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NUTRIENT DEFICIENCY DIAGNOSIS IN *Tectona grandis* L.f

BY

JAYAMADHAVAN A.

THESIS

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DECLARATION

I hereby declare that the thesis entitled **Nutrient deficiency diagnosis in *Tectona grandis* L f** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree diploma associateship fellowship or other similar title of any other University or Society

Vellanikkara
30 3 1996

JAYAMADHAVAN, A

Dr K Sudhakara
Associate Professor
Department of Silviculture
and Agroforestry

College of Forestry
Kerala Agricultural University
Vellanikkara Thrissur

CERTIFICATE

Certified that this thesis entitled **Nutrient deficiency diagnosis in *Tectona grandis* L f** is a record of research work done independently by **Sri Jayamadhavan, A** under my guidance and supervision and that it has not previously formed the basis for the award of any degree fellowship or associateship to him

Dr K Sudhakara
Chairman
Advisory Committee

Vellanikkara
30 3 1996

CERTIFICATE

We the undersigned members of the Advisory Committee of Sri **Jayamadhavan, A** a candidate for the degree of Master of Science in Forestry agree that the thesis entitled **Nutrient deficiency diagnosis in *Tectona grandis* L f** may be submitted by Sri Jayamadhavan A in partial fulfilment of the requirement for the degree

Dr K. Sudhakara
Associate Professor
Dept of Silviculture and Agroforestry
College of Forestry
Kerala Agricultural University
Vellanikkara Thrissur
(Chairman)

Dr C C Abraham
Former Special Officer
College of Forestry
Vellanikkara Thrissur
(Member)

Dr. P A Wahid
Associate Dean
College of Agriculture
Pilicod Kasaragod
(Member)

Dr P.K. Ashokan
Associate Professor
Dept of Tree Physiology & Breeding
College of Forestry
Vellanikkara Thrissur
(Member)

External Examiner

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JAYAMADHAVAN, A

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INTRODUCTION

Teak (*Tectona grandis* L f) a large deciduous tree is one of the most important timber trees of India It is referred to as the paragon among Indian timbers Teak is being extensively used in ship building construction of house bridge and wharf furniture and for most of the common purposes for which wood is used To meet the increasing demand for teak reducing its rotation age is being thought of widely This could be achieved by increasing its growth rate through proper nutrition

A knowledge of importance and deficiencies of different nutrient elements is a pre requisite in any plant nutrition programme Evidence indicates that forest trees do suffer from nutrient deficiencies and do not always attain their full growth potential (Mustanofa and Leaf 1965) Not every site quality supplies all the requirements for tree growth and forest fertilization is rapidly becoming an accepted component of silviculture in many parts of the world The success of an economically viable fertilizer programme requires an accurate diagnosis of nutritional status of forest stands in relation to sufficiency or deficiency Plant analysis if properly interpreted can be a useful tool in diagnosing the probability of response of stands to the application of fertilizers

Foliar analysis as a method for assessing the nutrient requirement of a given crop makes use of the fact that within certain limits there is a positive relationship among the doses of nutrient supplied leaf nutrient content and yield Eventhough Lagatu and Maume first developed foliar diagnostic technique as early as 1926 it has not been applied to teak Steenbjerg (1954) stressed the importance of standardising sampling procedures to eliminate all the factors that cause variation in leaf nutrient levels No information is available in teak with regard to the influence of site qualities on foliar nutrient concentrations and yield as reflected through increased basal area and volume Similarly no attempt has been made so far to study seasonal variations in foliar nutrient levels to standardise the time of leaf sampling canopy height leaf rank and diameter class from which leaf samples are to be collected and to find out critical concentrations of nutrients in leaves Information on these aspects would help us to evolve suitable fertilizer recommendations based on the nutritional status for obtaining higher yields in teak The present study was taken up with the following objectives

* To identify the nutritional factors limiting productivity in teak based on critical level concept

* To standardise canopy height time of sampling leaf rank and diameter class from which leaf samples are to be collected for nutrient deficiency diagnosis

* To evaluate the seasonal variations in foliar nutrient concentrations in teak

Review of Literature

REVIEW OF LITERATURE

Nutrient management is one of the major components of improving productivity of existing perennial crop plants At the same time very few works are seen to be carried out on the mineral nutritional aspects of tropical forest tree species Having been introduced mainly for the purpose of timber production teak has received very little scientific attention in the past Information on its nutritional behaviour has been meagre and management technology vary arbitrary This calls for renewed efforts on these lines based on information already generated in the field

2.1 Role of Nitrogen, Phosphorus and Potassium in growth and development of plants

2 1 1 Nitrogen

Nitrogen is reported to be the most important structural constituent of the cell Nitrogen containing compounds constitute 5 to 30 per cent of the dry weight of plants (Kramer and Kozlowski 1960) Stocking and Origun (1962) noted that as much as 70 per cent of the leaf nitrogen was present in the chloroplasts Greulach (1973) found that nitrogen being a constituent of organic compounds such as amino acids proteins purines pyramidines chlorophyll and many co enzymes this element was found to be involved in all processes associated with enzyme reactions and photosynthesis Nitrogen supply was found to control the use of carbohydrates and hence determined whether the plant will make vegetative or reproductive growth (Kraws and Kraybill 1918) Marschner (1982) found that nitrogen has a major role in maintaining the phytochormone balance in plants An interruption in nitrogen supply enhanced the abscisic acid content of tissues which subsequently favoured the leaf senescence

2 1 2 Phosphorus

Phosphorus was reported to play a major role in energy metabolism of all living cells eventhough the share of phosphorus was only 0 1 to 0 8 per cent of the total dry weight in plants (Epstein 1978)

Greulach (1973) and Agarwala and Sharma (1976) noted that phosphorus acted as a structural component of the membrane system of the cell the chloroplasts and the mitochondria It formed the main part of sugar phosphates ADP ATP nucleic acids nucleoproteins purine and pyramidine nucleotides flavin nucleotides and several other enzymes and co enzymes Being a component of nucleoproteins it is very important for cell division and transfer of hereditary traits as reported by Gauch (1972) Marschner (1982) found that phosphorus also favoured the movement of cytokinins from roots to other plant parts and hence its deficiency resulted in a decline in cytokinin content in these tissues

Phosphorus deficient plants produced purple bronze leaves since phosphorus played an important role in the synthesis of anthocyanin pigments (Gauch 1972)

2 1 3 Potassium

The property of potassium to occur primarily in the ionic form or as charged particles on colloidal surfaces has made it most apt to function as a catalyst or as a co factor for many enzymatic reactions of the cell (Ulrich and Ohki 1975) Evans and Sorger (1966) have reported the presence of more than 50 plant enzymes that need K for maximal activity

Potassium influenced stomatal opening and transpiration (Fischer and Hsiao 1968) Caporn *et al* (1982) noted that though potassium activated synthesis of chlorophyll an increased partitioning of K to the chloroplast in K deficient plants was the major reason for no substantial reduction in photosynthetic rates during the initial stages of deficiency of this element

Marschner (1982) found that deficiency of potassium resulted in reduced transport of cytokinins from roots but enhanced ABA export to grains which caused accelerated senescence

Greuelach (1973) stated that K deficiency may also be expressed as water imbalance as K is very important in regulating membrane permeability in plant cells

2.2 Diagnostic methods for nutritional deficiencies and disorders in trees

Generally diagnosis implies determination of the nutritional status of the site or trees Diagnosis of nutritional problems is essential to make a qualitative appraisal of which nutrient or nutrients were limiting the growth But more often it is important to know how severe the deficiency is and also to predict the response to given quantities of nutrients applied to correct it (Bowen and Nambiar 1984) On the practical side diagnosis of the nutritional problems is essential in forestry to make sound decisions concerning profitable and most effective use of manures and fertilizers (Landis *et al* 1989)

Diagnosis includes visual assessment based on symptoms plant tissue analysis soil analysis and biological estimations Among these techniques some have proved more useful in certain situations than others and all have their own merits and de merits Hence it is prudent to use a range of techniques and in general faster progress is made this way than by relying on a single technique (Gentle and Humphreys 1968)

Analysis of soil for nutrient levels has been practiced to diagnose nutrient need by plants Now a days tissue analysis is being widely used as a tool to identify the nutrient needs of plant Soil and tissue tests for predicting olive yields in Turkey were examined by Fox *et al* (1964) In many surveys primary positive correlation between soil nutrients and leaf nutrients were observed

Leaf nutrient levels were found to be better correlated with yield than soil nutrient levels (Ollagnier and Giller 1965) But in banana both foliar and soil analysis were necessary for determining fertilizer requirements (Champion 1966)

Leaf being the major metabolic organ is an ideal choice for sampling to ascertain fertilizer requirements Standard sampling procedure should be employed to eliminate all the factors that cause variation in leaf nutrient levels

2.3 Foliar diagnosis

Foliar diagnosis is based on the principle that plant behaviour is related to concentration of essential mineral elements in the leaf tissue Therefore foliar analysis as a method for assessing the nutrient requirement of a given crop makes use of the fact that within certain limits there is a positive relationship between doses of nutrient supplied leaf nutrient content and yield

Foliar diagnostic technique was first developed by Lagatu and Maume (1926) in France They defined foliar diagnosis as the assessment of chemical status at a given point in time of suitably selected leaves It was Loue (1951) in Ivory Coast who first used this technique for Robusta coffee

Leaf analysis indicates the status of soil fertility nutrient availability to plants and the critical level of plant nutrients Critical nutrient concentration is the level of a nutrient below which crop yield quality and performance are unsatisfactory Thus for leaf analysis to serve as a guide to crop fertilization it is essential to standardise the sampling procedures with respect to each nutrient

2.4 Foliar analysis vs soil analysis

Since leaf is the principal site of plant metabolism changes in the nutrient supply are reflected in the level of nutrient in leaf Analysis of the soil on the other hand provides information only on the amount of nutrient available at a given moment not on the amount actually taken up by the crop

Soil and tissue tests for predicting olive yields in Turkey were examined by Fox *et al* (1964) Leaf nutrient levels were found to be better correlated with yield In groundnut also foliar nutrient levels were better correlated with yield than soil nutrient levels (Ollagnier and Giller 1965) But in banana both foliar and soil analyses were necessary for determining the fertiliser requirements (Champion 1966)

The soil may not be able to provide all the time enough nutrients for optimum plant growth However many workers suggested soil tests for monitoring the nutrient requirement of young plants With regard to NPK nutrition of one year old apple trees soil analysis gave better results but with two year old trees foliar analysis was better (Klossowski and Czynczyk 1974) In pineapple a preplant soil analysis would be sufficient to indicate the P and K requirements (Plessis and Koen 1983) Hanson (1987) and Hancock and Nelson (1988) suggested soil test for monitoring the K status of young blueberry plant

Sakshaug (1982) conducted a nutrient survey of strawberry in Norway and Sweden In many surveys primary positive correlations between soil nutrients and leaf nutrients were observed Significant positive correlations between K values in the soil and in the leaf samples were most frequent

Although strong relationships between soil nutrients and leaf nutrients were observed in many crops little or no correlation was observed between soil and leaf nutrients in some crops Bopaiah and Srivastava (1984) reported that there was no significant correlation between soil and leaf nutrient with respect to N P and K in mango But in the case of blueberry weak correlations were noted between soil and leaf nutrient levels of P K Ca and Mg (Hanson 1987 Hancock and Nelson 1988)

2.5 Sampling procedure

Since leaf is the primary centre (Hanson 1987) where the major synthetic processes and vital functions of the plant take place changes in the nutrient pattern of the leaf can be related to the nutritional status of the soil and the level of fertilization to be adopted As a common practice the critical levels of the different nutrients are determined by the analysis of leaves which have not entered the phase of senescence and have fully matured physiologically The leaf thus selected is termed as the reference or index leaf

The foliar diagnosis technique is followed on the assumption that there is an empirical association between the final performance of the plant and the nutrient content of a particular plant part at a particular period of growth (Prevel *et al* 1974) The nutrient content of a leaf varies with the changes in external and internal factors So sampling is made at a period when the leaf nutrient level is relatively stable and related to the performance of the plant in quantity and quality

A standard sampling procedure should be employed to eliminate all the factors that cause variation in leaf nutrient levels Steenbjerg (1954) pointed out that neither deficient nor adequate levels of any individual nutrient could be defined because they were influenced by so many factors in particular by physical and chemical properties of the soil water supply climate and stage of development

Evans (1979) cited the various external and internal factors affecting leaf nutrient levels They include climate season time of the day age of the foliage position in crown and other factors

2.6 External factors affecting leaf nutrient levels

2 6 1 Climate and leaf nutrient levels

Certain physiological processes in plants are much affected by climatic variations Such climatic variations produce appreciable differences in plant nutrient content Most important climatic factors which influence the chemical concentration of leaves are rainfall and sunshine

Dufkova (1977) examined the influence of rainfall on leaf nutrient content of oil palm In a year with inadequate rainfall a positive correlation was established between leaf NPK content and yield of apple But in wet years negative or no correlation was found

An increase in percentages of macronutrients in the third leaf of sugarcane due to 200 mm rainfall two months prior to sampling was noted by Malavolta and Carvalho (1984) Phosphorus content increased by 0 016 0 034 per cent and K by 0 017 per cent According to Yaacob *et al* (1985) N and K contents of cashew leaves were higher during dry months than in wet months

The influence of sunshine and shade on leaf chemical composition was noted by Shorrocks (1961a) in rubber and Murray (1961) in banana as a direct relationship between potassium concentration in leaves and the number of sunshine hours two years earlier In pepper De Waard (1969) noted a significant reduction in leaf potassium concentration in the leaves taken from deep shade

2 6 2 Time of the day

Time of the day has an influence on nitrate level in plants Nitrate accumulates at night and is utilized during the day as carbohydrates are synthesized Therefore rapid test should not be made very early in the morning or late in the afternoon (Tisdale *et al* 1985)

According to Ulrich (1952) the best time for taking sample for diagnostic purpose was from 8 am to 12 noon The N content in the leaves of black pepper was found to decrease from early morning to late afternoon But K content remained unchanged (De Waard 1969) Sugiyama *et al* (1984) studied the diurnal fluctuation in the nutrient concentrations of spinach leaves in a pot culture experiment It was found that the concentration of N P K and Mg decreased after sunrise reached a minimum in the late afternoon and then increased to maximum to dawn

Ivarzen *et al* (1985) observed a diurnal effect on maize stalk nitrate content in a green house experiment and hence advised that sampling must be conducted at mid day or afternoon when nitrate concentrations are least likely to fluctuate from time of day effects

2 6 3 Leaf age and leaf position

Leaf analysis is used as a guide in planning fertilizer programmes So selection of index tissue is the most important The leaf composition depends on age and physiological stage of the tree position in the crown age of leaf season and other conditions of the leaf sampled (Emert 1954 1957 1959 Embleton and Jones 1964) Therefore before proposing the index tissue it is essential to determine the manner and extent of influence of these factors on leaf composition

Leaf sampling technique had been evaluated in many fruits like citrus (Koo and Sites 1956 Chandler 1970) guava (Arora and Singh 1972 Chadha *et al* 1973) mango (Pathak and Pandey 1976) and papaya (Awada and Long 1971)

De Waard (1969) studied the leaf nutrient content of black pepper at different leaf positions A significantly higher leaf N was recorded in the second leaf The P content of the leaf decreased on ageing but K content remained unaffected by the age of the leaf A negative linear relationship between N P and K content of rubber leaves with age of the leaf was noted by Guha and Narayanan (1969) But Ca and Mn showed a positive relationship with age of the leaf

According to Chadha *et al* (1973) the N P and K content of guava leaves decreased with increasing age of the leaf both in fruiting and non fruiting terminals Kumar and Grewal (1977) observed a reduction in leaf N content of pear from 2 36 to 1 94 per cent when the age of the leaf advanced from two to nine months

Baez *et al* (1981) collected leaf samples over the course of a year from upper middle and lower levels of crown of *Fitzroya cupressoides* trees and analysed for N P K Ca Mg Zn Cu Mn Fe and B Contents of N Ca and B fluctuated significantly over the course of the year and a significant effect of crown level was found for all elements except K and Mg

Relation between the chemical content of Scots pine needles and their crown position and age was analysed and found that N content decreased downwards from the crown apex K and Ca increased and P and Mg showed little change N P K and Mg contents decreased with increasing needle age whereas Ca increased (Czapla 1978)

Ponder *et al* (1979) showed seasonal variation in foliar composition of Black Walnut trees average dry weight of leaves altered with crown position and time of year Concentration of N P and K generally decreased as the season progressed but contents of Ca and Mg increased they were not affected by crown position

Variations in the nutrient content of leaves of poplar were determined in relation to position of leaves on the branch and date of sampling Best time of collecting samples was found to be the end of July It was also found that leaf samples should be taken from long shoots in the upper half of the crown (Frison 1979)

Shcherbak (1980) recommended the sampling of leaves from the middle part of replacement shoot during the final flowering phase for diagnosing raspberry plant nutritional requirements durıng the current season For early dıagnosıs wıth current season sampling of leaves from the mıddle part of bearıng shoot durıng the early flowerıng phase was recommended

For analysıng N P K and Mg status ın *P sylvestrıs* needles the ımportance ıs stressed of analysıng the topmost whorl separately ın plants wıth 1 2 or 3 needle year classes Analysıs of 1 2 and 3 year old needle ın branch whorls 1 2 and 3 showed varıatıon wıth age amount of nutrıent retranslocatıon and wıth nutrıent avaılabılıty (Raıto 1987)

Analyses were made of the N P K ratıos ın the needles of Norway spruce of the topmost whorl of older tree and the ratıo whıch exhıbıted optımum growth was 67 8 25 The ratıo over all age classes and sıte classes were 58 8 34 Also showed that the ratıo can ıncrease for N and decrease for K wıth ıncreasıng age and sıte class but the crown posıtıon (tree class) had no ınfluence on the N P K ratio of the needles (Fıelder and Hohne 1987)

Gopı (1981) analysed all the leaves ın coconut and revealed that the percentage of nıtrogen ın the leaf lamına ıncreased wıth ıncreasıng age of leaf tıll leaf number 6 and thereafter ıt gradually declıned the lowest value beıng observed ın the last few leaves

2.7 Seasonal variation

Variations of rainfall air temperature humidity and light intensity are expected to be reflected in the chemical composition of leaves Closely interacting with this is the changing demand for nutrients by the plants So understanding of this seasonal variation is essential for the choice of a sampling time

In nutritional studies in citrus the importance of seasonal changes in nutrient element has been emphasized by various workers (Jones and Parker 1950 Reuther and Smith 1955 Stephenson *et al* 1986) They have found it desirable to determine the foliar concentration of different nutrient elements at various seasons of the year

Bataglia *et al* (1976) opined that the N levels in the leaves of black pepper rose in the autumn but declined in winter The leaf P and K contents were higher in summer and declined in winter Sushama *et al* (1984) reported that the period just prior to flushing was most suitable for the collection of leaf sample in pepper for diagnostic purpose in Kerala

Studies conducted by Wahid *et al* (1981) in coconut revealed that the leaf N declined with onset of monsoon But leaf P increased slightly in rainy season whereas leaf K increased until December and thereafter declined A reduction in the N concentration of the foliar tissue in oil palm during summer months and an increase during rainy season were noted by Nair and Sreedharan (1983) But a reverse trend was observed in the case of P and K

Eight major elements and 19 minor elements were studied monthly in Scots pine needles (needle age 1 to 4 year old) and the highest overall nutrient content was found to be associated with 2 year old needless and the maximum content of most elements was in spring period (Repyakh *et al* 1981)

Schonan (1981) found that there was close relationship between height growth and rainfall in *Eucalyptus grandis* Changes in foliar concentration of N P K Ca Mg S and Zn conformed closely to the rate of height growth Fe showed an inverse relationship Foliar concentration of N Ca S Cu Zn and Fe were also related to rainfall Fe inversely

Nitrate contents in leaves and litter also showed seasonal variation For leaves values were maximum in September and minimum in April For litter values were maximum in February and minimum in January In soil the contents were maximum in September and minimum in July Significant correlations were observed among the variables within season (Pokhriyal *et al* 1988)

Ponder *et al* (1979) recommended early sampling dates for foliar analysis to overcome problems of seasonal variation

2.8 Selection of plant tissue for nutrient diagnosis

The leaf is the centre for physiological activity of plants It is the site where mineral nutrients are converted into structurally and metabolically active components along with the products of photosynthesis Consequently any deficiency or toxicity usually drastically affects the concerned enzyme activity Nutrient deficiency as well as toxicity is usually expressed by the leaves and thus leaves form an ideal plant part for nutritional diagnosis

Rogers *et al* (1955) showed that leaf was sensitive or even more sensitive than any other plant part for determining the nutrient status of strawberry For plantains leaf was found to be the specific tissue for diagnosing N P K Ca and Mg at all stages of growth (Samuels *et al* 1976) According to Quast (1978) leaf was the best for K level determination in apple

2 8 1 Tissue age stage and position

In cocoa 2nd or 3rd fully green leaf below the apex of shoot without petioles 4 to 8 weeks after main bloom could be taken for foliar analysis (McDonald 1934 Murray 1967)

According to Lott *et al* (1956) Culot *et al* (1958) and Malavolta and Gomes (1961) in coffee 3rd or 4th pair of leaves from apex of lateral fruiting or non fruiting twigs are suitable for foliar analysis

But in rubber trees of more than 4 years of age the tissues suited for analysis are leaves with mid rib but without petioles and the leaves should be four basal leaves from each whorl using one whorl per tree from lower branches in shaded areas For trees of 18 months to 4 years old four basal leaves from a terminal whorl in full sunlight should be selected (Shorrocks 1962b)

In the case of tea whole leaf should be taken and it should be the 2nd young leaf from terminal of tender shoot picked from May to mid July (Barua and Deb 1960)

Prevot and Bachy (1962) found that two pinnae from each side of rachis from the middle section of the pinnae bearing portion of rachis are suited for foliar analysis in oil palm But for palms upto 2 years old leaf number 9 and palms of more than 4 years old leaf number 17 or 17th and 25th leaves were found to be ideal

In apple matured leaves including petioles from spursor near base of current season growth representing average size and condition of leaves for section of orchard should be sampled (Boynton *et al* 1943 Kenworthy 1961 and Bould and Jarrett 1962)

Reuther and Smith (1955) Chapman (1960) and Steyn (1961) observed that spring cycle leaves of 4 7 months old should be sampled from fruit bearing terminals of orange for foliar analysis

In pineapple middle third section of white basal portion of the last fully developed leaf (D leaf) of three to four month old plant was identified as the best for sampling (Steyn 1961 and Sanford 1962)

2.9 Response of plants to mineral fertilization

Conflicting results on the response of plants to mineral fertilization has been reported on a study of the Madakkathara laterite soils of Kerala Significant increase in height and girth of cashew plants were observed by application of 1000 g N/tree/year over the lower doses of 500 or 250 g N/tree/year (Anon 1980)

Mathew (1990) studying the pattern of N response of cashew crop receiving constant levels over a period of 10 years found that the gap between 250 and 1000 g N/tree/year is very wide At 250 g the nut yield was 6 9 kg as against 8 34 kg for

1000 g after 10 years of the fertilizer application in seed progenies of cashew

Kumar and Nagabhushanam (1981) and Ghosh and Bose (1986) observed higher concentration of nitrogen in leaf and shoot when higher levels of nitrogen were applied to cashew trees Kumar (1985) found an increase in leaf N from 2 04 to 2 53 per cent by application of 300 g N/tree/year While leaf P decreased with increase in N application from 150 to 450 g N/tree/year and K content showed a significant decline from 0 99 to 0 90 per cent when N level was raised from 150 to 300 g/tree/year

The role of P in height and vegetative development of plants in early stages has been well documented

Kumar (1985) reported that the nut yield in seed progenies of cashew increased significantly from 1 49 kg/tree at P application level of 50 g P_2O_5/tree to 2 kg/tree at 150 g P_2O_5/tree/year He also reported that application of K increased the total chlorophyll and the constituent components percentage increase of chlorophyll a b and total chlorophyll at 150 g K_2O/tree/year application worked out to be 18 15 and 30 respectively over 50 g K_2O/tree/year

Lefebvre (1973) reported that application of K had significant effect in increasing the production particularly in the presence of N Ghosh (1988) and Ghosh (1990) recorded significant yield increase with 200 g K_2O/tree/year over no K application in cashew The yield increase was obtained dueto greater number of nuts/tree

Morozov and Shimanski (1981) analysed the growth and chemical composition of needles in Scots pine plantation of various density in relation to fertilizers and found that thinning and mineral fertilizers (N P and K) caused an increase in needle size and nutrient content

Neely (1980) conducted tree fertilization trials and sample trees (75 per species) were selected from stands of sixyear old *Acer platanoides* and seven year old *Quercus palustris* Nitrogen in three formulation of N P K at 2 4 or 6 lb per 1000 sq ft and ammonium nitrate at 6 lb per 1000 sq ft were applied to 100 sq ft of soil around individual trees Trunk diameters were recorded At 6 lb N per 1000 sq ft all three NPK fertilizers produced significantly greater growth than at lower rates NPK fertilizers were slightly better than ammonium nitrate

Sheedy (1980) found that in Jack pine there was significant correlation between foliage N P K Ca and Mg and height and dbh growth Foliage concentration of N and P were generally low and it is suggested that fertilisation of stands less than 60 year old would result in significant increase in growth

2.10 Critical level of nutrients

Critical level is defined as the concentration of the element in the leaf (dry weight basis) above which a yield response from the element in the fertilizer is unlikely to occur (Prevot and Ollagnier 1957) The term critical concentration refers to the optimum concentration of a given nutrient element in plant tissue above which response to further increment is doubtful or occurs at rapidly diminishing rate

The critical concentrations of different nutrient elements for different crops have been worked out by many workers and some of the important references are presented here

Brar *et al* (1980) reported that in glasshouse and field experiment with groundnut leaf concentration of Zn and B at preflowering stage should be raised and the yield increased with the application of 2 5 kg Zn per ha and 1 kg B per ha They also reported the critical level for Zn and B in leaves for groundnuts grown in Punjab as 25 ppm for both

In two year old *Leucaena leucocephala* a marked gradient in height from 6 12 m to 1 3 m was observed due to variation in available N (0 22 to 11 4 ppm) (Norani and Ng 1981)

Harbaugh (1987) identified foliar tissue analysis standards for N P and K in Caladium The optimal concentrations were found to be 4 3 per cent N 0 55 per cent P and 3 2 per cent K Regression analysis indicated that sufficiency range for foliar levels were 3 6 to 4 9 per cent Visible deficiency symptoms were obtained at less than 2 8 per cent N 0 18 per cent P and 1 4 per cent K Visible toxicity symptoms were observed at nutrient levels of more than 4 8 per cent N 0 7 per cent P and 4 5 per cent K

Balo *et al* (1988) reported that leaf analysis gave a good indication of nutrient status in grape vines The optimum leaf levels of P and K were 0 22 per cent and 1 2 per cent respectively the optimum N/K ratio was between 1 9 and 2 4 They also reported that establishment of the correct soil P and K levels increased grape yields by 1 to 5 tons per ha and improved grape quality

In cocoa grown in solution culture Loue (1961) reported that the deficient levels of nitrogen and potassium in leaves from 4 month old plant were 2 04 and 0 21 0 24 per cent respectively The critical level of phosphorus was 0 1 per cent

In arabica coffee the critical levels of nitrogen phosphorus and potassium in 4th pair of leaves from apex on outside fruiting branches were 2 60 0 16 and 1 80 per cent respectively (Culot *et al* 1958)

Lin (1961) reported that in young tea leaves 3rd from terminals of tender shoot the deficient level of nitrogen was less than 3 4 per cent

Research works on the nutrient deficiency aspect of tropical tree species has been found to be limiting In teak to meet its increasing demand reducing the rotation age is widely thought off which could be achieved by proper nutritioning By analysing the nutrients which are in short supply proper fertilizer recommendation could be made to better the growth of teak

Materials and Methods

MATERIALS AND METHODS

The present investigation pertaining to the diagnosis of nutrient deficiencies in teak was carried out at the College of Forestry Kerala Agricultural University Vellanikkara during 1992 94 The field work involved in the study was done in the teak plantations of Nilambur Details of the materials used and methods followed are presented

3.1 Site, climate and soil

Nilambur belonging to Malappuram district of Kerala State is situated within 10°10 and 30 North latitude and 75°35 and 76°35 longitude East of Greenwich The plain forests have an elevation varying from 30 metre to 300 metres and are interspersed with a network of rivers and rivulets (Ranganathan 1982)

The locality is subject to south west monsoon during the months of May June and July and north east monsoon in August September and October The extremes of temperature in the shade vary approximately between 17°C and 37°C (Ranganathan 1982)

As a result of heavy rainfall obtained in these parts coupled with high temperature lateritic soils are found The predominant parent rock being gneiss which disintegrates into very fine particles the important soil type of the forest areas of Nilambur is very fine loam of depths varying according to the slope

3 1 1 Selection of different sites for the study

To standardise the canopy height sampling time leaf rank and diameter class and for studying the seasonal variation of nutrient concentration Muttikkadavu teak plantation of site quality II belonging to Nilambur range was chosen This plantation is situated near the Karimpuzha river and has deep alluvial soil

For studying critical concentrations of nutrients in teak plantations belonging to four different site qualities were chosen

Site quality is referred to as a measure of the relative productivity of a site for a particular species In teak site qualities were determined based on the measurement of top height which is the average height of the dominant trees in a stand at a particular age As used in yield tables in India it refers to the height corresponding to the mean diameter of the 250 biggest diameter trees per hectare (Khanna 1984) In teak the site qualities were classified as given below (Khanna 1984)

Age of the crop	Top height in metres			
	I Quality	II Quality	III Quality	IV Quality
80 years	More than 35	25 1 35	15 25	Less than 15

Teak plantations belonging to different site qualities were selected based on information derived from the respective plantation maps kept in the South Nilambur Forest Division

A brief description regarding the four teak plantations chosen for this study are given below

1982 Edakode teak plantation (Sq I)

The teak plantation situated on the banks of Chaliyar river is blessed with deep alluvial soil in which teak grows well The height and diameter of trees recorded for this plantation varied from 10 m 16 m and 14 cm 22 cm respectively

1982 Nellikutha teak plantation (Sq II)

Situated in the Vazhikaddavu forest range and along side Nellikutha river this plantation also supports deep alluvial soil The height and diameter of trees in this plantation ranged from 9 m 14 m and 11 cm 19 cm respectively

1982 Edavanna teak plantation (Sq III)

This plantation coming under the Edavanna forest range is having lateritic soil which supports relatively poor teak growth The height of trees in this plantation varied from 9 m 11 5 m whereas their diameter ranged from 10 cm 15 5 cm

1982 Valluvassery teak plantation (Sq IV)

This plantation belonging to Nilambur forest range has uneven topography with rocky patches and supports lateritic soil The height and diameter of trees present in this plantation ranged from 7 5 m 10 5 m and 9 5 cm 14 5 cm respectively

3 2 Collection of leaf samples

Collection of leaf samples was made from the standing tree by climbing and hand picking

3.3 Standardisation of canopy height and time of sampling

First fully mature leaf samples were collected from the Muttikkadavu plantation from the top middle and bottom of the tree canopies at seven different time intervals during a day viz 5 a m 7 a m 7 a m 9 a m 9 a m 11 a m 11 a m 1 p m 1 p m 3 p m 3 p m 5 p m and 5 p m 7 p m Time of sampling was denoted by the midpoint of the interval as 6 a m

8 a m 10 a m 12 p m 2 p m 4 p m and 6 p m Top middle and bottom portions of the canopies were defined as the upper one third middle one third and lower one third of the canopy

Leaf samples were collected from four trees selected randomly from a plot Factors like age and site quality were kept uniform

The samples were analysed for N P and K The portion of the canopy and time of sampling for which the nutrient concentrations were high and coefficients of variation were less were considered suitable for leaf sampling

Details of the treatments are

3 canopy heights
7 times of the day
4 trees per plot
84 samples in all

3.4 Standardisation of diameter class and leaf rank

Diameter at breast height of all trees present in the 1987 Muttikkadavu Teak plantation were recorded and the entire plantation was divided into four diameter classes as mentioned below

Class I 7 10 cm to 10 25 cm

Class II 10 26 cm to 13 50 cm

Class III 13 51 cm to 16 75 cm

Class IV 16 76 cm to 20 0 cm

From each diameter class six trees were randomly selected Leaf samples were taken from these selected trees starting from the first fully mature leaf down to the fifth leaf on a branch These leaf samples were categorised as five different ranks Sampling was done from the canopy height and during the time of the day standardised in the previous study The leaf samples were analysed for N P and K Diameter class and leaf rank which gave minimum coefficient of variation and high concentrations of nutrients were adjudged best for sampling purpose

Details of treatments are

4 diameter classes

6 trees per diameter class

5 leaf ranks

120 samples in all

3.5 Seasonal variation

From the fourth fixed diameter class and second leaf rank six leaf samples were collected at monthly intervals from 9 a m to 11 a m from the bottom portion of the canopy

$$\text{Basal area} \quad \frac{\pi d^2}{4}$$

where d is the diameter (m) at breast height

The volume is calculated using the formula

$$\text{Volume} \quad \frac{\pi d^2}{4} \quad l$$

where d - diameter of the tree at breast height (m)

l height of the tree (m)

Leaves were sampled according to the technique standardised from previous experiments i e between 9 am to 11 am from the second leaf rank of the bottom canopy Leaf samples were analysed for N P and K Linear equation of the form Y B * X + A was used to predict the degree of relationship between the growth and N P and K concentration where Y is the basal area in m^2 or volume in m^3 X is the foliar nutrient concentration in percentage and A and B are constant In addition twenty five standard equations were also fitted and the equation which gave maximum predictability for yield based on the foliar nutrient concentration was also selected

3.7 Analytical methods

3 7 1 Plant analysis

The collected leaf samples were dried at 70°C and powdered using a grinder The powdered samples of each single tree were pooled and digested in a mixture of concentrated sulphuric acid and selenium (Prasad 1982)

3 7 1 1 Standardisation of digestion procedure

First fully mature leaf samples were collected from twelve randomly selected trees of the 1982 Muttikkadavu Teak plantation belonging to site quality II Samples were digested under three different methods to standardise the digestion procedure for the determination of N P and K This standardisation work was carried out to finalise whether the concentrated sulphuric acid Selenium mixture which can be used to analyse N P and K is as effective as the diacid mixture which can be used only for analysing P and K and the N digestion mixture (Kjeldahl digestion) which can be used only for analysing the N concentration The three methods tried were

1 Digestion with concentrated sulphuric acid and selenium mixture

The digestion mixture was prepared by adding 1 g selenium to one litre concentrated sulphuric acid and then boiling until the acid mixture became colourless To 0 5 g of the leaf sample taken in a boiling tube 5 ml of digestion mixture was added Then one ml of 30 per cent hydrogen peroxide was added carefully along the sides of the boiling tube and kept overnight before being taken up for digestion (Prasad 1982) The total nitrogen content of the digested samples was determined by micro kjeldahl distillation method as described by Jackson (1958) The phosphorus content of the samples were measured using chlorostannous reduced blue colour method The concentration of potassium in the samples were determined flame photometrically (Jackson 1958)

2 Digestion with Diacid mixture

The diacid mixture was prepared by mixing concentrated nitric acid and perchloric acid in the ratio 1 4 To 0 5 g of leaf sample 5 ml of diacid mixture was added kept overnight and then taken up for digestion (Prasad 1982) Heating was continued until the digestion mixture became colourless

3 Digestion with a mixture of anhydrous sodium sulphate copper sulphate and concentrated sulphuric acid (Kjeldahl digestion for N)

To 0 2 g leaf sample 2 g anhydrous sodium sulphate 0 2 g copper sulphate and 5 ml of concentrated sulphuric acid was added After storing it overnight the above mixture was taken up for digestion (Jackson 1958)

3 7 2 Statistical analysis

The data worked out for different parameters were compiled and tabulated Their mean values and other statistical parameters were determined

In the determination of critical nutrient level foliar nutrient concentrations were plotted against the basal area and the volume to develop an equation giving the best prediction For this twenty five standard equations (Appendix I) and simple linear equations were developed Details of equations developed are given in the Section 3 6 of this chapter

Results

RESULTS

The results of the study on the nutrient deficiency diagnosis of *Tectona grandis* L f are presented in this chapter The important findings are furnished under various heads viz standardisation of digestion procedure time of sampling of leaf canopy height leaf rank and diameter class seasonal variation of nutrients and determination of critical concentration

4.1 Standardisation of digestion procedure

Three digestion mixtures were tested for digesting the leaf samples viz concentrated sulphuric acid and selenium mixture diacid mixture containing and a mixture of concentrated sulphuric acid containing anhydrous sodium sulphate and copper sulphate in order to assess the nutrients in the leaves The data obtained are shown in Table 1

Digesting the leaf samples in concentrated sulphuric acid containing anhydrous sodium sulphate and copper sulphate gave the highest concentration of N This was closely followed by digestion with concentrated sulphuric acid selenium mixture The lowest concentration of N was observed when digested with diacid mixture containing perchloric acid and *sulphuric acid* No significant difference was observed between the N concentration determined using concentrated sulphuric acid sodium sulphate copper sulphate mixture and concentrated sulphuric acid selenium mixture

In the case of P and K highest concentration were recorded when digested with concentrated sulphuric acid selenium mixture However this was statistically on par with P and K concentrations determined by diacid mixture digestion

Based upon this finding digestion by sulphuric acid sclenium mixture was adopted in the determination of N P and K in the subsequent studies since all the three nutrients could be assessed after digestion using a single procedure This has the added advantage of being simple less expensive less laborious and less environmentally polluting

Table 1 Concentration of N P and K (%) in leaf samples as affected by different digestion acid mixtures

Digestion mixture	Percentage of					
	N	SD±	P	SD±	K	SD±
Sulphuric acid selenium mixture	2 602	0 227	0 306	0 033	1 599	0 150
Diacid mixture	2 100	0 253	0 292	0 034	1 586	0 132
Sulphuric acid Sodium sulphate Copper sulphate mixture	2 707	0 218	ND		ND	

ND - Not determined

4.2 Standardısatıon of canopy heıght

Leaves were sampled from three canopy heıghts vız top mıddle and bottom to standardıze the heıght of canopy from whıch leaf samples could be drawn for the determınatıon of N P and K It was found that the canopy heıght had no sıgnıfıcant effect on the folıar N P and K concentratıons (Table 2)

For N the coeffıcıent of varıatıon among the samples was lowest for the bottom canopy (9 02%) followed by the top canopy (11 04%) and mıddle canopy (11 38%)

Sımılarly for P also the coeffıcıent of varıatıon was lowest for the bottom canopy (25 21%) followed by the top canopy (38 98%) and the mıddle canopy (46 49%)

In the case of folıar K also the coeffıcıent of varıatıon was lowest for the bottom canopy (27 65%) followed by mıddle canopy (32 51%) and the top canopy (36 56%)

4.3 Standardısatıon of tıme of samplıng

Leaves were sampled durıng seven dıfferent tıme ıntervals of the day from 5 a m to 7 p m at an ınterval of two hours to determıne the best tıme for samplıng

Dıurnal varıatıons ın folıar N concentratıon are shown ın Table 3 The concentratıon of N ın the leaves exhıbıted an

Table 2 Variation of foliar nutrient concentration due to canopy height in teak

Canopy height	N		P		K	
	%	Coefficient of variation (%)	%	Coefficient of variation (%)	%	Coefficient of variation (%)
Top	2 51	11 04	0 28	38 98	1 64	36 56
Middle	2 45	11 38	0 24	46 49	1 58	32 51
Bottom	2 59	9 02	0 27	25 21	1 65	27 65

Table 3 Diurnal variation of the foliar nutrient concentration in teak

Sampling time	N %	N Coefficient of variation (%)	P %	P Coefficient of variation (%)	K %	K Coefficient of variation (%)
5 a m 7 a m	2 52	14 20	0 29	29 69	1 65	17 86
7 a m 9 a m	2 58	9 01	0 31	25 38	1 69	12 05
9 a m 11 a m	2 66	6 35	0 30	37 55	1 78	12 04
11 a m 1 p m	2 62	6 62	0 29	36 66	1 66	30 11
1 p m 3 p m	2 53	5 27	0 27	31 51	1 57	22 56
3 p m 5 p m	2 43	12 78	0 26	30 28	1 48	22 10
5 p m 7 p m	2 41	12 13	0 24	20 25	1 39	33 65

increasing trend from 6 a m (2 52%) till it reached a peak at 10 a m (2 66%) Thereafter it declined and was lowest at 6 p m The coefficient of variation was lowest at 2 p m (5 27%) the next lowest being at 10 a m (6 35%) In general the coefficient of variation was very high either during the early morning hours or during the late evening hours

Diurnal variations in foliar P concentration are shown in Table 3 The P concentration also increased from 6 a m (0 29%) reaching its peak at 8 a m (0 31%) Thereafter a gradual decline was observed the lowest value being observed at 6 p m (0 24%) The coefficient of variation was highest at 10 a m (37 55%) and it showed decreasing trend among samples collected either before or after 10 a m with the lowest being recorded at 6 p m (20 25%)

Diurnal variations in foliar K level are shown in Table 3 The foliar K concentration exhibited a pattern similar to that of N It increased from 6 a m (1 65%) reached its peak at 10 a m (1 78%) and then gradually declined reaching its lowest value at 6 p m (1 39%) The coefficient of variation was lowest at 10 a m (12 04%) starting with a decline from 6 a m onwards No definite pattern was observed in the change in the coefficient of variation during the afternoon hours However the highest coefficient of variation was observed at 6 p m (33 65%)

4.4 Standardisation of leaf rank

Leaves were sampled from five different leaf ranks starting from the first fully matured leaf down to the fifth leaf in a twig to find out the ideal leaf rank for the determination of nutrient elements

The variation of foliar N with leaf rank are shown in Table 4 The highest concentration was recorded in the second leaf rank (2 64%) closely followed by the first (2 63%) The N concentration gradually declined from the second leaf rank downwards till it reached its lowest in the fifth leaf rank (2 48%)

Similar trends were observed in the case of P and K concentration (Table 4)

In the case of foliar N the coefficient of variation showed a gradual decline from the first leaf rank (9 24%) till it reached the lowest in the fourth leaf rank (7 48%) However a further rise was observed in the fifth leaf rank (9 31%)

Lowest coefficient of variation for P was in the second leaf rank (46 61%) and the second lowest was observed in the third leaf rank (47 76%) Here also the highest coefficient of variation was recorded in the samples collected from the fifth leaf rank (60 63%)

Table 4   Variation of foliar nutrient concentration due to leaf rank in teak

Leaf rank	N		P		K	
	%	Coefficient of variation (%)	%	Coefficient of variation (%)	%	Coefficient of variation (%)
1	2 63	9 24	0 28	51 43	1 65	23 42
2	2 64	8 21	0 30	46 61	1 67	21 34
3	2 58	7 97	0 26	47 76	1 59	29 82
4	2 56	7 48	0 24	50 21	1 50	34 56
5	2 48	9 31	0 22	60 63	1 45	38 36

For K the lowest coefficient of variation was noticed in the second leaf rank (21 34%) Thereafter it started increasing reaching its highest value in the fifth leaf rank (38 36%)

4.5 Standardisation of diameter class

Leaves were sampled from four diameter classes as described in the methodology to standardize the ideal diameter class from which sampling could be done for the determination of the seasonal variation in the nutrient content

For all the three nutrients the foliar concentration increased with increasing diameter class (Table 5) However no definite pattern was observed in the coefficient of variation recorded in the four diameter classes

In the case of foliar N the coefficient of variation was lowest in the fourth diameter class (6 78%) and highest in the second diameter class (8 16%)

For P the coefficient of variation was found to be lowest in the fourth diameter class (38 44%) The second lowest was observed in the third diameter class (47 79%) and the highest in the second diameter class (51 45%)

As in the case of foliar N the coefficient of variation among samples for foliar K was lowest in the fourth diameter

Table 5 Variation of foliar nutrient concentration due to diameter class in teak

Diameter class (cm)	N %	N Coefficient of variation (%)	P %	P Coefficient of variation (%)	K %	K Coefficient of variation (%)
7 10 10 25	2 51	8 00	0 20	49 05	1 48	28 54
10 26 13 50	2 57	8 16	0 24	51 45	1 62	34 66
13 51 16 75	2 61	7 23	0 26	47 79	1 63	32 53
16 76 20 00	2 63	6 78	0 29	38 44	1 67	27 43

class (27 43%) and hıghest ın the second dıameter class (34 66%)

4.6 Seasonal varıatıons ın folıar nutrıent concentratıons

Based upon the procedure standardısed leaves of second leaf rank were sampled from the bottom canopy heıght of trees belongıng to fourth dıameter class at 10 O clock for a perıod of 13 months startıng from August 1993 to August 1994 to study the seasonal varıatıon of folıar N P and K concentratıon ın teak

The folıar N concentratıon showed a decreasıng trend from September onwards recordıng the lowest value ın the months of March (1 63%) and Aprıl (1 58%) (Fıg 1) Afterwards ıt started ıncreasıng reachıng a peak durıng the month of June (2 43%) It showed a slıght declıne durıng the months of July (2 33%) and August (2 30%)

The folıar P concentratıon also showed a sımılar pattern wıth the lowest levels beıng recorded durıng the months of February (0 19%) March (0 19%) and Aprıl (0 18%) (Fıg 2) Here also the hıghest value was recorded ın the month of June (0 29%)

Sımılarly for K there was a steady declıne ın the folıar concentratıon startıng from August 1993 (1 70%) down to Aprıl whıch recorded the lowest value (1 11%) as ın the case of N and

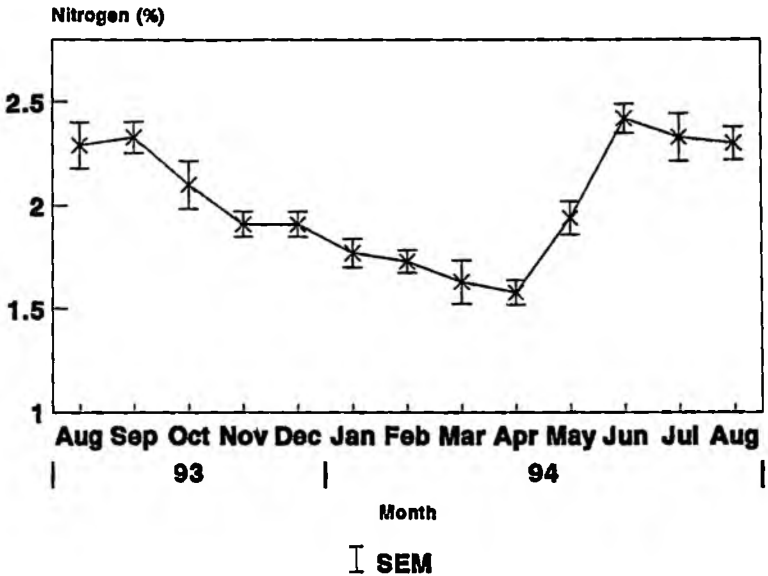

Fig.1 Seasonal variation of foliar nitrogen concentration in Teak

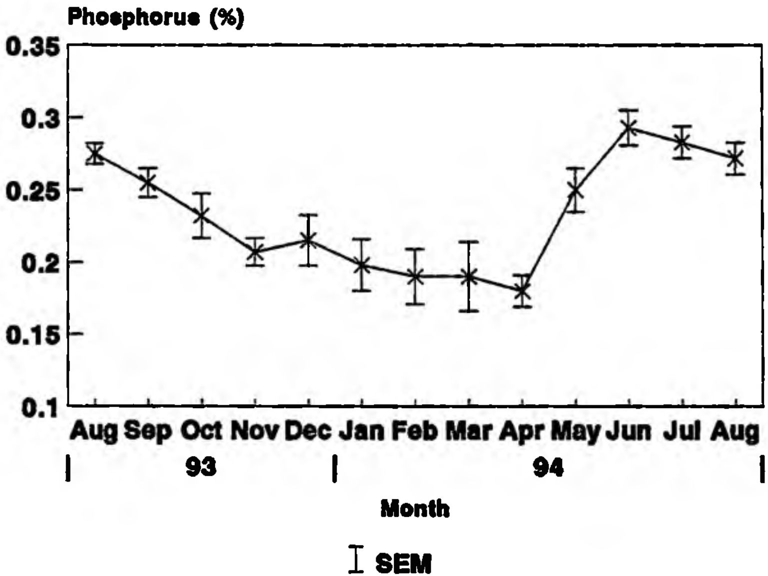

Fig. 2 Seasonal variation of foliar phosphorus concentration in Teak

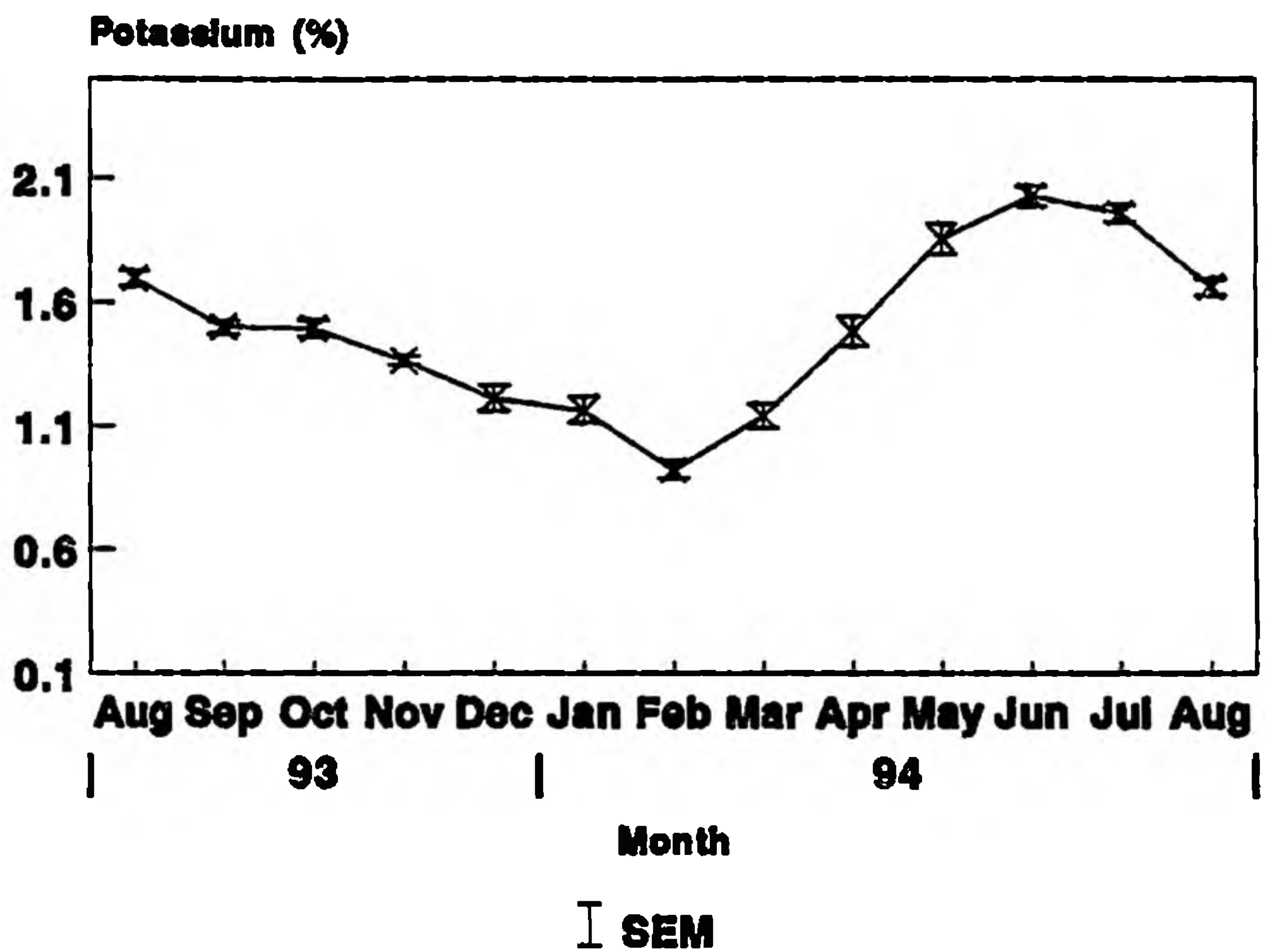

Fig. 3 Seasonal variation of foliar potassium concentration in Teak

P (Fig 3) From there a steep increase was observed with the peak value being recorded in the month of June (2 04%) Further decline was steeper than in the case of N and P with a relatively low value being observed in the month of August 1994 (1 66%)

4.7 Determination of critical nutrient level

Leaves were sampled from twenty five trees varying widely in their diameter classes from each of the four site qualities between 9 a m to 11 a m from the second leaf rank of the bottom canopy The variation in the foliar nutrient concentration and the growth of teak measured as basal area and volume at different sites and the related statistical characteristics of the data are given in Table 6

Compared to site quality IV the basal area and volume of site quality I increased by 109 per cent and 195 per cent respectively The corresponding increase in the foliar nitrogen phosphorus and potassium concentration were 58 per cent 29 per cent and 25 per cent respectively In all the four site qualities the coefficient of variation was highest for volume followed by basal area measurements The coefficient of variation for foliar nutrient concentrations were very low

The lowest and highest concentration of foliar nitrogen phosphorus and potassium were compared with the corresponding

Table 6 Variation in the basal area/volume growth of teak and the corresponding foliar nutrient concentration as affected by site quality

Variable	Site quality	Minimum	Maximum	Mean	Standard deviation	Standard error	Coefficient of variation (%)
Basal Area	I	0 015	0 038	0 023	0 007	0 001	30 4
	II	0 014	0 026	0 020	0 004	0 001	20 0
	III	0 009	0 018	0 014	0 003	0 001	21 4
	IV	0 008	0 017	0 011	0 003	0 001	27 2
Volume	I	0 118	0 461	0 236	0 106	0 021	44 9
	II	0 097	0 284	0 188	0 056	0 011	29 7
	III	0 063	0 166	0 105	0 032	0 006	30 4
	IV	0 045	0 142	0 080	0 033	0 007	41 3
N per cent	I	2 744	3 522	3 162	0 233	0 047	7 3
	II	2 576	3 192	2 854	0 155	0 031	5 4
	III	2 240	2 856	2 492	0 187	0 037	7 5
	IV	1 700	2 350	1 994	1 190	0 038	9 5
P per cent	I	0 270	0 380	0 320	0 033	0 007	10 3
	II	0 270	0 345	0 307	0 024	0 005	7 8
	III	0 240	0 310	0 272	0 020	0 004	7 3
	IV	0 200	0 290	0 247	0 027	0 005	10 9
K per cent	I	1 305	1 989	1 630	0 220	0 044	13 4
	II	1 237	1 809	1 553	0 172	0 034	11 1
	III	1 168	1 672	1 438	0 152	0 030	10 5
	IV	0 985	1 58	1 295	0 176	0 035	13 5

basal area and volume growth of teak in different site qualities (Table 7) The percentage increase from the lowest to the highest phosphorus and potassium concentration and the corresponding increase in basal area and volume were higher compared to that of foliar nitrogen concentration for all the site qualities

When plotted against the foliar nitrogen concentration both basal area and volume continued to increase with increasing nutrient concentration (Fig 4 and 5) The relationship represented a steady increase without much scattering For predicting the yield in terms of basal area and volume twenty five standard equations were tried initially to develop the best fitting equation for all the three nutrients The different equations are given in Appendix I The equations developed for foliar nitrogen concentration are given in Tables 8a and 8b respectively To predict the yield in terms of basal area and nitrogen concentration the simple linear model was of the form

Y B * X + A

Y 0 0119 * X 0 01423

where

Y Basal area in m^2 and

X Foliar N concentration (per cent) and

A and B are constants

This equation had the R^2 of 0 7024

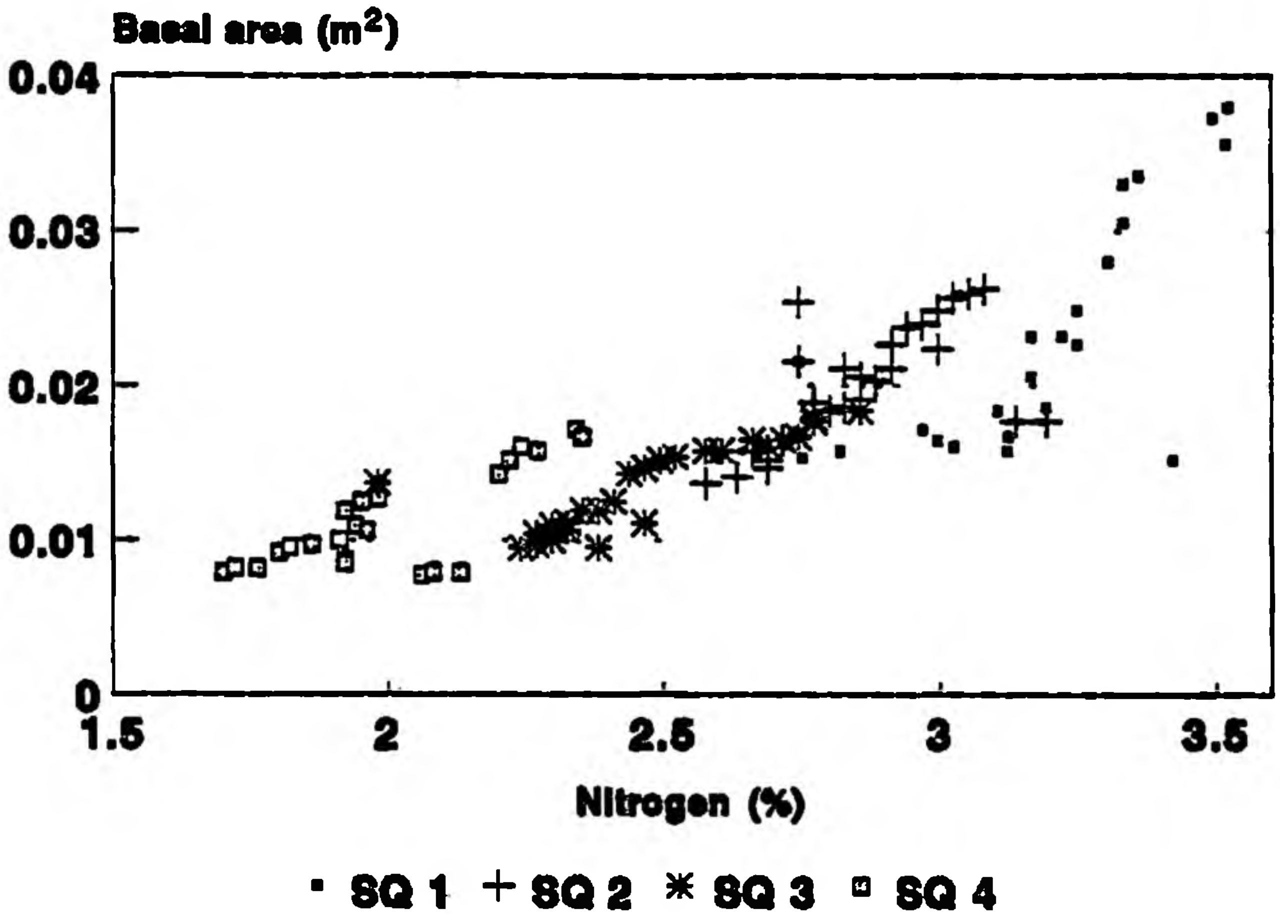

Fig.4 Relationship between basal area and foliar nitrogen concentration in Teak grown in different site qualities

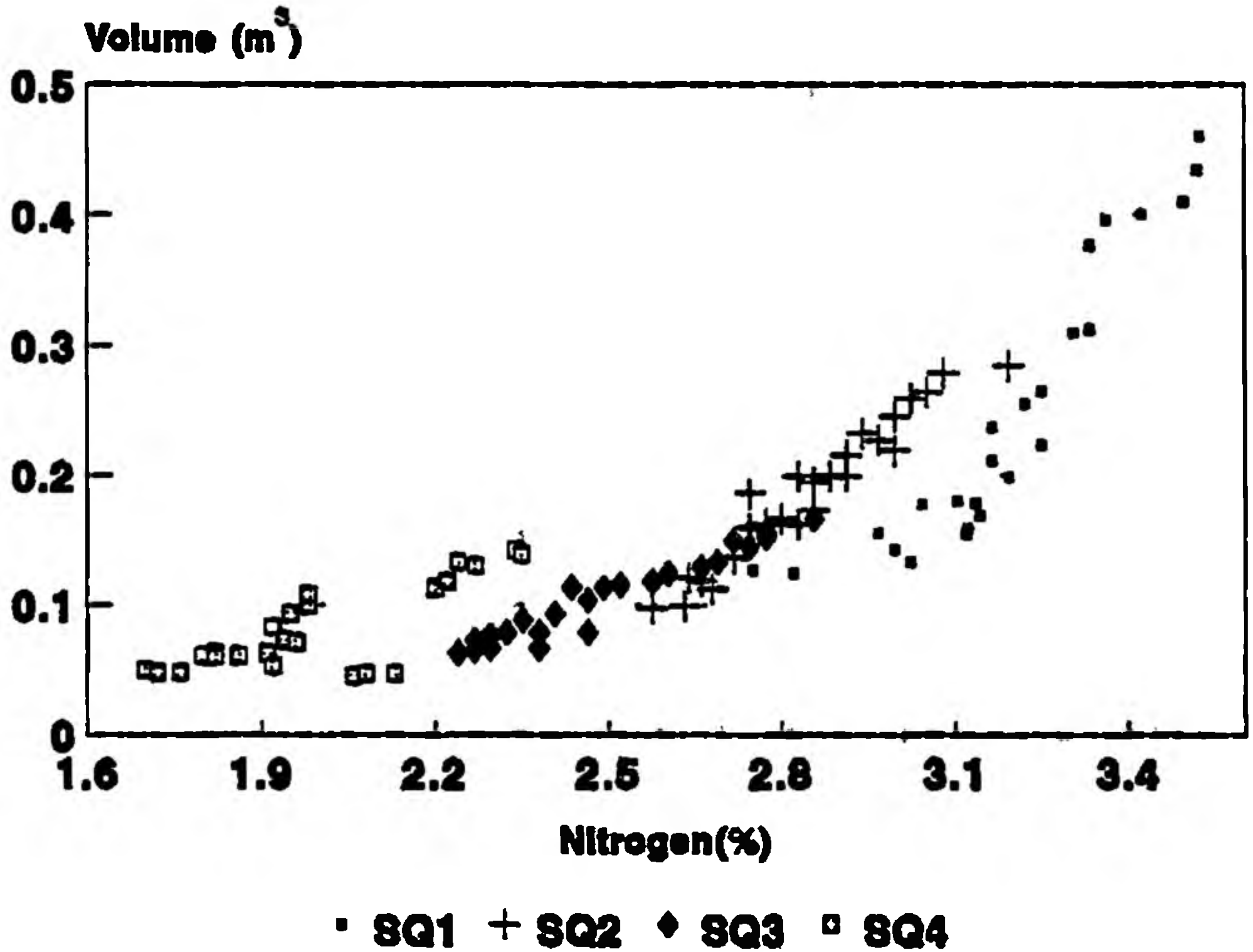

Fig.5 Relationship between volume and foliar nitrogen concentration in Teak grown in different site qualities

Table 7 Relationship between the lowest and the highest foliar nutrient concentration and the corresponding basal area and volume of teak as affected by site quality

Site quality		Nitrogen concen-tration	Basal area	Volume	Phos-phorus concen-tration	Basal area	Volume	Pota-ssium concen tration	Basal area	Volume
I	Lowest	2 740	0 216	0 169	0 270	0 018	0 198	1 310	0 022	0 169
	Highest	3 520	0 038	0 460	0 380	0 038	0 460	1 990	0 038	0 461
	Increase (%)	28	75	95	38	104	132	52	75	172
II	Lowest	2 580	0 014	0 097	0 270	0 013	0 097	1 236	0 013	0 097
	Highest	3 190	0 018	0 284	0 345	0 014	0 284	1 809	0 017	0 284
	Increase (%)	23	29	92	27	29	192	46	29	192
III	Lowest	2 240	0 009	0 063	0 240	0 009	0 067	1 168	0 009	0 066
	Highest	2 856	0 018	0 165	0 310	0 018	0 166	1 648	0 017	0 155
	Increase (%)	27	93	161	29	93	147	41	88	131
IV	Lowest	1 700	0 008	0 049	0 200	0 007	0 045	0 980	0 007	0 045
	Highest	2 350	0 017	0 138	0 290	0 017	0 142	1 580	0 017	0 142
	Increase (%)	38	11	179	45	116	208	60	123	214

Table 8a Relatıonshıp between basal area and folıar nıtrogen concentratıon ın teak

Eq No	COEF A	COEF B	COEF C	R^2	R^2C	Equatıon
1	0 0143	0 0119	0 0000	0 7054	0 7024	Y A+B*X
2	0 0000	0 0067	0 0000	0 0000	0 0000	Y B*X
3	193 70	47 91	0 0000	0 7429	0 7402	Y 1/(A+B*X)
4	0 0816	0 0252	0 0825	0 7381	0 7327	Y A+B*X+C/X
5	0 0442	0 0687	0 0000	0 6243	0 6204	Y A+B/X
6	0 0049	295 30	0 0000	0 7546	0 7521	Y X/(A*X+B)
7	0 1037	0 3609	0 3450	0 7235	0 7177	Y A+B/X+C/X*X
8	0 0225	0 0174	0 0057	0 7439	0 7387	Y A+B*X+C*X*X
9	0 0001	0 0023	0 0000	0 0000	0 0000	Y A*X+B*X*X
10	0 0029	1 7800	0 0000	0 7543	0 7518	Y A*X B
11	0 0024	2 0400	0 0000	0 7657	0 7633	Y A*B X
12	0 0851	0 0142	0 0000	0 7296	0 7268	Y B (1/X)
13	0 0061	0 3673	0 0000	0 7661	8 7637	Y A*X^(B*X)
14	0 0000	17 900	0 0000	0 3301	0 3232	Y A*X (B/X)
15	0 0024	0 7130	0 0000	0 7657	0 7633	Y A*e^(B*X)
16	0 0850	4 256	0 0000	0 7296	0 7268	Y A*e^(B/X)
17	0 0106	0 0293	0 0000	0 6693	0 6660	Y A+B*lnX
18	183 10	121 6	0 0000	0 7560	0 7536	Y 1/(A+B*lnX)
19	0 0023	2 5350	0 5492	0 7663	0 7615	Y A*B^X*X C
20	0 0000	283 80	4 0930	0 7661	0 7613	Y A*B^(1/X)*X C
21	0 0008	5 6000	22 980	0 7664	0 7616	Y A*e ((X B)/2)
22	0 0071	0 1390	0 8611	0 7663	0 7614	Y A*e^((lnX B)^2/C)
23	2 0850	3 3080	2 1060	0 7581	0 7531	Y A*X B*(1 X) C
24	0 0022	1 0750	0 5492	0 7663	0 7615	Y A*(X/B) C*e (x/b)
25	14 040	4 2950	25 590	0 7583	0 7533	Y 1/(A*(X+B) 2+C)

Table 8b Relationship between volume and foliar nitrogen concentration in teak

Eq No	COEF A	COEF B	COEF C	R^2	R^2C	Equation
1	0 2610	0 1575	0 0000	0 7032	0 7001	Y A+B*X
2	0 0000	0 0612	0 0000	0 0000	0 0000	Y B*X
3	32 970	9 1500	0 0000	0 7426	0 7400	Y 1/(A+B*X)
4	1 6500	0 4315	1 707	0 7833	0 7789	Y A+B*X+C/X
5	0 5010	0 8833	0 0000	0 5918	0 5876	Y A+B/X
6	13 430	56 710	0 0000	0 7628	0 7604	Y X/(A*X+B)
7	1 5100	5 8360	5 8470	0 7551	0 7501	Y A+B/X+C/X*X
8	0 4939	0 4462	0 1166	0 7963	0 7921	Y A+B*X+C*X*X
9	0 0596	0 0433	0 0000	0 0000	0 0000	Y A*X+B*X*X
10	0 0106	2 646	0 0000	0 7891	0 7870	Y A*X B
11	0 0080	2 898	0 0000	0 8077	0 8057	Y A*B X
12	1 565	0 0018	0 0000	0 7568	0 7543	Y B (1/X)
13	0 0316	0 5493	0 0000	0 8114	0 8095	Y A*X (B*X)
14	0 0000	25 45	0 0000	0 3159	0 3089	Y A*X (B/X)
15	0 0080	1 004	0 0000	0 8077	0 8057	Y A*e (B*X)
16	1 565	6 299	0 0000	0 7568	0 7543	Y A*e^(B/X)
17	0 2088	0 3810	0 0000	0 6507	0 6471	Y A+B*1nX
18	31 03	23 29	0 0000	0 7602	0 7577	Y 1/(A+B*1nX)
19	0 0066	6 4210	2 0100	0 8119	0 8080	Y A*B X*X C
20	0 0000	82450 0	7 280	0 8115	0 8076	Y A*B (1/X)*X C
21	0 0193	0 8626	6 487	0 8118	0 8079	Y A*e ((X B)/2)
22	0 050	0 3368	0 4299	0 8118	0 8079	Y A*e ((1nX B) 2/C)
23	41 74	4 210	1 385	0 7859	0 7815	Y A*X B*(1 X) C
24	0 023	0 5378	2 010	0 8119	0 8080	Y A*(X/B) C*e (x/b)
25	3 278	3 985	2 158	0 7656	0 7608	Y 1/(A*(X+B) 2+C)

However the super geometrical model gave the maximum predictabilty for the basal area based on the foliar nitrogen concentration

$Y \quad A * X^{BX}$

$Y \quad 0\ 00615 * X^{0\ 6\quad X}$

where

Y Basal area in m^2 and

X Foliar N concentration (per cent) and

A and B are constants

This equation had the R^2 0 7661

To predict yield in terms of volume and nitrogen concentration the simple linear model was of the form

$Y \quad B * X + A$

$Y \quad 0\ 1575 * X \quad 0\ 261$

where

Y Volume in m and

X Foliar N concentration (per cent) and

A and B are constants

This equation had the R^2 of 0 7032

Here also the super geometrical mode gave the maximum predictability for the volume based on the foliar nitrogen concentration

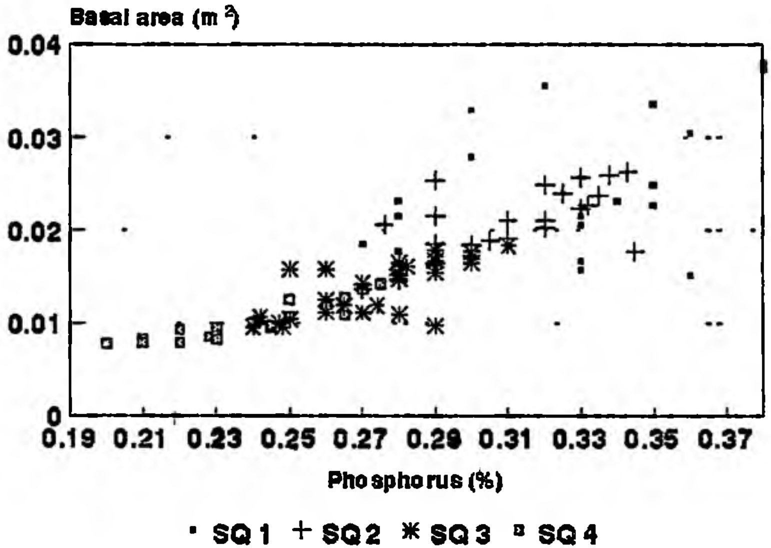

Fig. 6 Relationship between basal area and foliar phosphorus concentration in Teak grown in different site qualities

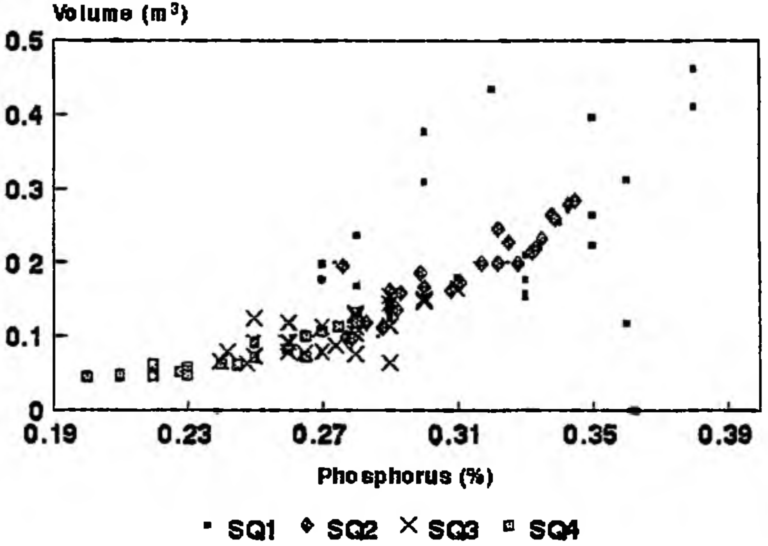

Fig. 7 Relationship between volume and foliar phosphorus concentration in Teak grown in different site qualities

$Y \quad A * X^{BX}$

$Y \quad 0\ 0316 * X^{0\ 549\ \ X}$

where

Y Volume in m and

X Foliar N concentration (per cent) and

A and B are constants

This equation had the R^2 0 8114

On plotting basal area and volume against the foliar P concentration both the parameters showed an increasing trend with increasing nutrient concentration However unlike in the case of foliar N concentration a little scattering was noticed in this relationship (Figs 6 and 7)

The equations developed to predict the yield in terms of basal area and volume based upon the foliar phosphorus concentration are given in Tables 9a and 9b respectively To predict the yield in terms of basal area and phosphorus concentration the simple linear model was of the forms

$Y \quad B * X + A$

$Y \quad 0\ 1441 * X \quad 0\ 0242$

where

Y Basal area in m^2 and

X Foliar P concentration (per cent)

A and B are constants

This equation had the R^2 0 6781

Table 9a Relationship between basal area and foliar phosphorus concentration in teak

Eq No	COEF A	COEF B	COEF C	R^2	R^2C	Equation
1	0 0242	0 1441	0 0000	0 6781	0 6748	Y A+B*X
2	0 0000	0 0611	0 0000	0 0000	0 0000	Y B*X
3	236 60	588 60	0 0000	0 7397	0 7371	Y 1/(A+B*X)
4	0 0574	0 2024	0 0046	0 6817	0 6751	Y A+B*X+C/X
5	0 0560	0 0110	0 0000	0 6397	0 6360	Y A+B/X
6	102 40	47 90	0 0000	0 7990	0 7970	Y X/(A*X+B)
7	0 1127	0 0422	0 0422	0 6816	0 6750	Y A+B/X+C/X*X
8	0 0069	0 0025	0 2103	0 6817	0 6751	Y A+B*X+C*X*X
9	0 0257	0 2924	0 0000	0 0000	0 0000	Y A*X+B*X*X
10	0 3565	2 472	0 0000	0 7567	0 7542	Y A*X B
11	0 0013	5772	0 0000	0 7454	0 7428	Y A*B X
12	0 1794	0 5054	0 0000	0 7549	0 7524	Y B (1/X)
13	0 0000	32 39	0 0000	0 7265	0 7237	Y A*X (B*X)
14	0 0608	0 2957	0 0000	0 7501	0 7475	Y A*X^(B/X)
15	0 0013	8 66	0 0000	0 7454	0 7428	Y A*e (B*X)
16	0 1794	0 6825	0 0000	0 7549	0 7524	Y A*e (B/X)
17	0 0680	0 0404	0 0000	0 6641	0 6607	Y A+B*1nX
18	147 1	170 8	0 0000	0 7758	0 7735	Y 1/(A+B*1nX)
19	4 497	0 0192	3 587	0 7579	0 7529	Y A*B X*X C
20	0 2813	0 7857	1 603	0 7575	0 7525	Y A*B^(1/X)*X^C
21	0 0376	0 4751	0 0429	0 7590	0 7540	Y A*e ((X B)/2)
22	0 3262	1 194	1 996	0 7577	0 7527	Y A*e ((1nX B) 2/C)
23	2 085	3 308	2 106	0 7581	0 7531	Y A*X^B*(1 X) C
25	3783 0	0 3669	37 84	0 8163	0 8126	Y 1/(A*(X+B)^2+C)

Table 9b Relationship between volume and foliar phosphorus concentration in teak

Eq No	COEF A	COEF B	COEF C	R^2	R^2C	Equation
1	0 3863	1 880	0 0000	0 6613	0 6578	Y A+B*X
2	0 0000	0 5557	0 0000	0 0000	0 0000	Y B*X
3	41 29	112 8	0 0000	0 7451	0 7425	Y 1/(A+B*X)
4	1 436	3 723	0 1466	0 6819	0 6753	Y A+B*X+C/X
5	0 6509	0 1403	0 0000	0 6004	0 5963	Y A+B/X
6	24 03	9 280	0 0000	0 8219	0 8201	Y X/(A*X+B)
7	1 675	0 7051	0 0764	0 6789	0 6722	Y A+B/X+C/X*X
8	0 1647	2 001	6 71	0 6824	0 6758	Y A+B*X+C*X*X
9	0 8589	4 765	0 0000	0 0000	0 0000	Y A*X+B*X*X
10	13 07	3 661	0 0000	0 7857	0 7835	Y A*X B
11	0 0033	380900 0	0 0000	0 7773	0 7750	Y A*B X
12	4 693	0 3648	0 0000	0 7804	0 7782	Y B (1/X)
13	0 0000	47 68	0 0000	0 7454	0 7428	Y A*X (B*X)
14	0 9459	0 4365	0 0000	0 7740	0 7717	Y A*X (B/X)
15	0 0033	12 85	0 0000	0 7773	0 7750	Y A*e (B*X)
16	4 693	1 008	0 0000	0 7804	0 7782	Y A*e (B/X)
17	0 8097	0 5221	0 0000	0 6356	0 6318	Y A+B*1nX
18	32 48	32 91	0 0000	0 7896	0 7875	Y 1/(A+B*1nX)
19	59 06	0 0954	4 324	0 7859	0 7814	Y A*B X*X C
20	11 99	0 9164	3 346	0 7857	0 7813	Y A*B (1/X)*X^C
21	0 5941	0 5135	0 0349	0 7869	0 7825	Y A*e ((X B)/2)
22	90630 0	6 103	4 030	0 7858	0 7814	Y A*e ((1nX B) 2/C)
23	41 74	4 210	1 385	0 7859	0 7815	Y A*X B*(1 X) C
25	854 5	0 3552	3 665	0 8522	0 8492	Y 1/(A*(X+B) 2+C)

The maximum predictability for the basal area based on the foliar phosphorus concentration was observed with the Couchy model

$$Y \quad 1/(A * (X + B)^2 + C)$$

$$Y \quad 1/(3783 * (X \quad 0\ 3669)^2 + 37\ 84)$$

where

Y Basal area in m^2 and

X Foliar N concentration (per cent) and

A B and C are constants

This equation had the R^2 0 8163

To predict yield in terms of volume and phosphorus concentration the simple linear model was of the form

$$Y \quad B * X + A$$

$$Y \quad 1\ 880 * X \quad 0\ 3863$$

where

Y Volume in m and

X - Foliar N concentration (per cent)

A and B are constants

This equation had the R^2 of 0 6613

Here also the maximum predictability for the volume based on the foliar phosphorus concentration was observed with the Couchy model

$$Y = 1/(A * (X + B)^2 + C)$$

$$Y = 1/(854.5 * (X - 0.3552)^2 + 3.665)$$

where

Y = Volume in m and

X = Foliar P concentration (per cent) and

A and B are constants

This equation had the R^2 = 0.8522

Similar to that of foliar nitrogen concentration when basal area and volume were plotted against the foliar potassium concentration the relationship represented a steady increase without much scattering (Fig 8 and 9)

The equatios developed to predict the yield in terms of basal area and volume based upon the foliar potassium concentration are given in Tables 10a and 10b respectively To predict the yield in terms of basal area and potassium concentration the simple linear model was of the form

$$Y = B * X + A$$

$$Y = 0.02697 * X - 0.0228$$

where

Y = Basal area in m^2 and

X = Foliar K concentration (per cent)

A and B are constants

This equation had the R^2 of 0.7621

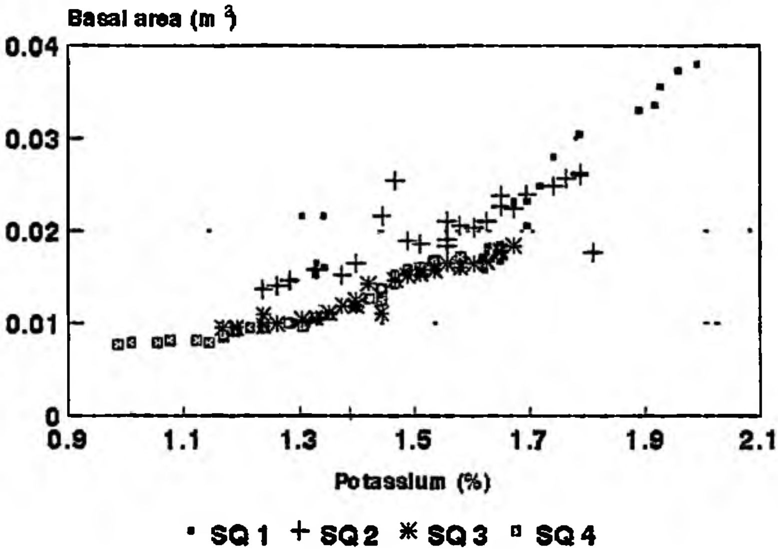

Fig. 8 Relationship between basal area and foliar potassium concentration in Teak grown in different site qualities

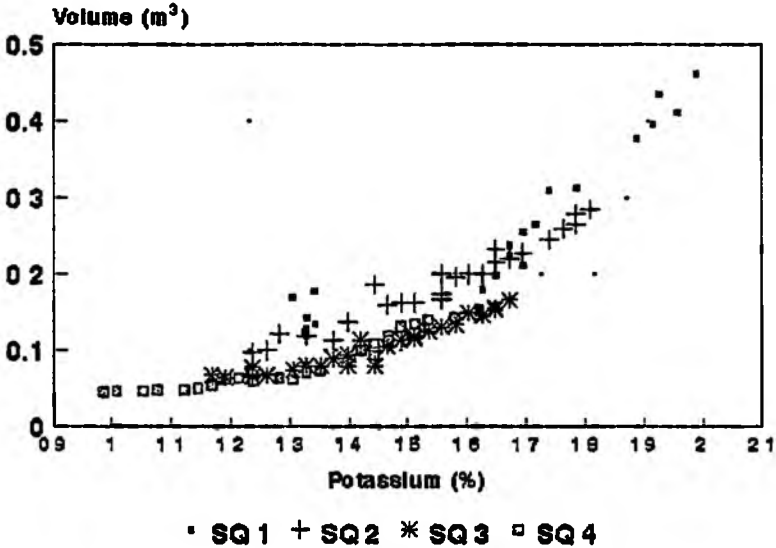

Fig. 9 Relationship between volume and foliar potassium concentration in Teak grown in different site qualities

Table 10a Relationship between basal area and foliar potassiumconcentration in teak

Eq No	COEF A	COEF B	COEF C	R^2	R^2C	Equation
1	0 0228	0 0270	0 0000	0 7621	0 7596	Y A+B*X
2	0 0000	0 0119	0 0000	0 0000	0 0000	Y B*X
3	224 94	106 20	0 0000	0 7729	0 7706	Y 1/(A+B*X)
4	0 1162	0 0590	0 0666	0 8014	0 7973	Y A+B*X+C/X
5	0 0528	0 0517	0 0000	0 6726	0 6692	Y A+B/X
6	85 06	221 1	0 0000	0 8050	0 8030	Y X/(A*X+B)
7	0 1276	0 2620	0 1444	0 7783	0 7738	Y A+B/X+C/X*X
8	0 0324	0 0491	0 0256	0 8125	0 8086	Y A+B*X+C*X*X
9	0 0052	0 0111	0 0000	0 0000	0 0000	Y A*X+B*X*X
10	0 0066	2 287	0 0000	0 7945	0 7924	Y A*X B
11	0 0015	4 887	0 0000	0 8030	0 8010	Y A*B X
12	0 1426	0 0418	0 0000	0 7727	0 7704	Y B (1/X)
13	0 0080	1 142	0 0000	0 8008	0 7987	Y-A*X (B*X)
14	0 0052	4 498	0 0000	0 7161	0 7132	Y A*X^(B/X)
15	0 0015	1 587	0 0000	0 8030	0 8010	Y A*e (B*X)
16	0 1426	3 175	0 0000	0 7727	0 7704	Y A*e^(B/X)
17	0 0026	0 0380	0 0000	0 7220	0 7192	Y A+B*1nX
18	127 20	156 2	0 0000	0 7960	0 7939	Y 1/(A+B*1nX)
19	0 0013	5 729	0 2314	0 8030	0 7990	Y A*B X*X C
20	0 0003	25 79	4 585	0 8019	0 7979	Y A*B (1/X)*X C
21	0 0000	6 588	10 17	0 8032	0 7991	Y A*e ((X B)/2)
22	0 0049	0 5931	0 8307	0 8025	0 7984	Y A*e ((1nX B) 2/C)
23	2 085	3 308	2 106	0 7581	0 7531	Y A*X B*(1 X) C
24	0 0015	0 5729	0 2314	0 8030	0 7990	Y A*(X/B) C*e (x/b)
25	79 51	2 151	28 18	0 8046	0 8006	Y 1/(A*(X+B) 2+C)

Table 10b Relationship between volume and foliar potassium concentration in teak

Eq No	COEF A	COEF B	COEF C	R^2	R^2C	Equation
1	0 3842	0 3628	0 0000	0 7907	0 7886	Y A+B*X
2	0 0000	0 1086	0 0000	0 0000	0 0000	Y B*X
3	39 24	20 48	0 0000	0 7879	0 7858	Y 1/(A+B*X)
4	2 241	0 9998	1 323	0 8800	0 8775	Y A+B*X+C/X
5	0 6230	0 6803	0 0000	0 6679	0 6645	Y A+B/X
6	20 95	43 23	0 0000	0 8434	0 8418	Y X/(A*X+B)
7	1 892	4 251	2 452	0 8427	0 8394	Y A+B/X+C/X*X
8	0 6798	1 104	0 4944	0 8982	0 8961	Y A+B*X+C*X*X
9	0 1833	0 1893	0 0000	0 0000	0 0000	Y A*X+B*X*X
10	0 0352	3 440	0 0000	0 8517	0 8502	Y A*X B
11	0 0038	10 93	0 0000	0 8642	0 8628	Y A*B X
12	3 522	0 0085	0 0000	0 8246	0 8228	Y B (1/X)
13	0 0467	1 723	0 0000	0 8642	0 8628	Y A*X (B*X)
14	0 0247	6 729	0 0000	0 7588	0 7564	Y A*X (B/X)
15	0 0038	2 392	0 0000	0 8642	0 8628	Y A*e (B*X)
16	3 522	4 766	0 0000	0 8246	0 8228	Y A*e (B/X)
17	0 0400	0 5063	0 0000	0 7334	0 7306	Y A+B*1nX
18	20 48	30 32	0 0000	0 8226	0 8208	Y 1/(A+B*1nX)
19	0 0018	23 90	1 139	0 8650	0 8622	Y A*B X*X C
20	0 0001	424 7	7 719	0 8639	0 8611	Y A*B (1/X)*X C
21	0 0013	2 373	3 225	0 8653	0 8625	Y A*e ((X B)/2)
22	0 0301	0 4184	0 4506	0 8645	0 8617	Y A*e ((1nX B) 2/C)
23	41 74	4 210	1 385	0 7859	0 7815	Y A*X B*(1 X) C
24	0 0068	0 3151	1 139	0 8650	0 8622	Y A*(X/B) C*e (x/b)
25	20 84	1 975	2 838	0 8476	0 8445	Y 1/(A*(X+B) 2+C)

170733

The maximum predictability for the basal area based on the foliar potassium concentration was observed with the Parabolic model

$Y \quad A + B * X + C * X^2$

$Y \quad 0\ 0324 \quad 0\ 0491 * X + 0\ 0256 * X^2$

where

Y Basal area in m^2 and

X Foliar K concentration (per cent) and

A B and C are constants

This equation had the R^2 0 8125

To predict yield in terms of volume and foliar potassium concentration the simple linear model was of the form

$Y \quad B * X + A$

$Y \quad 0\ 3628 * X \quad 0\ 3842$

where

Y Volume in m^3 and

X Foliar K concentration (per cent)

A B and C are constants

This equation had the R^2 of 0 7907

Here also the maximum predictability for the volume based on the foliar potassium concentration was observed with the Parabolic model

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$Y \quad A + B * X + C * X^2$

$Y \quad 0\ 6798 \quad 1\ 104 * X + 0\ 4944 * X^2$

where

Y Volume in m^3 and

X Foliar K concentration (per cent) and

A B and C are constants

This equation had the R^2 0 8982

However a higher R^2 could be obtained when the basal area and volume were related to both N and K concentrations by using multiple linear regression equation Nutrient levels and nutrient ratios were considered in different combinations as the independent variables and the maximum prediction was observed with the model

$Y \quad A + Bx + Cx_2 + Dx_3$

Basal area $\quad 0\ 022 + 0\ 005\ x + 0\ 018\ x_2 \quad 0\ 002\ x_3$

Volume $\quad 0\ 429 + 0\ 083\ x + 0\ 220\ x_2 + 0\ 068\ x_3$

Where

x foliar N concentration

x_2 foliar K concentration

x_3 ratio of foliar K by foliar N concentration

Y Basal area (m^2) or volume (m^3)

A B C and D are constants

The above models gave R^2 values of 0 82 and 0 83 for basal area and volume respectively

For all the four site quality plantations when basal area and volume were plotted against their respective foliar nutrient concentrations the yield parameters were found to increase with increasing foliar nutrient levels (Fig 4 5 6 7 8 and 9) A linear increase was observed in the case of foliar N and K whereas scattering was found in foliar P

Since the yield parameters increased with increasing nutrient levels and a plateau could not be observed from where the yield parameters decrease with increasing nutrient levels the critical nutrient level could not be fixed for any of the three nutrients

Discussion

DISCUSSION

5.1 Standardisation of canopy height

Results revealed that the bottom canopy recorded the highest concentrations of foliar N and K and the second highest concentration for foliar P Moreover the bottom canopy recorded the lowest coefficient of variation in the case of all the three nutrients Hence leaves taken from the bottom portion (the lower one third) of the tree canopy could provide a representative sample Further by restricting the sampling to branches at the bottom portion of the canopy the corresponding coefficients of variation for N P and K were diminished and the efficiency of the sampling was improved Also the bottom canopy is more convenient for plucking the leaves from the practical point of view

A tree s crown is a complex structure consisting of foliage of different ages growing at different positions within the crown (Ellis 1975) These varying positions have quite different environmental characteristics Consequently expressions of foliar nutrient concentrations are subjected to variation mainly depending on the solar radiation it receives In a dense forest usually the top canopy provides ideal leaf for sampling since it receives a greater proportion sunlight to enhance its productivity than the lower portion of canopy (Gosz *et al* 1978) More the availability of light more efficient will be the photosynthesis and higher will be the foliar nutrient concentration (Zakia *et al* 1983) However in a ten year old teak plantation there is seldom a chance for canopy closure thereby providing almost equal amount of sunlight for each of the three crown positions Hence the photosynthetic activity in all these positions are unlikely to undergo much variation

Evidences of low nutrient concentration in the shaded foliage are available from a study in *Pinus radiata* (Mead and Will 1976) Therefore they may be contributing very little to the net photosynthate production But in a young teak plantation shading of the leaves in the bottom crown position is very unlikely Further partially shaded leaves were observed to be the most productive in Douglas fir (Woodman 1971) This finding ties in well with reports of Hodges (1967) who showed that the seedlings of many Pacific North West Conifers photosynthesized best in the partially shaded boundary at the edge of forest openings

These likely differences within the tree which can occur when leaves of different age or position in the crown are sampled at different times of the season can be made as constant as practicable and the sampling position as sensitive as possible to growth measure by careful choice and definition

5.2 Standardisation of time of sampling

Results of the study indicated that leaves sampled between 9 a m to 11 a m recorded the highest concentration of foliar N and K It also had the second highest concentration of foliar P Further samples collected during this period recorded the lowest coefficient of variation for foliar K and the second lowest coefficient of variation for foliar N Based on these results 9 a m to 11 a m was taken as the best time for sample collection

Ivarsen *et al* (1985) observed that the best time to collect samples of corn is at mid day when nutrient concentrations are least likely to fluctuate from time of the day effects

Samples collected at 10 a m has the advantage of receiving a good amount of sunlight for their photosynthetic activity to be at peak (Whyte 1973)

Positive rates of net photosynthesis are recorded in the morning as soon as light intensity exceeds the compensation point (Daniel *et al* 1979) In the early morning stomata are open temperatures are low water is most available tissues are turgid and carbon dioxide content of the air is above average because winds and convection currents have not yet dispersed the carbon dioxide produced during the night by plant respiration decomposition of organic matter and soil respiration

Consequently rates of photosynthesis normally increase in direct proportion to increase in light intensity The increasing rate of photosynthesis will positively influence the nutrient concentration of foliage By mid to late morning rates of photosynthesis have reached their maximum and have started to decline because temperature are above the optimum plant water potentials are decreasing the stomata are partially closed and possibly the photosynthate is accumulating This decreasing rate of photosynthesis will subsequently influence the leaf nutrient concentration which are having a decreasing trend in the afternoon hours

5.3 Standardisation of leaf rank

The annual shoot in a branch contains leaves that cover a range of physiological development The foliar concentration of many elements were found to vary with the stage of leaf development (Barrows 1959) Since leaf analysis is used as a guide in planning fertilizer programmes selection of index tissue is very important (Lamb 1977)

Results revealed that the second leaf rank is the ideal one to sample in teak since it recorded the highest concentration of foliar N P and K Also it had the lowest coefficient of variations for foliar P and K

Foliage of different ages in trees is often distinctly different in nutrient levels but current foliage is generally accepted as the most useful for diagnostic purposes (Leaf 1973) Current foliage usually has higher concentration and often has lesser between tree variability although this is not invariably true for all elements and all crown positions (Lowry and Award 1969) Similarly Commerford (1981) found that while K levels in *Pinus resinosa* on a K deficient site were highest in the youngest foliage older foliage had the lowest between tree variations It was suggested that as the nutrient stress results in translocation of the more mobile elements from older to current foliage analysing the older foliage would give a better indication of this stress However nutrient concentration in older foliage does not always give the best correlation with growth (Van den Driesche 1974) and under severe stress older foliage may have fallen

Moreover leaves of different ages show variation in their photosynthetic efficiency mainly because of the marked effects of different rates of respiration The amount of assimilates used by leaves in respiration is normally 5 to 10 per cent of gross photosynthate production however young leaves have been found to respire considerably more than this amount (Huber and Rusch 1961) In conifers which usually maintain several age classes of needles concurrently the fully expanded one year old foliage is the most important of all age classes As foliar age increases net photosynthesis decreases (Brix 1983) In this study also a decreasing trend in the foliar nutrient concentration starting from the second leaf rank down to the fifth was found This clearly supports the view that the younger the leaves more active they are physiologically and higher will be their foliar nutrient concentration

Eventhough the first leaf rank was the youngest of the five leaf ranks it is supposed to be in a stage of development yet to achieve their full maturity Hence its foliar nutrient concentration is likely to be lower than the second leaf rank which is often recognised as the youngest fully matured leaf in a twig

5.4 Standardisation of diameter class

Results revealed that the fourth diameter class which is the biggest of all the four diameter classes chosen for the study recorded the highest concentration and the lowest coefficient of variation for all the three foliar nutrients Based on the above observations the fourth diameter class was taken as the ideal one to sample for the determination of seasonal variation in nutrient concentration

The increase in the foliar nutrient concentration with increasing diameter class may be due to the fact that the trees which grow actively have a greater capacity to take up more nutrients when compared to the less active ones or availability of large nutrient concentration may be resulting in larger diameter growth Further more active the trees more will be their photosynthetic efficiency

Similar results were obtained in the study on critical concentration where basal area and volume showed an increasing trend with increasing foliar nutrient concentration Rosily (1990) in her study in cashew observed that for a unit increase in leaf K per cent an yield increase of 5 129 kg nuts could be obtained It is only logical that a high yielding teak representing a higher diameter class need more quantity of nutrients than a low yielding teak

5.5 Seasonal variations in foliar nutrient concentrations

Sampling schemes have long recognized the marked seasonal variation in nutrient levels in a plantation ecosystem For most species seasonal trends differ markedly between nutrients with the more mobile elements (e g N P K) tending to show low levels in summer periods while less mobile elements such as Ca and Al tending to accumulate through out the growing season (Nambiar and Bowen 1984)

Similarly results of this study reveal a very low concentration of N P and K being recorded in the summer months starting from February to April Afterwards it started increasing reaching its peak during June

In teak leaf fall occurs during the months of January February and March and flushes start during the months of May and June Physiologically new flushes will be more active and will certainly have more nutrient concentration than the older ones As discussed in the standardisation of leaf rank young leaves are found to photosynthesize more efficiently than the older ones Moreover net photosynthesis decreases with increasing age So the newly produced leaves can be one of the reasons for the high foliar nutrient concentration recorded during the months of June and July

Precipitation is an important source of nutrient input in any ecosystem Rain brings with it appreciable quantities of most plant nutrients There is also interception on plant surfaces of wind borne elements (aerosols) which adds to the nutrient content of rain water flowing over the plant The amount of N brought in by precipitation and aerosol to the soil varies with location from 2 to 13 kg/ha/year Input of P and K from aerosol and precipitation are of the order of 0 1 to 0 9 and 0 1 to 7 7 kg/ha/year respectively (Kimmins 1977) Further throughfall plays an important role in stimulating the decomposition process thus making the nutrients readily available from the soil This has added significance in the increased nutrient uptake during the rainy months (Mayer and Ulrich 1974)

Ludelers and Buneman (1973) observed a very high nutrient uptake in apple during the months of June July August and September Nutrient reserves in the trees from previous year s nutrient cycling were mobilised in June with the commencement of rain which is highly essential for flower bud initiation which occurs during the months of June and July

A large quantity of nutrients are taken up by plants along with the uptake of moisture from the soil Since there is unlimited supply of soil moisture during the rainy season the uptake of nutrients is also relatively high resulting in a higher foliar nutrient concentration (Eriksson 1959)

However despite the continuance of rain a decline in the foliar nutrient concentration was observed during the months of July and August Significant leaching coupled with a larger demand of nutrients for the new growth would have been responsible for the decrease in the nutrient status of the foliage (Lindberg *et al* 1979) This decline was steeper in the case of K than the other two nutrients This could be due to the fact that K being a more mobile element is easily leached down by the rain compared to N and P (Tukey 1970)

The low foliar nutrient concentration observed during the summer months may be partly due to the insufficient soil moisture and partly due to the leaf fall As tissues senesce as at leaf abscission nutrient ions other than those irretrievably bound to structural tissues are liable to be withdrawn back into the living tissues resulting in a lower concentration in the foliage (Albrektson *et al* 1977) The decrease in the foliar nutrient concentration during the summer months may also be due to the fact that the plant will be preparing for the new flush with greater accumulation of dry matter (Miller *et al* 1976)

5.6 Determination of critical nutrient level

In most productive forest regions of the world nutrient supplies are adequate for growth However productivity of even high site quality forest land can generally be enhanced by application of fertilizers because the availability of nutrients in the rooting zone may be too low to permit maximum growth rates In such circumstances determining the critical nutrient level will be highly beneficial

Results revealed an increasing trend in both basal area and volume with increasing foliar nutrient concentration for all the four site qualities

Since one of the aims of the foliar diagnosis is to predict yield based on the nutrient levels of leaf tissue attempts were made to formulate prediction equation considering the status of nutrients and their ratios The equations developed produced a good relationship between the yield parameters and foliar nutrient concentrations especially N and K The critical nutrient level could not be determined since for all the site qualities yield parameter increased with increasing foliar nutrient concentration and no plateau was obtainable

The foliar concentration of N P and K was found to be higher in better site qualities where conditions are more favourable for growth It is only logical that a high yielding teak growing in better site qualities need more quantity of nutrients than a low yielding teak Also high nutrient availability in soil is normally reflected in high foliar concentration (Miller 1982)

The equations developed represents a good relationship between foliar nutrient concentration and yield This is an indication of the very strong influence of the nutrients in increasing the growth of teak The results thus strongly convey the need for recommending fertilizer application for teak based on the relation between foliar N P and K on the one hand and basal area and volume of teak on the other

The failure in fixing the critical concentration could be due to the efficient nutrient cycling which is quite common in teak plantations (Nwoboshi 1984) Nutrient distribution coupled with rotation length and degree of harvesting has important applications in maintaining the sustained productivity of the plantation site (Woods 1976) During the rotation mainly the nutrients in the leaves are recycled yearly At 15 years of age this amounted to 30 50 per cent of the total annual uptake in teak At this age a teak stand of site quality I whose dry weight was about 592 mt/ha contained about 2 228 kg of N 1788 kg of K and 447 kg of P per hectare The annual nutrient requirement at the same age was estimated as 357 kg of N 328 kg of K and 76 kg of P per hectare (Nwoboshi 1984) This is a clear indication of the efficient nutrient cycling occurring in a young teak plantation

A primary factor in understanding nutrient availability and cycling rates is that the growth of the forest will cause nutrients to be retained in biomass or litter thus reducing nutrient availability This is a normal pattern and most plant species commonly those used in plantations have evolved mechanisms to deal with reduced availability In most of the forest ecosystems nutrient cycling rates and nutrient requirements are expected to show parallel patterns Deficiency of a nutrient is very unlikely in such an ecosystem unless it is subjected to adverse environmental effects

Thus this study has recognised the importance of sampling the teak leaves between 9 a m to 11 a m from the second leaf rank and the bottom canopy of the fourth diameter class in teak Foliar nutrient concentration were subjected to monthly variation with higher concentrations being recorded during rainy months and lower concentration during the dry months

The present investigation has also shown that the basal area and volume increased with increasing foliar nutrient concentration So it is clearly recommendable that these yield parameters could be increased further by adequate supply of the appropriate nutrient elements

Summary

SUMMARY

Diagnosis of nutrient deficiency of teak (*Tectona grandis* L f) was taken up with the basic objective of determining the critical concentration values for three foliar nutrients namely N P and K An attempt was also made to standardize the sampling height time of sampling leaf rank and diameter class from which leaves could be collected These standardised parameters were employed in the study of seasonal variation of foliar nutrient elements and in the determination of critical concentration Study was also undertaken to finalise whether the concentrated sulphuric acid selenium mixture which can be used to analyse N P and K is as effective as the diacid mixture which can be used only for analyzing P and K and the N digestion mixture (Kjeldahl digestion) which can be used only for analysing the N concentration

For the standardisation and the seasonal variation study leaf samples were collected from a ten year old second quality teak plantation belonging to Nilambur range of Malappuram district For studying the critical nutrient level leaf samples were taken from four different Teak plantations of Nilambur range belonging to first second third and fourth site qualities Chemical analysis of the leaf samples for N P and K were carried out in the College of Forestry Kerala Agricultural University Vellanikkara

The salient findings of the present investigation are summarised below

1 Concentrated sulphuric acid selenium mixture was taken up for digesting the leaf samples since it can be used for analysing all the three nutrients viz N P and K The P and K values recorded by this mixture were higher than those by diacid mixture Further the foliar N concentration observed when analysed with concentrated sulphuric acid/selenium mixture did not show much variation from those observed under concentrated sulphuric acid anhydrous sodium sulphate copper sulphate mixture which can only be used for the analysis of N

2 Leaf sample collection from the bottom canopy from 9 a m to 11 a m was taken as the standard since it recorded the maximum concentration and minimum coefficient of variation than the top and middle canopies Similarly the second leaf rank and fourth diameter class were found to be the ideal for collecting the leaf sample

3 In the seasonal variation study it was observed that for all the three nutrients higher values were recorded during the rainy months viz June July August and September and lower concentrations during the dry months viz January February March and April

4 For the determination of critical nutrient level the basal area and volume of each tree were plotted against their respective foliar N P and K concentration Since both the yield parameters showed an increasing trend with increasing foliar nutrient concentration the critical nutrient level for any of these elements could not be fixed

5 The following equations were developed for predicting the yield based on foliar nutrient level

A simple linear model of the form Y B * X + A was used to predict the yield in terms of basal area or volume and the foliar nutrient concentration

Where

Y basal area (m^2) or volume (m)

X foliar nutrient concentration and

A and B are constants

But the predictability value was higher when basal area or volume was related to foliar nitrogen phosphorus and potassium concentration using the super geometric model Couchy model and parabolic model respectively

The super geometric model used for the relationship between basal area or volume and foliar nitrogen concentration was of the form

$$Y \quad A * X^{BX}$$

where

Y Basal area m^2 or volume m

X Foliar N concentration (per cent) and

A and B are constants

The Couchy model which gave the maximum predictability value for the relationship between basal area or volume and foliar phosphorus concentration was of the form

$$Y \quad 1/(A * (X+B)^2 + C)$$

Y Basal area (m^2) or volume (m^3)

X Foliar P concentration (per cent) and

A B and C are constants

The parabolic model fitted for the relationship between basal area or volume and foliar potassium concentration was of the form

$$Y \quad A + B * X + C * X^2$$

Y Basal area (m^2) or volume (m^3)

X Foliar K concentration (per cent) and

A B and C are constants

However a higher R^2 could be obtained when basal area and volume were related to both N and K concentrations by using multiple linear regression equation of the form

$$Y \quad A + Bx \quad + Cx_2 + Dx_3$$

where

x_1 foliar N concentration

x_2 foliar K concentration

x_3 ratio of foliar K by foliar N concentration

Y Basal area (m^2) or volume (m)

A B C and D are constants

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NUTRIENT DEFICIENCY DIAGNOSIS
IN *Tectona grandis* L.f

BY

JAYAMADHAVAN A.

ABSTRACT OF A THESIS

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Department of Sılvıculture and Agroforestry
COLLEGE OF FORESTRY
Vellanıkkara Thrıssur 680 654

1996

ABSTRACT

The foliar nutrient concentration of ten year old Teak plants collected from the Nilambur Teak plantation were analysed to standardize the canopy height time of sampling leaf rank and diameter class during the period 1992 94 Also the leaf samples from the standardised position and time interval were analysed for a period of thirteen months starting from August 1993 to August 1994 to study the variation in the foliar N P and K concentration with season Further leaf samples from four different site qualities viz site quality I II III and IV were analysed to determine the critical nutrient level The chemical analysis of the leaf samples were carried out in the College of Forestry Kerala Agricultural University Vellanikkara

Since mean nutrient concentration was high and varied little among the samples leaves taken from the bottom position of the crown during the time interval 9 a m to 11 a m were taken as the standard Similarly the second leaf rank from the tip and the fourth diameter class which was the largest (16 75 cm 20 cm) were found to be ideal for sampling The foliar nutrient concentration were higher during the period starting from June to September which received high rainfall and were low during the drier months of January February March

and April Equations were developed to predict the yield based on foliar nutrient concentration

A simple linear model of the form Y B * X + A was used to predict the yield in terms of basal area or volume and the foliar nutrient concentration where Y basal area (m^2) or volume (m) X foliar nutrient concentration and A and B are constants

But a higher predictability was obtained for the relationship between basal area or volume and foliar nitrogen phosphorus and potassium concentration when fitted with super geometrical model Couchy model and parabolic model respectively The super geometrical model used for the relationship between basal area or volume and foliar nitrogen concentration was of the form

$$Y - A * X^{BX}$$

where

Y Basal area or volume

X Foliar N concentration (per cent) and

A and B are constants

The Couchy model fitted for the relationship between basal area or volume and foliar phosphorus concentration was of the form

Y $1/(A * (X+B)^2 + C)$

Y Basal area (m^2) or volume (m^3)

X Foliar P concentration (per cent) and

A B and C are constants

The parabolic model which gave the maximum predictability value for the relationship between basal area or volume and foliar potassium concentration was of the form

Y $A + B * X + C * X^2$

Y Basal area (m^2) or volume (m^3)

X Foliar K concentration (per cent) and

A B and C are constants

Higher R^2 could be obtained when basal area and volume were related to both N and K concentration by using multiple linear regression equation of the form

Y $A + Bx + Cx_2 + Dx$

where

x foliar N concentration

x_2 foliar K concentration

x_3 ratio of foliar K by foliar N concentration

Y Basal area (m^2) or volume (m)

A B C and D are constants

However the critical nutrient level could not be determined since for all the site qualities the basal area and volume increased with increasing foliar nutrient concentration

Appendix I

Twenty five standard equations used for predicting the yield in terms of basal area and volume

Eq No	Equations	
1	Y A+B*X	STR LINE
2	Y B*X	LINE THRU ORG
3	Y 1/(A+B*X)	REC STR LINE
4	Y A+B*X+C/X	LIN AND RECIP
5	Y A+B/X	HYPERBOLA
6	Y X/(A*X+B)	RECIP HYPERBOLA
7	Y A+B/X+C/X*X	2ND ORD HYP
8	Y A+B*X+C*X*X	PARABOLA
9	Y A*X+B*X*X	PAR AT ORIGIN
10	Y A*X B	POWER
11	Y A*B X	MOD POWER
12	Y B (1/X)	ROOT
13	Y A*X (B*X)	SUPER GEOMET
14	Y A*X (B/X)	MOD GEOMETRIC
15	Y A*e (B*X)	EXPONENTIAL
16	Y-A*e (B/X)	MOD EXPONENTIAL
17	Y A+B*1nX	LOGARITHMIC
18	Y 1/(A+B*1nX)	RECIP LOG
19	Y A*B X*X C	HOERL FUNCTION
20	Y A*B (1/X)*X C	MOD HOERL
21	Y A*e ((X B)/2)	NORMAL
22	Y A*e ((1nX B) 2/C)	LOG NORMAL
23	Y A*X B*(1 X) C	BETA
24	Y A*(X/B) C*e (x/b)	GAMMA
25	Y 1/(A*(X+B) 2+C)	CAUCHY