrients limiting crop production, the crop yield can be increased by refined fertilizer recommendation. The advantages of the DRIS approach are found in its ability to rank the nutrient elements in their order of limiting importance on productivity, on accurate assessment of nutrient balance and on making valid diagnoses over a wide range of tissue ages which are not possible when the conventional approach is followed (Walworth and Sumner, 1987; Sumner, 1990).

3.3 Fertilizers

Fertilizer is any carrier containing one or more plant nutrients. It may be a mined or manufactured material containing one or more essential plant nutrients, in an available form. Over 20 fertilizers are produced and used in India. They are solid materials in powder, prilled or granular forms.

3.3.1 Types of fertilizers

Fertilizers can be classified based on their nutrient supplying capacity and specific characteristics (Kanwar, 1976; Tisdale *et al.*, 1985; Tandon, 1994) into different groups. In addition, there are a large number of physical mixtures, micronutrient products and their formulations. Multinutrient fertilizers can be either complex fertilizers or physical mixtures.

3.3.1.1 Nitrogenous fertilizers

The common nitrogenous fertilizers are ammoniacal (ammonium sulphate, ammonium chloride and ammonium phosphate), nitrate (sodium nitrate, calcium nitrate and nitrophosphate), amide (like urea) and slow release forms (urea-formaldehyde and oxamide), those containing ammonium and nitrate ions (ammonium nitrate and calcium ammonium nitrate) and solutions of N (like unhydrous ammonia and aqueous ammonia).

3.3.1.1.1 Urea

Urea is the most commonly-used nitrogenous fertilizer in rubber plantations. Urea (NH_2 CO NH_2) is a white crystalline substance containing about 46 per cent N. The N content of urea is higher than that of any other solid nitrogenous fertilizer. It is manufactured by the reaction of anhydrous ammonia and carbon dioxide under very high pressure. Urea is water soluble and undergoes hydrolysis in soil under field conditions. In soil, it is initially converted to ammonium carbonate and then to nitrate. Being a concentrated fertilizer, transportation and storage cost per unit of N for urea are considerably less than that of ammonium sulphate or other solid N fertilizers. Another advantage of the use of urea as a N fertilizer is that it can be used as a spray for foliar application. A 0.5 to 3.0 per cent solution of urea can be used for foliar application.

Urea when mixed with soil, dissolves quickly in the soil water and ammonium ions are liberated. The ammonium ions(NH_4^+) can be held in the exchange sites, absorbed by plant roots or converted into nitrate (NO_3^-). The nitrate thus produced is weakly held in the soil. It is available for absorption by roots, but can also be lost by leaching.

3.3.1.1.2 Ammonium sulphate

Ammonium sulphate is quick acting and contains 20.6 per cent N. On application to the soil it reacts with soil colloids, thereby replacing bases chiefly Ca from the exchange complex. Ammonium sulphate dissolves in water and ammonium (NH_4^+) and sulphate (SO_4^-) ions are formed. It is an acid forming fertilizer. In spite of the high solubility, the fertilizer is not lost in leaching because of the absorption of ammonium by soil colloids and slow release through nitrification.

3.3.1.1.3 Ammonium chloride

Ammonium chloride is a white crystalline fertilizer containing 25 per cent N. It is obtained as a by-product in the ash industry and hence comparatively cheap. On application to soil, ammonium chloride releases ammonium and chloride ions. Ammonium chloride removes Ca from the soil as calcium chloride and thus tends to create residual acidity equivalent to that of ammonium sulphate application.

3.3.1.1.4 Calcium ammonium nitrate

Calcium ammonium nitrate (CAN) is a neutral fertilizer that contains 25 per cent N of which half is nitrate nitrogen and the other half ammoniacal nitrogen. Ammonium nitrate during its manufacture is mixed with limestone to produce granular calcium ammonium nitrate. It cannot be mixed with lime, basic slag, cyanamide, *etc.* as N will be lost in the form of ammonia.

3.3.1.2 Phosphatic fertilizers

Phosphatic fertilizers are classified into water-soluble P fertilizers (super phosphate : 16 - 20% P_2O_5; concentrated super phosphate : 40 - 48% P_2O_5; monoammonium phosphate : 48% P_2O_5 and diammonium phosphate : 46% P_2O_5), citrate soluble P fertilizers (dicalcium phosphate : 35 - 40% P_2O_5 and basic slag : 3.0 - 5.0% P_2O_5) and insoluble P fertilizers (rock phosphate : 20 - 30% P_2O_5 and bonemeal : 18 - 20% P_2O_5). The available P_2O_5 includes water soluble and citrate soluble P_2O_5.

Water-soluble phosphates when added to soil, quickly dissolve in the soil water. As soon as the fertilizer dissolves, oxides of Al, Fe and carbonates of Ca and Mg binds the P and forms sparingly soluble compounds. Phosphatic fertilizers commonly-used in rubber plantations are super phosphate, ammonium phosphate and rock phosphate.

3.3.1.2.1 Super phosphate

Ordinary grades of super phosphate which contain 16 to 20 per cent water-soluble P_2O_5 are made by treating rock phosphate containing insoluble tricalcium phosphate with sulphuric acid. A large portion of the phosphate is thus changed into water-soluble mono-calcium form. Super phosphate is a grey ash-like powder and should be stored in moisture-proof godowns to prevent conversion of monocalcium phosphate to dicalcium or tri-calcium forms.

3.3.1.2.2 Ammonium phosphate

Two types of ammonium phosphates are available. Monoammonium phosphate (11% N and 48% P_2O_5) and diammonium phosphate (18% N and 46% P_2O_5). Both grades are manufactured by reaction of sulphuric acid on rock phosphate to produce phosphoric acid and reaction of phosphoric acid with ammonia.

Ammonium phosphate is water soluble, grey in colour and least hygroscopic, with excellent storage qualities. It supplies both N and P and is used in preparing fertilizer mixtures.

3.3.1.2.3 Rock phosphate

Rock phosphate consists largely of tricalcium phosphate ($Ca_3(PO_4)_2$). The total P content ranges from 18 to 30 per cent. The common forms are chlor, fluor and carbonate apatites. They are water insoluble and the P becomes slowly available to plants on acid soils with pH less than 6.0. The availability of P in these phosphate rocks are measured as citric solubility and can vary depending upon origin of the rock and fineness on grinding. In India, there are different deposits and the commonly available rock phosphates for direct application are Mussoorie rock phosphate (Uttar Pradesh), Rajphos (Rajasthan), Maton rock phosphate (Rajasthan) and Megaphos (Madhya Pradesh). These indigenous sources contain 18 to 20 per cent P_2O_5. Imported rock phosphates containing higher content of P_2O_5 (29.0%) are also available. Rock phosphates are the most commonly-used P fertilizer in rubber plantations as the soil is acidic. The chances of P fixation can be reduced by the use of these water insoluble phosphates. The slow availability is advantageous because of the perennial nature of the crop. It is cheaper compared to other P sources.

3.3.1.2.4 Bonemeal

Bonemeal contains 18 – 20 per cent of P_2O_5 and is slow acting. It contains three per cent N also. In combination with ammonium sulphate or green manure, it is more effective. Bonemeal gives best results in acid soils since its P is rendered soluble by the acidity and made available to the plants. Being costly, it is not used commonly in rubber plantations. Nevertheless, it is used for the preparation of ready mixtures of concentrated organic manures.

3.3.1.3 Potassium fertilizers

The two K fertilizers are muriate of potash (MOP) and sulphate of potash (SOP). Both are imported and the former is the commonly-used K fertilizer. The K fertilizers are readily soluble in water. The K^+ ions in solution, are held on the clay complex as an exchangeable cation, absorbed by roots, fixed by clay particles or lost by leaching.

3.3.1.3.1 Muriate of potash

Muriate of potash (potassium chloride) contains 60 per cent K_2O. Its composition on elemental basis is about 50 per cent K and 50 per cent Cl. The colour ranges from white to pink. Ninety nine per cent of potash used in India is in the form of MOP.

3.3.1.3.2 Sulphate of potash

Sulphate of potash (potassium sulphate) contains 50 per cent K_2O and 18 per cent S. SOP has excellent physical properties and stores well even in damp conditions. The SOP has a low salt index, does not add to the salinity and is also chloride-free.

3.3.1.4 Magnesium fertilizers

Magnesium is mainly supplied through commercial magnesium sulphate (Epsom salt, $MgSO_4.7H_2O$) containing 16.0 per cent MgO and 13 per cent S both in readily available form. Magnesite ($MgCO_3$) which contains about 35 to 40 per cent MgO is also used in rubber plantations. Magnesite is ideal for the preparation of mixtures containing urea. Dolomite is another source of Mg which is a double carbonate of Ca and Mg. It contains 12 per cent Mg.

3.3.1.5 Micronutrient fertilizers

3.3.1.5.1 Zinc sulphate

Two grades are available, the heptahydrate form having 21 per cent Zn and the monohydrate form, having 33 per cent Zn. The heptahydrate form is more commonly used.

3.3.1.6 Fertilizer mixtures

Fertilizer mixtures are physical mixtures, made by simple mixing of straight fertilizers to get a mixture of a particular grade or ratio. A fertilizer grade refers to the guaranteed minimum percentages of N, P_2O_5 and K_2O present in a fertilizer mixture. Physical mixtures in powder form do not have uniformity in composition within a bag or a lot because their ingredients are not bound together and can separate out due to differences in size, weight and density. Usually fillers or make-weight materials are added to a mixed fertilizer to make up the difference between the weight of the added ingredients required to supply the plant nutrients in a particular quantity of a given analysis or ratio.

The fertilizer mixtures generally recommended in rubber plantations for the various stages of growth under different locations are 10-10-4-1.5 NPKMg and 12-12-6, 15-10-6, 10-10-10 and 12-12-12 NPK mixtures. The quantity of straight fertilizers in different fertilizer mixtures is given in Table 2.

Table 2. Composition of different fertilizer mixtures

Mixture	Quantity of straight fertilizers (kg)					
	Urea	AP	RP	MOP	Mg	Filler
15-10-6 NPK	33.0	—	50.0	10.0	—	7.0
10-10-10 NPK	22.0	—	50.0	17.0	—	11.0
12-12-12 NPK	26.0	—	54.0	20.0	—	—
10-10-4-1.5 NPKMg	22.0	—	50.0	7.0	4.0	17.0
10-10(5)*-4-1.5 NPKMg	11.0	25.0	25.0	7.0	4.0	28.0
12-12-6 NPK	26.0	—	60.0	10.0	—	4.0
12-12(6)*-6 NPK	13.0	30.0	30.0	10.0	—	17.0

* 50% water-soluble P through AP

AP - Ammonium phosphate (20-20 N, P_2O_5) RP - Rock phosphate (20% P_2O_5)
MOP- Muriate of potash (60% K_2O) Mg - Magnesium sulphate (16% MgO)

3.3.1.7 Complex fertilizers

In a complex fertilizer, materials containing different nutrients are reacted in the factory and processed into granular form. The granulated formulations in interntional trade consist of compound fertilizers manufactured by chemical reaction. Hot liquid ammonium nitrate is mixed with dry-powdered rock phosphate, potassium chloride and kieserite to produce a range of products with varying NPK composition. Other compounds are manufactured by reacting nitric acid and phosphoric acid with ammonia, dry-powdered potassium chloride and kieserite followed by granulation. During complexation, the ingredients are uniformly and securely mixed together. There is thus no chance for separation and, till the end, each granule retains the composition it had while leaving the factory. Such products are easy to handle and when applied to the soil give an even distribution of the individual nutrients.

3.3.2 Fertilizer calculation

The general formula for converting the quantity of a nutrient into the quantity of fertilizer required is :

$$\text{Fertilizer needed (kg)} = \frac{\text{kg nutrient needed}}{\text{per cent nutrient in the fertilizer}} \times 100$$

Example

$$\text{Urea needed for 30 kg N} = \frac{30}{46} \times 100 = 65.22 \text{ kg}$$

where 46 is the percentage of N in urea.

3.3.3 Fertilizer recommendations

Fertilizer recommendation for rubber at its various growth phases has been derived through a series of agronomic trials conducted by the Rubber Research Institute of India (RRII) over the years in different agroclimatic regions of rubber cultivation. The nutritional requirements of the plant at various stages of growth *viz.* nursery, immature and mature phases vary greatly. The response to fertilizer application is also dependent on the management practices adopted.

The RRII recommends discriminatory fertilizer application for economic and efficient nutrient management. However, general fertilizer recommendations for the traditional and non-traditional regions are also provided.

3.3.3.1 Discriminatory fertilizer recommendation

Fertilizer recommendation based on soil and leaf analyses ensures site- and situation-specific fertilizer application for rubber.

Discriminatory fertilizer recommendations are usually practised from the fifth year of planting. Current and previous year's nutrient values of the plantation, nutrient interactions, age of the tree, plant population, history of cover crop establishment, canopy density, TPD, *etc.* are considered for formulating fertilizer dosage. Discriminatory fertilizer usage for rubber has gained popularity among the smallholders.

3.3.3.1.1 Based on soil analysis

As soil collection is easy, planters prefer to analyse soil samples. Soils analysed for OC, available P, K and Mg are rated as low, medium and high (Table 3).

Table 3. Soil fertility standards

Parameter	Standard		
	Low	Medium	High
Organic carbon (%)	<0.75	0.75 - 1.50	>1.50
Available P (mg/100 g soil)	<1.00	1.00 - 2.50	>2.50
Available K (mg/100 g soil)	<5.00	5.00 - 12.5	>12.50
Available Mg(mg/100 g soil)	<1.00	1.00 - 2.50	>2.50

The fertilizer dose is usually arrived at based on the analytical values for OC, available P, available K and available Mg. Medium values of the above nutrients indicate that the normal dose of fertilizers is more or less adequate for the trees. When the values for OC, P and K are within the limits of the medium range, 30 kg N, 30 kg P_2O_5, and 30 kg K_2O are recommended for mature rubber. If all the values are high, the dose of these nutrients can be brought down to 15 kg per ha. On the contrary, if all the values are low, N can be increased to 40 kg per ha and P and K to 36 kg per ha. In the case of P, if the values are high, application of P can even be withheld. If soil pH is high (>5.2) water soluble forms of P fertilizers are recommended.

The dose for each element, however, may require modifications even if the values are within a range. Incidence of TPD, age of the trees, stand per ha, stimulation practices, *etc.* need careful considerations while deciding the dose of each element. For example if the incidence of TPD is high, additional dose of K need not be applied even if the K level is low as this may further influence TPD incidence. The dose of fertilizers can be marginally reduced after 10 years of exploitation of the trees and considerably when a plantation is nearing replanting. The total quantity of fertilizers can be reduced if the stand per ha is low.

3.3.3.1.2 Based on leaf analysis

Leaf samples are analysed for N, P, K, Mg and Ca. The values are rated as low, medium and high (Table 4). Fertilizer doses are formulated in the same way as done in the case of soil analysis.

Table 4 . Critical levels for leaf nutrient concentration

Nutrient	Low	Medium	High
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

3.3.3.1.3 Based on both soil and leaf analyses

Discriminatory fertilizer recommendation based on soil and leaf analyses is the most ideal approach. In this case more consideration is given for leaf analysis data.

3.3.3.2 Recommendations through DRIS

In the DRIS approach, the state of balance of nutrients in plant system is considered by fixing ratios of nutrients as norms rather than the absolute values. The standard DRIS norms for the nutrients N, P, K, Ca and Mg have been established and is given in Table 5 (Joseph *et al.*, 1993).

Table 5. General DRIS norms for *Hevea brasiliensis*

Forms of expression	Norm	CV (%)
N/P	13.8762	14.3
K/N	0.3824	20.9
K/P	5.2585	22.2
Ca/N	0.2987	29.7
Ca/P	4.1019	31.8
Ca/K	0.8231	41.2
Ca/Mg	3.3282	27.5
N/Mg	11.3825	20.9
P/Mg	0.8348	24.8
K/Mg	4.3973	32.8

For fertilizer recommendation, each leaf sample is analysed for the total nutrient status as in the case of conventional sufficiency range approach. From the analytical values, DRIS indices for the individual nutrients are arrived at using specific mathematical equations. The total concentration of N, P, K, Ca and Mg and the corresponding DRIS indices for one sample is given in Table 6 as an example.

Table 6. Nutrient concentration and DRIS indices

Nutrient	Total concentration (%)	DRIS index
N	3.42	8.0
P	0.18	–16.0
K	1.14	–1.4
Ca	0.88	–3.0
Mg	0.34	12.4

DRIS indices for individual nutrients measure the extent of the deviation from the established norms. A positive index value indicates relative sufficiency and negative value indicates insufficiency. In the above example, P, Ca and K indices are negative indicating relative insufficiency and among the three, P is diagnosed as the most deficient followed by Ca and K. Based on these index values, the nutrient elements can be arranged in their order of insufficiency.

After diagnosing the nutrient balance in the plant system and arranging the elements in the order of insufficiency, the quantity of fertilizer is derived. The quantity and type of fertilizers are decided taking into account other factors like soil fertility status,management practices, clone, age of trees, exploitation system, stimulation practices, yield, disease incidence, *etc.* as well. By keeping the general fertilizer recommendation of 30:30:30 NPK kg per ha as the base, deviations ranging from approximately 0.33 (10 kg) to 1.33 (40 kg/ha) times is recommended depending on the diagnosis of the situation. In certain situations with high soil P status, P fertilizer can even be omitted from the fertilizer schedule for one or two years. Critical assessment and correct diagnosis of the situations, however, require considerable experience and expertise.

3.3.3.3 General fertilizer recommendation

In case the discriminatory approach is not possible for one reason or another, general fertilizer recommendations can be followed.

3.3.3.3.1 Seedling nursery

3.3.3.3.1.1 Basal application

A basal dressing of 2.5 t of compost or well-rotten cattle manure and 350 kg of powdered rock phosphate (18 - 20% P_2O_5) for every effective hectare, *i.e.* 25 kg of compost and 3.5 kg of rock phosphate per 100 m^2 of bed is recommended. Fertilizer application based on soil testing will be more effective and useful. If the same beds are used repeatedly, rock phosphate application is necessary only once in three years because of its residual effect.

3.3.3.3.1.2 Top dressing

Application of 2500 kg of 10-10-4-1.5 NPKMg mixture per effective hectare, *i.e.* 25 kg per 100 m^2, is applied. The details of fertilizer mixtures are given in Table 2. Six to eight weeks after the first application, 550 kg of urea per effective hectare is given.

3.3.3.3.2 Budwood nursery

The objective of manuring budwood nursery is to obtain maximum quantity of budwood of good quality in a period of 10 to 12 months from the second crop of budwood.

3.3.3.3.2.1 Basal dressing

At the time of preparing the nursery bed, 150 kg of powdered rock phosphate per ha, *i.e.* 1.5 kg per 100 m^2 of the nursery bed is incorporated in the soil as basal dressing.

3.3.3.3.2.2 Top dressing

NPKMg 10-10-4-1.5 mixture at the rate of 250 g per plant is given as top dressing in two split doses. The first dose is applied two to three months after planting the budded stumps or cutting back if budding is carried out *in situ* and the second dose eight to nine months after planting. The fertilizer is applied in a circular band around the plants, leaving an area up to 8 cm from the base of the plant.

NPKMg 10-10-4-1.5 mixture at the rate of 125 g per plant is given as single application two to three months after cutting back for the second and subsequent crops of budwood.

3.3.3.3.3 Immature rubber

Proper manuring is highly essential at the immature phase to accelerate growth and reduce unproductive phase in rubber. Good management in the immature phase also improves the soil fertility status and reduces the fertilizer requirement in the initial years of tapping (Punnoose *et al.*, 1976).

At the time of filling the pits 12 kg of compost or well-rotten cattle manure and 175 g of rock phosphate are incorporated to provide good soil conditions for development of the root system of the young plant. In newly-cleared forest areas it is enough to apply 175 g rock phosphate alone well mixed with the top 20 cm soil in the pits, as the surface soil may be fairly rich in organic matter.

The fertilizer recommendation for the first four years is given in Table 7. In Kanyakumari district of Tamil Nadu, northern districts of Kerala and Karnataka, Goa and Maharashtra areas, available Mg status of the soil is high and application of 12-12-6 mixture is recommended. In all other regions 10-10-4-1.5 NPKMg mixture may be applied. For the first two years, it is advantageous to apply 50 per cent of the phosphate in the water-soluble form (Karthikakuttyamma *et al.*, 1980). Therefore, during the first two years after planting, 10-10(5)-4-1.5 and 12-12(6)-6 mixture containing 50 per cent of the phosphate in the water-soluble form is recommended. During the third and fourth years the 10-10-4-1.5 and 12-12-6 mixtures containing only water-insoluble P is used.

Table 7. Schedule of manuring during first four years of immaturity

Year of planting	Months after planting	Time of application	Dose of mixture per plant (g)		Quantity of mixture per ha (kg)	
			10-10-4-1.5	12-12-6	10-10-4-1.5	12-12-6
1	3	Sept.-Oct.	225	190	100	85
2	9	April-May	450	380	200	170
2	15	Sept.-Oct.	450	380	200	170
3	21	April-May	550	480	250	215
3	27	Sept.-Oct.	550	480	250	215
4*	33	April-May	450	380	200	170
4*	39	Sept.-Oct.	450	380	200	170

* *If legume ground cover is not established, the dose recommended for the third year may be* continued during the fourth year also

Fertilizer recommendation from fifth year depends on the management practices followed in the initial years. If the young plants have been properly mulched and leguminous ground cover established and well maintained, the general recommendation is to apply 30:30:30 NPK kg per ha in two split doses, one in April-May and the other in September-October from fifth year till the plants become ready for tapping. This can be supplied through 250 kg per ha of 12-12-12 NPK mixture. In areas where no legume ground covers have been established, application of 60:40:24 NPK kg per ha per year is recommended and can be provided through 400 kg per ha of 15-10-6 NPK mixture in two split doses of 200 kg each. This recommendation can be followed during the 5th and succeeding years till the plants become ready for tapping.

3.3.3.3.4 Rubber under tapping

For the rubber under tapping the recommended dose of NPK is 30:30:30 kg per ha which can be supplied through straight fertilizers or through 10:10:10 mixture at the rate of 300 kg per ha.

3.3.3.4 For north-eastern region

In the north-eastern region (Tripura, Assam, Manipur, Meghalaya and Mizoram) the soils are highly degenerated due to indiscriminate shifting cultivation which is preceded by burning of organic debris or due to heavy nutrient removal through cultivation of thatch grass. The available N and P status are very low in these soils. These soils are rich in illite clay minerals with high K fixation and low availability of K warrants the application of more K fertilizer. The Mg status is very high. For compensating the low K and high

Mg status, Mg is skipped from the fertilizer schedule and the dosage of K is increased to overcome the deleterious effects of high Mg. The ad hoc fertilizer recommendation for immature rubber based on soil test data and fertilizer trial conducted in polybag plants in Tripura (Krishnakumar and Potty, 1989) is given in Table 8.

Table 8. Fertilizer schedule for immature rubber in the north-eastern region

Year of planting	Dose of NPK (kg/ha)	Time of application	Quantity of 12-12-6 mixture	
			per plant (g)	per ha (kg)
1	14:14(7):7 *	April-May	280 **	125
		Sept.-Oct.	500	225
2	50:50(25):25	April-May	500	225
		Sept.-Oct.	500	225
3	65:65:35	April-May	600	270
		Sept.-Oct.	600	270
4	50:50:25	April-May	500	225
		Sept.-Oct.	500	225

* In the first and second years 50% of P is supplied through water-soluble sources

** *Polybag plants*

If polybag plants are planted during April-May, 280 g of 12-12(6)-6 NPK mixture may be applied two to three weeks after planting, followed by 500 g of the same mixture during September-October. If planting is done during August, 500 g of the mixture is applied two to three weeks after planting.

Based on ground cover management in the initial years, separate fertilizer recommendation is given from fifth year up to tapping. For areas where cover crop has been established, NPK at the rate of 35:35:35 kg per ha in two split applications during the pre- and post-monsoon periods is recommended. For areas where cover crop has not been established NPK at the rate of 75:50:30 kg per ha is recommended, which can be supplied through 500 kg of 15-10-6 mixture in two split doses of 250 kg each during pre- and post-monsoon periods.

For rubber under tapping NPK at the rate of 35:35:35 kg per ha is recommended.

3.3.4 Soil and leaf testing laboratories

Fertilizer recommendations are given from the soil and leaf testing laboratories of the RRII as well as from the regional laboratories at Nedumangad, Adoor, Palai, Kanjirappally, Moovattupuzha, Trichur, Calicut, Thaliparamba and Mangalore. The laboratory at Kottayam and the regional laboratories at Calicut, Moovattupuzha and Adoor have mobile laboratories (Plate 27. a,b). The laboratory at the Regional Research Station, Agartala, Tripura caters to the needs of the rubber growers of the entire North East India. The soil testing laboratory at RRII is equipped with the modern analytical instruments like auto-analyser (Plate 27. c), atomic absorption spectrophotometer (Plate 27. d) and N-analyser (Plate 27. e).

3.3.5 Choice of fertilizers

Nutrients can be supplied through straight fertilizers as well as through standard mixtures (Table 2). Mixing of straight fertilizers on the estate (Plate 28. a) is cheaper.

Mg status, Mg is skipped from the fertilizer schedule and the dosage of K is increased to overcome the deleterious effects of high Mg. The ad hoc fertilizer recommendation for immature rubber based on soil test data and fertilizer trial conducted in polybag plants in Tripura (Krishnakumar and Potty, 1989) is given in Table 8.

Table 8. Fertilizer schedule for immature rubber in the north-eastern region

Year of planting	Dose of NPK (kg/ha)	Time of application	Quantity of 12-12-6 mixture	
			per plant (g)	per ha (kg)
1	14:14(7):7 *	April-May	280 **	125
		Sept.-Oct.	500	225
2	50:50(25):25	April-May	500	225
		Sept.-Oct.	500	225
3	65:65:35	April-May	600	270
		Sept.-Oct.	600	270
4	50:50:25	April-May	500	225
		Sept.-Oct.	500	225

* In the first and second years 50% of P is supplied through water-soluble sources

** Polybag plants

If polybag plants are planted during April-May, 280 g of 12-12(6)-6 NPK mixture may be applied two to three weeks after planting, followed by 500 g of the same mixture during September-October. If planting is done during August, 500 g of the mixture is applied two to three weeks after planting.

Based on ground cover management in the initial years, separate fertilizer recommendation is given from fifth year up to tapping. For areas where cover crop has been established, NPK at the rate of 35:35:35 kg per ha in two split applications during the pre- and post-monsoon periods is recommended. For areas where cover crop has not been established NPK at the rate of 75:50:30 kg per ha is recommended, which can be supplied through 500 kg of 15-10-6 mixture in two split doses of 250 kg each during pre- and post-monsoon periods.

For rubber under tapping NPK at the rate of 35:35:35 kg per ha is recommended.

3.3.4 Soil and leaf testing laboratories

Fertilizer recommendations are given from the soil and leaf testing laboratories of the RRII as well as from the regional laboratories at Nedumangad, Adoor, Palai, Kanjirappally, Moovattupuzha, Trichur, Calicut, Thaliparamba and Mangalore. The laboratory at Kottayam and the regional laboratories at Calicut, Moovattupuzha and Adoor have mobile laboratories (Plate 27. a,b). The laboratory at the Regional Research Station, Agartala, Tripura caters to the needs of the rubber growers of the entire North East India. The soil testing laboratory at RRII is equipped with the modern analytical instruments like auto-analyser (Plate 27. c), atomic absorption spectrophotometer (Plate 27. d) and N-analyser (Plate 27. e).

3.3.5 Choice of fertilizers

Nutrients can be supplied through straight fertilizers as well as through standard mixtures (Table 2). Mixing of straight fertilizers on the estate (Plate 28. a) is cheaper.

Phosphorus is mainly supplied through rock phosphates. During the initial two years 50 per cent of the recommended quantity of P is supplied through super phosphate for good root development and early establishment of the plants. The recommended dosage of 30:30:30 for the mature rubber can be supplied through 250 kg per ha of 12-12-12 NPK mixture. Instead, any complex fertilizer of the grades 15-15-15 or 17-17-17 or 19-19-19 NPK can be used, the quantities being 200 kg, 175 kg and 160 kg, respectively. 10-26-26 NPK complex (115 kg) mixed with urea (40 kg) or ammonium phosphate sulphate, 20-20 (150 kg) with muriate of potash (50 kg) or 65 kg diammonium phosphate (18 - 46) mixed with 40 kg urea and 50 kg muriate of potash may also be used. Diammonium phosphate is recommended only for soils having pH 6.0 and above. Bowl sludge, a latex centrifuge factory waste, containing magnesium ammonium phosphate is also a good source of P (George *et al.*, 1994).

In plantations where trees exhibit Mg deficiency in addition to the above, addition of 50 kg per ha of commercial magnesium sulphate is recommended.

3.3.6 Fertilizer application

3.3.6.1 Time

The time of fertilizer application depends mainly on the moisture status of the soil. There should be sufficient moisture in the soil at the time of application of the fertilizers and at the same time the chances of loss through leaching should be minimum. Accordingly, the time for fertilizer application is to be scheduled with the southwest and northeast monsoons. The first application should be made during pre-monsoon (April-May) and the second application during post-monsoon (September-October) periods. The first application should be made after a few pre-monsoon showers but before the onset of regular monsoon. The second application on the other hand should be undertaken after the cessation of southwest monsoon but before the onset of the northeast monsoon.

3.3.6.2 Method

Fertilizers can be applied to the soil as well as leaves. Foliar application however, is resorted for correcting nutrient deficiencies. Soil application of fertilizers is the common practice in rubber. The fertilizers should be applied in the zones where root activity is maximum.

3.3.6.2.1 Seedling nurseries

In seedling nurseries fertilizer should be spread about 8 cm away from the base of the plants on a 14 cm wide linear band in between two rows and should be gently forked in with a hand rake (Plate 28. b).

3.3.6.2.2 Budwood nurseries

For the first crop of budwood, application should be made during September-October and March-April either in a band 8 cm away from the base of the plant or in between two rows and lightly forked. For the second and subsequent crops, single application during September-October is adequate.

3.3.6.2.3 Immature rubber

In the case of young plants, the root system will be limited. The first application is done by evenly distributing the fertilizer over a circular band of about 30 cm around the base of the plant leaving about 7 cm from the base. The second application should also be done in circular band, the band width being 45 cm leaving 15 cm all around the plant base (Plate 28. c,d). The fertilizer applications in subsequent years till the canopy closure, should be made in circular bands of increasing width. The applied fertilizer should be slightly forked into the soil (Plate 28. e).

3.3.6.2.4Mature rubber

Once the canopy closes, *i.e.* five to six years after planting, fertilizers should be applied in square or rectangular patches in between rows, each patch serving four trees (Plate 28. f). In steep areas, fertilizers can be applied on the contours in between two trees. Light forking to incorporate the fertilizers into the topsoil is necessary. In cover crop existing areas or areas where cover crop has died out leaving a thick mulch, it is enough to broadcast the fertilizers in between two rows of trees. Placement of fertilizers in deep pockets and application too close to the base of the trees should be avoided. Mulching is advisable after fertilizer application.

3.3.6.2.5Foliar application

Foliar application is the method by which fertilizers are applied as a solution on the leaves. The fertilizer is dissolved in water and sprayed with a suitable spraying equipment. Foliar spray on tall trees is difficult and care should be taken to prepare the correct concentration of the spray solution. When quick recovery from nutrient deficiency is desired, foliar application is more effective than soil application. Urea low in biuret (<0.5%) can be sprayed onto the foliage up to a concentration of three per cent. It can also be incorporated into fungicide mixtures.

For polybag plants and immature rubber, three per cent solution of urea or two per cent solution of ammonium phosphate sulphate (20 - 20 NP) may be used. For zinc deficiency, a 0.5 per cent solution of fertilizer grade zinc sulphate may be used. With zinc sulphate 0.25 per cent lime should be added to reduce residual acidity.

3.4 Organic manures

Organic manures are materials derived from plant, animal and human residues which contain plant nutrients in complex organic forms. They are evaluated on the basis of their N content and the amount of organic matter present. On the basis of N content, organic manures are grouped into bulky organic manures and concentrated organic manures. Farmyard manure (FYM), compost, biogas slurry *etc.* are examples of bulky organic manures. The common concentrated organic manures are oil cakes, bloodmeal, fish manure, *etc.* The nutrient content in different organic manures vary (Table 9).

Organic manures differ from fertilizers in several respects. Their nutrient contents are low and hence bulk quantities have to be applied. The nutrient content of organic manures also vary from place to place, lot to lot and according to the method of preparation. However, organic manures should not be seen only as carriers of nutrients. They improve soil physical properties, enhance multiplication of soil microorganisms, and furnish organic acids which help to dissolve soil nutrients. Organic manures can be used in a harmonious manner to compliment chemical fertilizers.

Table 9. Nutrient content(%) of different organic manures

Manure	N	P_2O_5	K_2O
Farmyard manure	0.5 - 1.5	0.4 - 0.8	0.5 - 1.9
Compost	0.4 - 2.0	0.3 - 1.0	0.7 - 1.5
Neem cake	5.2 - 5.3	1.0 - 1.1	1.4 - 1.5
Cotton seed cake	3.9 - 4.0	1.8 - 1.9	1.6 - 1.7
Fish manure	4.0 -10.0	3.0 - 9.0	0.3 - 1.5
Green manure	0.5 - 0.7	0.1 - 0.2	0.6 - 0.8
Groundnut cake	7.0 - 7.2	1.5 - 1.6	1.3 - 1.4

3.5 Manuring of cover crops

Manuring leguminous cover crops with rock phosphate and muriate of potash is beneficial for increased dry matter production, N-fixation and nutrient turnover (Mathew *et al.*, 1978). In general, application of 150 kg of powdered rock phosphate per ha is recommended in two split doses, the first, one month after sowing and the second, two months after the first application. Areas where available K is low, 50 kg of muriate of potash per ha is also added along with rock phosphate. In both cases, it is enough to broadcast the fertilizers on the strips or patches where the cover crops are planted.

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