STAND DENSITY MANIPULATION AND FERTILIZATION STUDIES ON TEAK

By

SANJAYKUMAR R. GAWANDE

THESIS

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE

MASTER OF SCIENCE IN FORESTRY

KERALA AGRICULTURAL UNIVERSITY

FACULTY OF AGRICULTURE

COLLEGE OF FORESTRY

VELLANIKKARA - THRISSUR

1991

Dedicated to ......

My Beloved Parents

DECLARATION

I hereby declare that this thesis entitled "Stand density manipulation and fetilization studies on teak " 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.

Place: Vellanikkara
Date :

(Sanjay R. Gawande)

CERTIFICATE

Certified that this thesis, entitled "Stand density manipulation and fertilization studies on teak" is a record of research work done independently by Shri. Sanjay R. Gawande 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. B. Mohankumar
Associate Professor and
Chairman, Advisory
Committee,
College of Forestry,
Kerala Agricultural
University.

Place : Vellanikkara
Date : 1 2 92

Approved by :

Chairman

Dr. B. Mohankumar,
Associate Professor,
College of Forestry,
Kerala Agricultural University.

Members

~~1. Dr~~. C. C. Abraham,
Special Officer,
College of Forestry,
Kerala Agricultural University.

2. Dr. N. K. Vijayakumar,
Associate Professor,
College of Forestry,
Kerala Agricultural University.

3. Shri. V.K.G. Unnithan,
Associate Professor,
Dept. of Agrl. Statistics,
College of Horticulture.

External Examiner

23 3 92

Dr O Anchanam Alagia Pillai

CONTENTS

ACKNOWLEDGEMENTS

I wish to express my deep sense of gratitude and indebtness to Dr. B. Mohankumar, Associate Professor, College of Forestry, Kerala Agricultural University, and Chairman of my Advisory Committee for his valuable guidance, critical suggestions and constant encouragement during the course of this investigation and writing of this thesis.

I am grateful to Dr. C.C. Abraham, Special Officer, Dr. N.K. Vijayakumar, Associate Professor, College of Forestry, and Shri. V.K.G. Unnithan, Associate Professor, College of Horticulture, for their sincere help, guidance, inspiring suggestions and encouragement duing the course of the investigation and also the preparation of the manuscript.

My sincere gratitude to Dr. Sankar, Head of Department of Soil Science Division, Kerala Forest Research Institute and thanks are also due to Dr. K.Jayaram, Head of Statistic Division, Mr. Rajan and Mr. Sreekumar, Programmers, Kerala Forest Research Institute, for helping me in the tedious computations.

I am greatly indebted to Dr. Kesava Rao, Mrs. Shilaja, Dept. of Agrl. Meteorology for helping me in developing models in the computer and their kind co-operation during the course of work.

The author is also grateful to library staff of Kerala Forest Research Institute, College of Horticulture and College of Forestry, Kerala Agricultural University, Vellanikkara for the invaluable help and assistance received during the course of this research work.

I am thankful to Kerala Agricultural University for granting me a Junior Fellowship and also contingent expenditures for the research without which this work was not possible.

Thanks are also due to M/s BLAISE COMPUTER CONSULTANCY, Mannuthy for neat typing and reprography work.

Last, but not the least, I would like to thank my all friends for the help and encouragement received at various stages of this work. Among them Mr.Abdul Aziz is highly acknowledged.

(SANJAYKUMAR GAWANDE)

LIST OF TABLES

Introduction

I. INTRODUCTION

Teak (*Tectona grandis* Linn. f.) is the paragon among oriental timbers. Dietrich Brandis aptly described it as a "jewel that shines and shimmers in the diadem of tropical trees". The natural habitat of teak is between 10° and 25° N on the Indian subcontinent and in the south-east Asia especially in Laos, Combodia and Vietnam. It is cultivated quite extensively in the warm tropics throughout the world, for instance in Congo, Cameroon, Zaire, Nigeria, Thailand, Honduras, and Costa Rica.

In India the principal states growing teak are Kerala, (76,502 ha; KSFD, 1990), Madhya Pradesh, Maharashtra, Gujarat, Karnataka, Andhra Pradesh, Tamil Nadu, Rajasthan, West Bengal, Bihar, Orissa and Andamans covering a total area of about 7.1 million ha (CFC, 1984). However, the productivity of teak plantations in India is generally very low (6.5 m^{-3} ha^{-1} yr^{-1}; Agrawal, 1985). Reasons for the low productivity include weed competition particularly when the plantations were young (Anoop et al., 1991), poor management (Karunakaran, 1970; Iyer, 1982) nutrient deficiencies and stagnation. Although reports of improved growth rates of hardwoods in response to fertilizer application are available (Hoyle, 1970; Saffard, 1973; Auchnoody and Filip, 1977), fertilizer application in teak plantations has been rarely attempted in the past. Furthermore, only some isolated attempts were made in the past to characterize the fertilizer requirement of teak in the Indian context (FRI, 1955; FDAP, 1964; Bhatnagar et al., 1969; Banerjee, 1973; Ram Prasad et al., 1986; Kishore, 1987).

As a silvicultural tool, fertilization will enable intensive forestry to be practised almost indefinitely without fear of loss in productivity through nutrient drain from the site. Under intensive forest management (fast growth, short rotations and full tree utilization) most forest sites might suffer a net loss in nutrient reserves over time (second rotation decline). The capability to identify and replenish such massive nutrient losses by fertilization is very important in the context of the ever-increasing demand for timber. Furthermore, balanced fertilization can contribute to increase the resistance of trees to damage from insects, diseases and other adverse environmental factors also (Baule, 1973) through enhanced tree vigour. Fertilization has great value in accelerating recovery from thinning also (Miller, 1984).

As regards to thinning the age old thinning norm - begin early, thin frequently, thin moderately - seems to be in vogue in the case of teak particularly on the better quality teak areas of India (Kadambi, 1972), notably in Nilambur (Kerala) where, thinning normally begins as early as the fourth year and are repeated at 8,13,20,30 and 45 years (or its slight variants) with a rotation of age of 60 years (Karunakaran, 1970; Adiyodi, 1973; Iyer, 1982). Incidentally fifty year rotations are also practiced in several parts of the state.

In studies involving thinning and fertilization of a large number of forestry species the general consensus is that response to fertilization is greater in the thinned stands as the resources become available to fewer, larger, selected stems. Such considerations favour the coincidence of thinning and fertilizing operations. Detailed information on thinning and fertilization are, however, lacking in the case of teak under the eco-climatic conditions of Kerala.

Moreover, large gaps exists in our knowledge on the effects of stand density manipulation, site quality and nutrition on the components of assimilation, such as leaf area, photosynthesis and distribution of assimilates. Hence the present investigation was carried out with the objective of developing fertilization and density manipulation strategies for teak plantations.

Determination of the effect of thinning and fertilization on teak growth and development including tissue nutrient levels under different site quality levels and understanding of the nature of relationships between stand leaf area index, stemwood growth, growth efficiency and NPK availability in teak as well as characterization of the allometry of tree biomass, leaf area and foliage biomass in young teak trees, were the major focal points of the present study.

Review of Literature

II. REVIEW OF LITERATURE

Fertilization and thinning are the two basic silvicultural tools available for regulation and control of growth and yield in forest plantations. Thinning manipulates stand density and thereby modifies the competition environment, while fertilization alters the nutrient capital of the site. An attempt is made here to review the available literature on nutrient requirements and nature and effects of thinning and fertilization on forest plantations with particular reference to teak.

2.1 Nutritional Requirements of Teak

Teak is characterized by relatively high nutrient requirements. Zech and Drechsel (1991) reported that nutrient deficiencies can bring about reduced stand growth in teak. The deficiency of all elements except potassium has significantly reduced height, growth and dry matter production in teak seedlings (Kaul et al., 1972; Hase and Foelster, 1983). However, only few studies on teak nutrition have been conducted in India and the results are also, by and large, inconsistent. Trials at Nilambur and elsewhere indicated that application of NPK in young plantations boosted growth rate of teak (FRI, 1955; FDAP, 1964; Banerjee, 1973; Kishore, 1987). Bhatnagar et al. (1969) from sand culture studies on teak suggested that application of 680 mg each of N, P_2O_5 and K_2O increased growth of teak. Fertilizers at the rate of 0,150 or 300 kg/ha of urea and 0,75 or 150 kg/ha of super phosphate stimulated growth of a 10 year old teak plantation (Ram Prasad et al., 1986). They concluded that fertilizers significantly increased height and diameter increments of teak trees.

However, Maun (1977) observed that application of slow release tablets (18:8:6 NPK) did not improve the growth of teak seedlings. Similarly several authors (Briscoe and Ybarra-coronado, 1972; Jackson, 1973; Sunderalingam, 1982) reported that application of N alone did not significantly improve the growth of teak.

2.2 Fertilizer use in Plantation Forestry

With intensification of forestry practices, multiple nutrient deficiencies became common and the practice of applying compound NP, KP and NPK fertilizers or blended mixtures of fertilizers containing these elements became popular in forestry (Bengtson, 1976; Ballard, 1980). Further, application of K was found to be useful in producing higher volume increment (Ballard, 1980). However, there is little information on how frequently elements other than N and P are to be applied to stands.

2.2.1 Stimulation of Growth

Stimulation of hard wood growth by fertilizer application on good sites has been reported by several authors (Mader et al., 1969; Hoyle, 1970; Auchnoody and Filip, 1973; Mader, 1973, Safford, 1973; Tiarks and Haywood, 1986). Ranwell et al. 1974, reported that application of fertilizers increased the growth rates of Eucalyptus grandis and Pinus patula by 30 per cent, compared to unfertilized trees. In case of sugar maple also improved growth was observed when treated with N,P and K alone or in combination (Shetron, 1976).

There are reports showing increases in height, diameter and basal area owing to fertilizer application. Paovilainen (1976) indicated that in sedges and pines, NPK stimulated basal area increment. Nitrogenous fertilizers also increased basal the area and height of Pinus radiata (Hemter and Hay, 1983). In Loblolly pine also significant increases in height and diameter were observed on addition of N and P fertilizers (Bolstand and Allen, 1987).

It has been suggested that environment regulates plant productivity through its influences on leaf area, carbon fixation and carbon allocation pattern (Kramer, 1986). Environmental factors limiting leaf area include nutrient and water availability, as well as temperature. Fertilizers increased leaf area index (LAI) in a number of conifer species (Miller and

Miller, 1976; Binkely and Reid, 1984). Foliage biomass was significantly increased in Loblolly pine by NPK application. In fact, moderate levels of fertilizers produced 1.6 times higher foliage weight than unfertilized controls (Duffy, 1977). Fertilizers were used to accelerate foliage production and formation of a permanent cover (Duffy, 1977; Hocker, 1982). In Eucalyptus camaldulensis above ground biomass increased by 35 per cent with NPK fertilizers (Knockert and Mandouri, 1980).

2.2.2 Timing, Frequency and Doses of Fertilizers

There is very little quantitative evaluation of how much nutrient a species need for high and substained growth rates and optimum stem wood production. The characteristics of fertilizers used in forests, their relative effectiveness, transformation and movement in forest ecosystems are critical and needs consideration (Baule and Fricker, 1970; Bengtson, 1973,1976, Pritchett, 1979; Ballard, 1984). Miller (1984) has developed nutritional guides for trees which suggest that nutritional demand of trees is usually high before canopy closure. Therefore, fertilizer responses are most likely to be realised at this stage and the response will be lower in mid-rotation, because much of nutritional demand will be met by retranslocation.

Fertilizing of young plantations is generally practiced to hasten crown closure and reduce time of weeding (Kanwana and Leaf, 1974). Further, fertilization of established stands is effective in increasing growth and shortening rotation length. Paovilainen (1975) reported that the need for N was greater at the pole stage than at maturity. In Eucalyptus grandis it was seen that fertilizer should be applied just enough to ensure rapid canopy closure (Donald and Schutlz, 1977; Louppe, 1985). Due to translocation and reuse of nutrients in trees the uptake of all nutrients by the stand from the soil also decreased with age (Attiwill, 1980). Hence, he concluded that fertilization at young stage is beneficial for forest plantations. In a study, on Picea abies, Badan et al. (1977) found it is profitable to use NPK and Ca in pole stage stands. Further, they observed that fertilization of seventy year old stand resulted in reduced increments.

The major factors determining frequency of fertilizing established stands appear to be the frequency of other silvicultural operations and duration of response from single application (Woollons and Will, 1975; Hamamoto, 1981). Spot application of N and P fertilizers usually provide a short-term response seldom retaining effectiveness beyond 3-5 years (Ballard, 1980). The frequency of fertilization also depend upon various site factors which play important roles in the fertilizer effect. From an experiment on Pinus elliottii with nitrogen (30 and 150 lb/acre) and NPK fertilizers (30:60:60 and 150:60:60 lb/acre), Walker and Morcock (1965) concluded that nitrogen treatments did not give significant diameter increment whereas, a combination of NPK resulted in a slight increase in diameter growth. In _Abies alba_ and _Pinus strobus_, N,P and K fertilizers (10:10:10 kg/ha) were effective in increasing height increment of both species; while NPK (11:22:16 kg/ha) had significant effects on the height and girth increments (Ciancio and Martire, 1974). The results of Frison (1976), in _Populus_ (I-214) with NPK at the rate of 160, 200 and 300 kg/ha indicated that NPK application had significant effects on the volume increment. Another study in a 13 year old _Pinus elliottii_ stand by Shoulders and Tiarks (1980), indicated that surface application of NPK (403:95:64 kg/ha) increased total volume growth during the next six years. Application of P in conjunction with N and K often has synergistic effects on the utilization of these elements, probably through stimulating root activity, increasing soil cation exchange capacity (Ryden et al., 1977) and reducing volatization of N (Wollum and Davey, 1975).

Suvorov (1973), studied the effects of application of nitrogen alone on Norway spruce and found that as nitrogen increased, the content of chlorophyll in needles, the rate of photosynthesis, respiration and root mass with height and diameter increment increased. This increase was 2 to 3 times more than that of trees that did not receive nitrogen. In case of 9- year old Populus deltoides plantation, application of 150 or 300 lb/acre of N increased diameter increment in the co-dominant and intermediate classes (De Bell et al., 1975). Nitrogen and phosphorus were found to be better than NPK and NPS treatments at 5, 10 or 15 NP per plant for growth stimulation.

Negative responses to combined fertilization are also reported in the literature. Salonie and Mackay (1980) reported that neither 48 kg/ha of NPK nor 224 kg/ha of Urea gave detectable differences over the next ten years in a 28 - year old balsam fir plantation. Similar results were obtained by Stone (1982), when 2.6 kg per tree of NPK (20:20:20) did not significantly affect sugar maple over six years. With Tilima americana and Ulnus americana, Stone et al. (1982) observed that 2.6 kg of NPK had no effect on diameter or basal area over the six years. The probable reasons for negative response could be site factors which may have a direct influence on the fertilization effect.

2.3 Thinning

It is necessary that number of plants per unit area in stands is gradually reduced as the crop advances in age, ie. the stands should be thinned as they grow with age. Thinning may, therefore, be defined as " a felling made in an immature stand for the purpose of improving the growth and form of the trees that remain, without permanently breaking the canopy" (Khanna, 1984). The control of density levels in a stand has tremendous impact on stand structure, productivity and its ability to produce multiple outputs. Density management is the manipulation and control of growing stock to achieve through initial spacing and intermediate cuttings. Prasoon Kumar (1991) has designed a teak density management diagram that provides insights on stand density regulation for various management objectives.

2.3.1 Effect of Stand Density Manipulation on Tree Growth

Tree morphology is markedly affected by stand density. In dense stands, as in sparser stands the live crown ratio is lower due to the earlier death of lower limbs on account of mutual shading and "crown competition" (Putz et al., 1984). This also results in higher bud loss and lower foliage production owing to physical crowdings, as crowns rub against each other in the wind. Long and Smith (1989), remarked that the growth and development of individual trees in an young stand depend in large part, on the initial stand density.

Stand density, however, has very little effect on height growth except where the stand is extremely dense or so open that the trees are distinctly isolated (Smith, 1962). Further he noted that variation in radial growth that can be induced by thinning is very wide. Larson (1969), observed that xylem increments were thicker in close proximity of the crown in thinned stands, resulting in more cylindrical boles than those of widely spaced stands, Grah, (1961) and Barger and Ffolliott, (1970) also reported that the relationship between stem characteristics and initial stand density affects the value and utility of a log for a particular end product.

Nebekar et al. (1985) suggested that quite apart from improving the growth and value of stands, thinning also results in hazard reduction for insect infection, disease epidemics and damages due to abiotic agents.

2.3.2 Thinning Studies in Teak

Thinning in teak is a very important intermediate operation. It is generally recognized that teak requires ample room for its development and that once the crowns have been allowed to be restricted, they do not respond rapidly to thinning (Blanford, 1923). Pongsopha (1962) suggested that heavy thinning is desirable in plantations, as it significantly increased height growth and basal area increment. Sarlin (1966) reported that diameter, basal area and volume improvement of teak were markedly depressed before thinning but resumed later. Ram prasad (1973) suggested that in early stages at least more stems per unit area may be retained and the crop can be opened up more at the later stages. Teak gave best results on thinning when 50 per cent of basal area was removed compared to 70 and 80 per cent of basal area removal, showing that teak need light thinning for best results. Larson and Zaman (1985) suggested that as teak trees mature, they use canopy space less efficiently. Indicating that thinning should become more intense and perhaps more frequent as the stand matures. Abayomi et al. (1985), recommended that teak plantations are to be thinned at ages 5/10/15 and 20 year to residual stocking of 800/600/400/300 stems ha^{-1} respectively to produce good stocking of large sized timber by age 50-60 years.

2.3.3 Stand Density Manipulation of other Forestry Species

In a 15 year old *Pinus taeda* plantation thinned to 8 ft x 8 ft, basal area, diameter and height increment registered a three-fold increase (Bower, 1965). Kalaghe and Mwinomeke (1983) observed significant increases in diameter and volume growth consequent on thinning, but basal area decreased after seven years of the treatment. Height growth, nevertheless remained unaffected in a 10-year old *Pinus patula* stand thinned at four intensities, ranging form 0 to 69 per cent stem removal. In case of 5 to 8-year old *Pinus kesiya* plantation thinned at 0, 30, 50 and 70 per cent of the basal area, removal of 50 and 70 per cent basal area significantly increased diameter and height growth in trees (Orallo, 1985). Werner (1987) concluded that timber stand improvement should begin in the sapling stage (1-8 m tall) with selection of well formed trees.

Thinning is found to have a tremendous effect on biomass. Ballard (1980) reported that thinning temporarily reduced biomass, but it regained quickly depending on the site conditions. Hocker (1982) suggested that with *Populus trimuloides*, thinning of young stands, decreased total above ground biomass, but net annual biomass accumulation was not greatly different between thinned and unthinned stands. Aussenac et al. (1982), indicated that one year after thinning, basal area of thinned stand was 101 per cent greater than that of an unthinned stand and removal of alternate tree rows in a 19-year old Douglas fir plantation increased the incident light reaching ground level to 7.3 per cent.

2.4 Thinning and Fertilization

Forest crops are thinned both to generate immediate returns and to stimulate growth of the remaining trees, a dual purpose approach which often leads to compromise over the type and intensity of the thinning employed. Woollons (1985) remarked that there is a strong interaction between thinning and fertilization. On nutritionally poor sites, fertilizer response tends to occur irrespective of stocking, whereas on better sites thinning may be a pre-requisite for a response to fertilizer (Woollons, 1980). He further added that it would be prudent to combine stand thinning and nutrients in a single application.

There is abundant literature on the interactions between thinning and fertilization. The general consensus among authors is that the value of responses in thinned stands is normally greater, as the nutrient are made available to fewer and selected stems (Ballard, et al., 1981). Such considerations favour the coincidence of thinning and fertilization operations. Miller et al. (1981) reported that fertilizers can be used to accelerate recovery from thinning or from any similar injury such as insect defoliation.

Thaiutsa et al. (1976) suggested that either thinning or thinning followed by fertilization may help in enhancing the diametric growth of young teak plantations. In 50-year old red oak plantations, Lozano (1975) observed that combined fertilizer and thinning treatments significantly increased diameter growth in selected dominant trees. But the interaction effect was not significant. Winston (1977) observed similar effects in Jack pine also. Haapanen et al. (1979) found that the effect of fertilizers (145 and 95 kg/ha of N and P) culminated sharply after 3 to 4 years of the treatment, whereas the effect of thinning continued for a longer period. Furthermore, both treatments together showed better effects than either of them alone. Miller (1984) showed that in Douglas fir, heavy thinning reduced gross growth per acre during the first 5-10 years, but nitrogen fertilization with 150 to 600 pounds/acre increased gross growth in both thinned and unthinned stands. Graney (1983) reported that fertilization increased diameter growth of oaks in thinned and unthinned stands. The maximum response of fertilizer was in first and second years, whereas thinning response continued up to the fifth year. Groot et al. (1984) examined the effects of 45 year old Jack pine to low thinning and urea fertilization (336 kg N/ha). Thinning had no significant effect but fertilizers resulted in an average annual gross volume growth of 2 m^3 ha^{-1} and this continued upto the 10 year. Similarly Barton and Madguick (1987) showed that in Agathis australis stands, reduction in number of stems per ha to 700 had negligible effects on stand basal area growth compared to a stand of 3000 stems ha^{-1}. Fertilizer application increased form quotient and form factor also (Morozov et al., 1985).

It is observed that fertilization and thinning have substantial effects on growth of many species. In teak generally "D" grade thinning is followed. The effect of different intensities of thinning in combination with fertilizers have not been systematically evaluated in teak in the past.

Materials and Methods

III. MATERIALS AND METHODS

3.1 Site

To evaluate the effects of thinning and fertilization of stands on the growth of teak, an experiment was conducted in the Kailasam and Kalindi blocks of the Kerala Agricultural University estate at Vellanikkara (10°32'N latitude and 76°10'E longitude at an altitude of 22.25 meters above MSL) during 1990-1991. The site enjoys a warm humid climate with a mean maximum monthly termperature ranging from 29.12°C (July) to 36.18°C (March) and mean minimum monthly temperature ranging from 22.13°C (Jan) to 24.98°C (April) and an annual precipitation of 2756.17 mm (1984-91). The soil of the experimental site is a well drained lateritic loam. The site was planted with one year old teak seedlings at 2m x 2m spacing during June, 1985.

3.2 Experimental Design and Layout

The experimental variables consisted of factorial combinations of three thinning intensiteies and three levels of fertilizers as detailed below:

<u>Thinning intensities</u>:

T_0 = Control (no thinning)

T_1 = Removal of alternate diagonal rows.
(50% reduction in density)

T_2 = Removal of every third diagonal row.
(30% reduction in density)

Fertilizer levels:

F_0 = No fertilizers (control)

F_1 = 50:25:25 kg of N, P_2O_5 and K_2O ha^{-1} $yr.^{-1}$

F_2 = 100:50:50 kg of N, P_2O_5 and K_2O ha^{-1} $yr.^{-1}$

With the object of finally selecting the required 27 experimental plots, the tree heights and girths in the entire plantation was surveyed (extent:ca 5 ha). Eighty eight 12 m x 12 m plots were established and all the teak trees/saplings were enumerated for this purpose. On the basis of tree height, plots were then classified as low (<2.5 m), medium (2.5 m to 3.5 m) and high (>3.5 m), and 27 plots (nine each per "site class") were selected and treatments applied randomly to these plots considering the three "site quality classes" as blocks (replications).

3.3 Thinning, sampling and Sapwood cross sectional area determination procedures

Thinning was carried out during July 1990. Trees in the diagonal rows were first marked and then cut with a hacksaw as per the treatment protocol. Leaves, branches and stem were separated and the height of the felled tree measured using a meter tape. Stems of the felled trees were then divided into 1 m sections and their girth were also recorded. One inch-disks were removed from these sections using a hacksaw and their sapwood heart wood boundary was marked. The interior and exterior boundaries of the sapwood were then copied on to tracing paper, and the cross-sectional area calculated from the paper weight-paper area relationship. Fresh weights of bole, branches and leaves were recorded in the field itself.

Three sub-samples, each of branch and stem were taken from every thinned plot for determining the moisture content. The leaf area of six samples (approximately 250 g) were also measured per plot with an optical planimeter (LiCor Li-3100, LiCor Lincoln, Nebraska, USA). The foliage, wood and branch samples were weighed after oven drying the samples for 48 hours at 80°C and the total dry weight of stem wood, leaves and branch wood were estimated. The dried samples were ground to pass through a 2 mm sieve for preparing samples for the chemical analyses.

3.4 Fertilization

Fertilizers as per the treatment schedule were applied during the period from 28th to 30th July 1990 (after thinning). Nitrogen was applied as urea (46% N), phosphorus as super phosphate (16% P_2O_5) and potassium as muriate of potash (60% K_2O). The required amounts of fertilizers were separately weighed out for each tree, mixed together and applied in the basins (0.5 m radius and 15 cm depth) around the tree. For uniformity, basins were taken for each tree in the control plots also.

3.5 Weeding and prunings

In all, three weedings were carried out (15 to 18 July, 1990, 3 to 5 November, 1990 and 7 to 9 February, 1991). The lower and non-functional branches were also pruned twice (November 1990 and March 1991) using a bill-hook.

3.6 Observations recorded

Pre-treatment observations were recorded in June 1990 from 21st to 28th. Height and girth of trees were measured by using marked bamboo poles and a diameter tape respectively. After imposing the treatments, tree heights and girths were measured periodically in November, 1990, February 1991 and again in May 1991. Diameter at breast height, quadratic mean diameter, basal area, mean tree height increment and stand density were caculated from these observations following the formulae provided in Table 1. Leaf samples were collected at three months interval for chemical analyses.

3.7 Laboratory Analysis

Representative composite samples of leaves, branch wood and stem wood were analysed for nitrogen (micro-kjeldahl method), phosphorus (Vandomolybdo phosphoric acid, yellow colour method-spectophotometry) and potassium (flame photometry) in six replicates each (Prasad, 1982).

WEATHER DATA

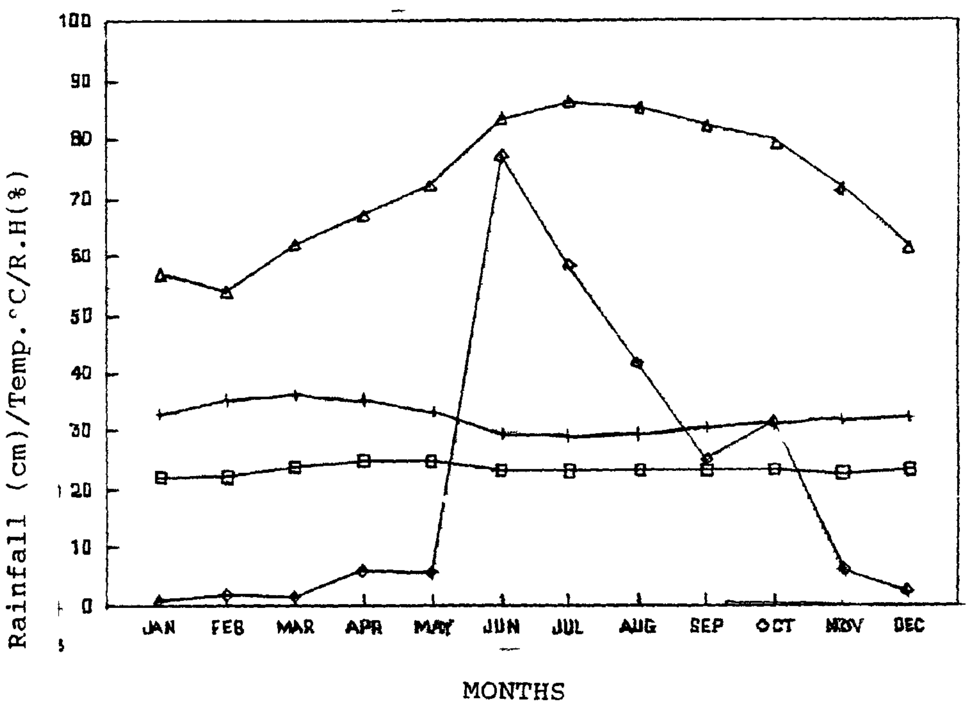


Fig. 1. Mean montnly rainfall, mean maximum and mean minimum temperature, mean relative humidity at Vellanikkara for the period from 1984 to 1991 (◇—◇—◇—◇ : Rainfall, +—+—+—+ maximum temperature, □—□—□—□ minimum temperature, △—△—△—△ Relative humidity)

Table I. Equations used for the calculation of variables

Variables	Equations	Unit
1. Diameter at breast height(DBH)	GBH/π	cm
2. Quadratic mean diameter (Dq)	$\sqrt{\Sigma (DBH)^2/N}$	cm
3. Basal Area(BA)	$\sqrt{\Sigma (GBH^2/4\pi)/\text{plot area}}$	$cm^2\ m^{-2}$
4. Basal Area Increment	Difference between IBANov=BANov-BAAug IBAFeb=BAFeb-BAAug IBAMay=BAMay-BAAug	$cm^2\ m^{-2}$
5. Mean tree height (Ht.)	$\Sigma\ Ht/N$	m
6. Height Increment	Difference between IHNov=Ht Nov - Ht Aug IHFeb=Ht Feb - Ht Aug IHMay=Ht May - Ht Aug	m
7. stand density	N/plot area	Sq.m ha^{-1}

Abbreviations used:

GBH - Girth at breast height overbark
N - Number of trees/plot
Ht - Heights of individual tree
Σ - Summation
cm - centimeter
m - meter
IBAAug - Increment in Basal Area of Augest
IBANov - Increment in Basal Area of November
IBAFeb - Increment in Basal Area of February
IBAMay - Increment in Basal Area of May
π - 3.141592
IHNov - Increment in height of November
IHFeb - Increment in height of February
IHMay - Increment in height of May

Composite post treatment soil samples were also taken from each plot during may 1991 and used for determination of chemical properties namely, total nitrogen (Kjeldhal method), available phosphorus (chlorostannous reduced molybdophosphoric blue colour method in hydrochloric acid system), available potassium (normal neutral ammonium acetate extraction; flame photometry) and organic carbon (Walkley and Black method, Jackson, 1967) in three replicates.

3.8 **Statistical Analysis**

Analysis of covariance technique was used for comparing the tree growth characters, (with previous stage obserations as co-variates). Plant nutrient levels and soil physico-chemical properties were compared following the analysis of variance technique using standard statistical packages.

Linear regression models were developed following the least square method linking leaf area and dry weight of foliage to sapwood cross sectional area at breast height/collar level and total tree biomass to diameter at breast height/collar diameter and height. Furthermore, leaf area and leaf dry weight were similarly related to DBH/GCL using a non-linear curve fitting routine (PLOTIT).

Results and Discussions

IV. RESULTS AND DISCUSSION

4.0 Stand growth and yield charcteristics

The effects of site quality, thinning treatments and fertilizer application on various stand growth parameters are presented in this section.

4.1 Radial growth of trees

Site quality, thinning and fertilizers did not markedly influence the quardratic mean diameter of trees at any of the stages of obseravations (Table 2 and Fig. 2 a,b,c). High site quality recorded 69% higher Dq (quadratic mean diameter) during May 1991 over the low site quality. But the differences were statistically not significant. However, over a period of time there might be statistically significant variations in the radial growth rates of trees. Furthermore, several workers in the past did not observe any significant influence of site quality on radial growth. For instance, Stone (1977) reported that in Acer saccharum, Acer rubrum and Betula alleghaniensis, site effect on diameter increment was very small or even negative. In another study, Liu (1984) also did not observe variations in diameter growth of china fir (Cunninghamia sp.) as a function of site conditions.

As regards to thinning intensity, removal of alternate diagonal rows increased radial growth to the tune of about 17%

Fig. 2a Effect of site quality on Quadratic mean diameter (Dq)

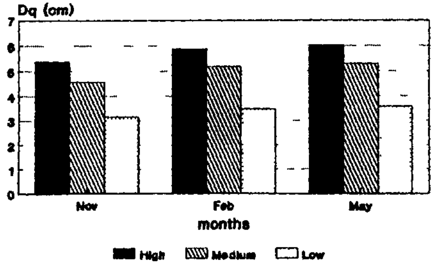


Fig. 2b Effect of Thinning intensities on quadratic mean diameter (Dq)

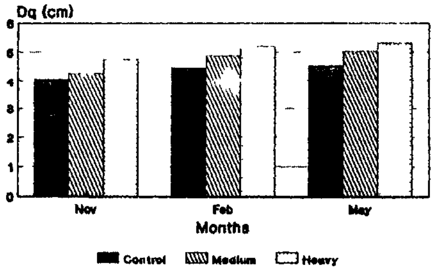


Fig.2c Effect of Fertilization on Quadratic mean diameter (Dq)

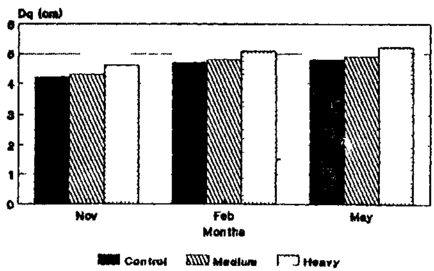


Table 2. Effect of site quality, thinning treatments and fertilizers on Quadratic Mean Diameter (Dq.), Basal Area and Basal Area Increment of teak saplings.

Treatments	Quadratic Mean Diameter (cm)			Basal Area ($cm^2 m^{-2}$)			Basal Area Increment ($cm^2 m^{-2}$) (With respect to Aug. 1990)		
	NOV 90	FEB 91	MAY 91	NOV 90	FEB 91	MAY 91	NOV 90	FEB 91	MAY 91
1 <u>Site quality</u>									
High	5.39	5.90	6.02	6 17	7.45	7.76	0 54	1.82	2.14
Medium	4.56	5 18	5 30	4 48	5.83	6 10	0.44	1 79	2.06
Low	3.16	3.46	3 57	2.24	2.69	2.85	0.16	0.61	0.76
F-test	NS	NS	NS	NS	NS	NS	NS	NS	NS
SEM (+)	0.03	0 09	0 11	0 07	0 25	0 29	0.07	0.25	0 29
CD (0 05)	-	-	-	-	-	-	-	-	-
II <u>Thinning Intensities</u>									
Control (No thinning)	4 06	4 47	4 55	5 32	6.48	6.71	0.38	1.54	1 78
Medium	4.28	4 87	5 03	3 83	5 02	5 34	0 41	1.61	1 92
Heavy	4 76	5 20	5 31	3 75	4 46	4.66	0 35	1.07	1.27
F-test	NS	NS	NS	NS	NS	NS	NS	NS	NS
SEM (+)	0.03	0.09	0 11	0.07	0 25	0.29	0.07	0.25	0 29
CD (0 05)	-	-	-	-	-	-	-	-	-
III <u>Fetilization</u>									
Control (No fetilizer)	4.21	4 68	4 78	4 10	5.12	5 32	0 30	1 32	1.52
Medium	4.30	4 79	4.89	4 73	5.88	6.13	0.39	1.55	1.79
Heavy	4 59	5 07	5 23	4 06	4 96	5 26	0 44	1 35	1 64
F-test	NS	NS	NS	NS	NS	NS	NS	NS	NS
SEM (+)	0 03	0 09	0 11	0 07	0 25	0 29	0 07	0 25	0 29
CD (0 05)	-	-	-	-	-	-	-	-	-

NS = Not significant

(over the control during May 1991). Similarly, heavy fertilization also stimulated radial growth by 9% over no fertilizers. However, these differences were also statstically not significant. This perhaps, may be due to the relatively short period of observations (only one growing reason has elapsed since the treatments were applied) and over a period of time there might be major differences among the treatment levels. Thinning actually results in the opening up of canopies which in turn, facilitates light penetration into the stand. Consequently the survivors allocate proportionately more assimilates for stemwood production. In this context, Lanner (1985) following the classical concept of 'plant as an integrated system of sinks' argued that radial growth results from the activity of a relatively "weak sink", the cambium. Consequently in crowded stands, as the crowns are small and bears little foliage, cambial growth must depend on current photosynthesis and gets little in competition with the stronger sink of apical meristem. Threfore, thinning facilitates crown expansion and the additional carbohydrate is allocable to the wood increment. Previous studies have shown that in teak, heavy thinning and the consequent heavy lateral clearance stimulated diameter growth of survivors after four years (Beumee, 1922). Lloyd (1955) also reported that diameter growth of alder increased slightly six years after thinning. Abayomi et al. (1985), however, did not observe changes in diameter increment consequent on stand thinning of teak.

Fig.3a Effect of site quality on Basal Area.

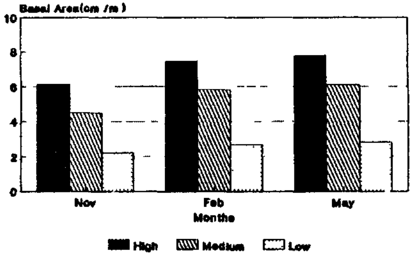


Fig.3b Effect of Thinning intensities on Basal Area.

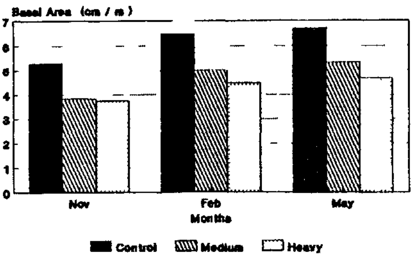
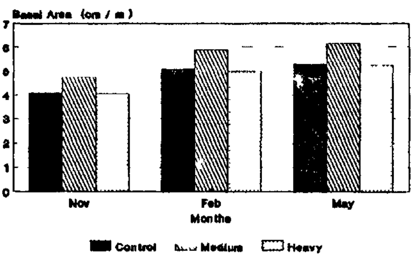


Fig.3c Effect of Fertilization on Basal Area.



In *Abies balsamea* and *Picea maria* stand thinning and fertilization (NPK) together gave a significant diameter increment only after seven growing seasons (Bolghari, 1980). A number of other workers, also did not observe significant variations in radial growth of trees consequent to fertilizer application during the first one or more years. For example, Fahlroth (1969) for pines, Stone et al. (1982) for *Tilima americana* and *Ulnus americana* and Laing et al. (1985) for poplar.

4.2 Basal Area

Data presented in Table 2 and Fig. 3 a, b, c suggest that basal area increased over a period of time. Although statisically not different, high sites consistently recorded higher basal areas and basal area increments. As regards to thinning, basal area decreased in response to thinning intensities and the highest basal area and basal area increments were recorded in the control and moderately thinned plots respectively. The literature on thinning effects on basal area increment of teak is very scarce. However, it is well established that thinning improves growth rates of the survivors and hence it is expected that there might be a marked increase in the basal area increments of the thinned plots in the coming years. Pongsopha (1962) reported that in teak, increase in thinning intensity increased basal area and he further suggested that heavy thinning is most desirable for teak. Increase in basal area, consequent on thinning was also reported by

Bower (1965) in *Pinus taeda* after three years, Zavitkovsi and Dawson (1977) in *Pinus banksiana* after six years and Barton and Madguick (1987) in *Agathis australis* after five years. Kalaghe and Mwinomeke (1983), however, noted that in *Pinus patula*, thinning significantly decreased basal area. However, Abayomi et al. (1985) reported that thinning treatments had no influence on the basal area increment in teak.

With respect to fertilizers, the medium level of fertilizers recorded slightly higher basal area and basal area increments. The differences were, nevertheless statistically not significant. Briscoe and Ybarra-coronado (1972) also reported that addition of N, Ca and Mg on different sites did not markedly affect teak basal area increment.

4.3 Height growth in teak

High sites consistently recorded higher values for mean tree height even though statistically being at par with other site quality classes (Table 3 and Fig. 4a, b, c). Incidentally the high site quality recorded 112 per cent and 33 per cent increase in height values over low and medium site class [redacted]ively (May 1991).

Thinning, however, exhibited perceptible differences in height growth in November 1990 and May 1991. Heavy (3.57 m) and moderate (3.65 m) levels of thinning were significantly superior to the unthinned plots during November 1990 and May 1991 (Fig. 4b).

Fig 4a Effect of site quality on mean tree height

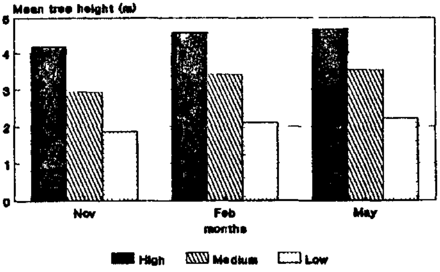


Fig 4b Effect of thinning intensities on mean tree height

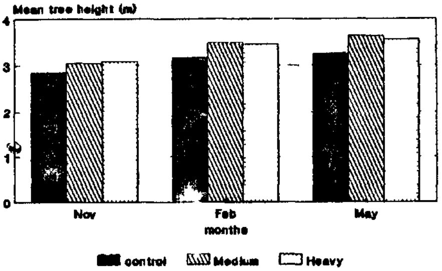


Fig 4c Effect of fertilization on mean tree height

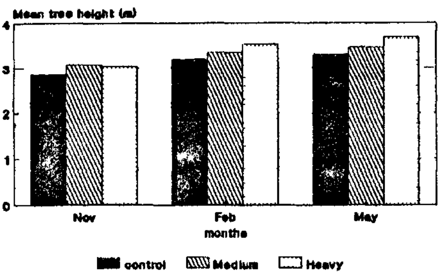


Table 3. Effect of site quality, thinning treatments and fertilizers on Mean tree Height and Height Increment of teak saplings.

Treatments	Mean tree Height (m)			Height Increment (m) (With respect to Aug.1990		
	NOV 90	FEB 91	MAY 91	NOV 90	FEB 91	MAY 91
I. Site quality						
High	4.18	4.58	4.70	0.54	1.82	2.14
Medium	2.94	3.43	3.54	0.44	1.79	2.06
Low	1.88	2.11	2.22	0.16	0.60	0.76
F-test	NS	NS	NS	NS	NS	NS
SEM (±)	0.02	0.06	0.07	1.02	2.6[illegible]	[illegible] 00
CD (0.05)	-	-	-	-	-	-
II. Thinning Intensities						
Control (No thinning)	2.86	3.17	3.25	0.38	1.54	1.78
Medium	3.05	3.49	3.65	0.41	1.61	1.92
Heavy	3.09	3.46	3.57	0.35	1.07	1.27
F-test	*	NS	*	NS	NS	NS
SEM (±)	0.02	0.06	0.07	1.02	2.66	3.00
CD (0.05)	0.07	-	0.22	-	-	-
III. Fertilization						
Control (No fertilizer)	2.84	3.21	3.30	0.30	1.32	1.52
Medium	3.01	3.36	3.47	0.39	1.55	1.79
Heavy	3.14	3.55	3.70	0.44	1.35	1.64
F-test	NS	NS	NS	NS	NS	NS
SEM (±)	0.02	0.06	0.07	1.02	2.66	3.00
CD (0.05)	-	-	-	-	-	-

NS = Not significant
* = Significant at 5 per cent level.

Increase in height of individual stems, is probably through a redistribution and concentration of the site's growth potential on fewer stems. As a silvicultural practice, thinning concentrates the growth potential of a stand on "crop" trees and removes suppressed and dying trees, besides increasing the economic gain (Nebekar, et al., 1985). Response to thinning is, however, tempered by most of the factors that influence tree and stand growth (age, density, species site index etc.).

Nevertheless, it is almost axiomatic that height growth of the canopy trees is insensitive to stand density. Lanner (1985) explains that even under strong competition resulting from dense stocking, apical meristem which incidentally is a strong sink, draws the necessary carbohydrates it needs to attain its potential growth. With increased spacing, more resources become available, but a leader's potential is fixed by its stem unit component and therefore, thinning should not result in any logical height increase in the dominants. However, the response to thinning observed in the present study is in terms of mean height (which considers all trees in the stand), which probably has strong bearings on stand density.

Pongsopha (1962) reported that teak requires heavy thinning which is at variance with the present study wherein it was found that so far, medium thinning (30 per cent reduction in density) was at par with heavy thinning in stimulating height growth of teak, however, over a period of time the present trends might also change. Sarlin (1966) also reported that height increment was better in teak after thinning.

Regarding fertilizers, although fertilizer application moderately increased the mean tree height, on the average there was no significant difference among fertilizer levels. Nevertheless, interaction effect of site quality with fertilizers was significant. High site quality in general recorded higher values of tree height particularly in combination with high (157% more than the combination of low site quality with no thinning) and medium doses of fertilizers (Table 3a).

Previous studies have clearly established that mean tree height and height increments were markedly altered by fertilizer application over a period of time. For instance, Gambi (1979) in *Abies alba* observed that NPK effects were evident over a period of two years and were greatest in the second year of application. Similar results were observed by Ciancio and Martire (1974) in *Abies alba* and *Pinus strobus*; Timofeev (1974) in Scot pine; Scott et al. (1982) in Jack pine, Laing et al. (1985) and Yost et al. (1987) in *Eucalyptus saligna*; and Shafii et al (1989) in Douglas fir.

The enhanced height growth of the trees particularly on the high sites supplied with heavy and medium rates of chemical fertilizers (Table 3a) is explicable in terms of nitrogen accumulated in the tissues consequent on fertilizer application (see: Table 6a). As the soil nutrient levels were at par

Table 3a. Effect of site quality x fertilization interaction on mean tree height in November 1990.

	Fertilization		
	Control (no-fertilizers)	Medium	Heavy
Site Quality			
High	3.84	4.34	4.35
Medium	3.01	2.71	3.11
Low	1.69	1.98	1.97
F-test	*		
SEM (±)	0.04		
CD (0.05)	0.13		

* Significant at 5 per cent level

(Table 8), this points to the fact that tree growth on the high sites was perhaps nutrient limited. On this basis it can be argued that contrary to the widely held dogma among the Indian foresters that forestry plantations can maintain sustainable productivity without chemical fertilizers and even when fertilizers are required it is only for the low sites, there is a strong need for fertilizing teak plantation especially those on the high quality sites.

Miller (1981) suggested that the most important response of fertilizer application is, "an acceleration through time" or a reduction in rotation length. Data presented in Table 3a highlight this possibility. The treated trees will, however, eventually revert to the growth curve appropriate to the site at a point that commensurate with the development stage (Miller, 1980). Timing of the fertilizer application is also important. Again, because much of the storage occurs in foliage, it is important that crowns should not be too sparse before applying fertilizers. In fact Miller (1980) has even suggested a case for applying fertilizer once to build-up the foliage mass, and a second time to fill this with the desired nutrient.

4.4 Allometry of woody biomass, foliage area and dry weight

Stand yield is a function of density and the biomass allocation pattern of individual stems. Ovington (1957) reviewed the world literature on forest biomass and suggested that a significant relationship exists between form of tree and its dry matter content. Differences in woody biomass yield between species and sites could be due to differences in biomass allocation which might reflect in the allometry of biomass and foliage area. Some consideration of allometry is also necessary for tree growth prediction and modelling (Fownes and Harrington, 1990). Newbould (1967) suggested that parameters such as GBH (girth at breast height), DBH (diameter at breast height) or height can be very effectively used to predict tree biomass. Allometric equations relating leaf area or biomass to trunk diameters or tree height have been developed for a number of tree species including some fast growing tree species (Lim, 1988; Schubert et al., 1988; Rana et al., 1989; Fownes and Harrington, 1990). A number of authors have suggested that dry matter production can be used to measure site quality differnces also (Moller, 1945; Ovington et al 1963 ; Baskerville, 1965). Furthermore, leaf and tree biomass allometry undergoes substantial changes over the course of stand development.

4.4.1 Woody biomass

Allometric relationships were not evolved for teak trees in the past. Therefore, linear biomass equations were developed linking oven dry tree biomass to D^2H [$(DBH)^2$ x height] on the one hand (see Fig.5a; Eq 1) and diameter at breast height and height on the other (Eq. 2). Analysis of variance of both the models are presented in Appendix VI and VII. In addition, tree biomass

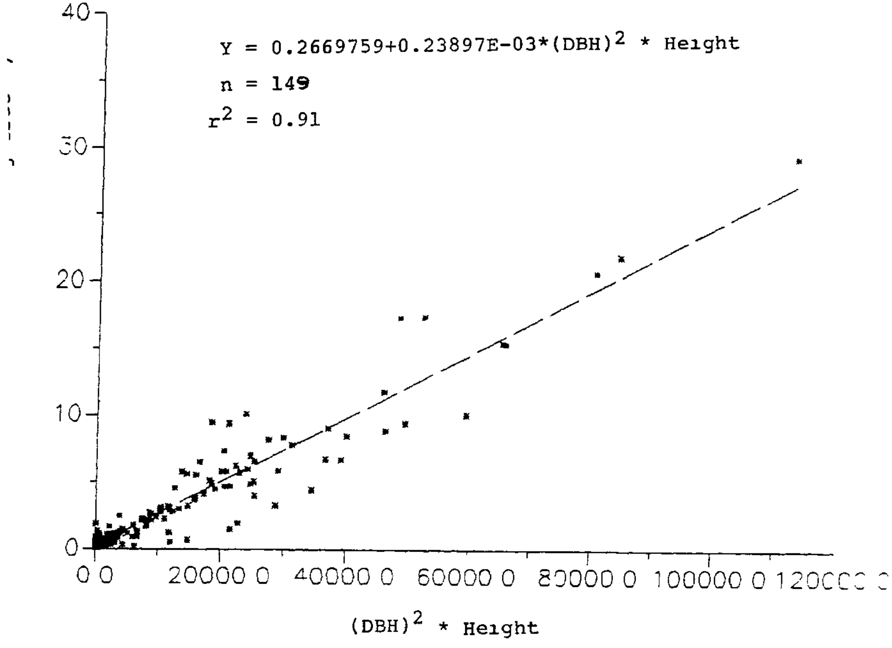


Fig.5a. Relationship between total biomass and $(DBH)^2$*Height

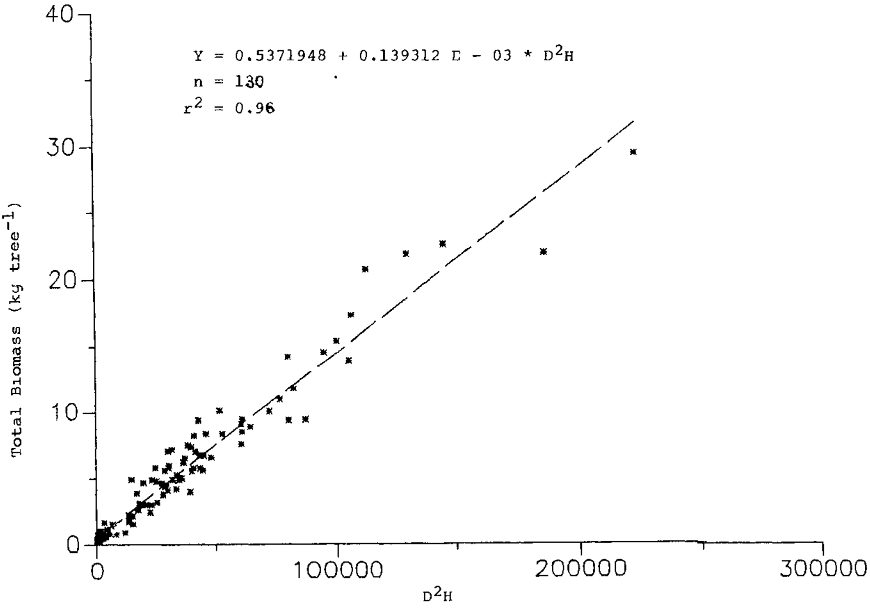


Fig. 5b. Relationship between total biomass and (collar diamter)^2 * Height

was regressed on to [collar D^2 * H] and collar diameter and total tree height respectively (See Fig.5b; Appendix VIII and IX)

$$\text{Tree Biomass} = 0.2669759+0.2389763\text{ E-03} * [(\text{DBH})^2 * \text{Height}]$$
$$(r^2 = 0.91;\ n = 149) \text{ .... [Eq. 1]}$$

$$\text{Tree Biomass} = 5.3908\ (\text{DBH}) + 2.557\ (\text{Height}) + 58.982508$$
$$(r^2 = 0.52;\ n = 197) \text{ .... [Eq. 2]}$$

$$\text{Tree Biomass} = 0.5371948 + 0.139312\text{ E-03} * [(\text{DCL})^2 * \text{Height}]$$
$$(r^2 = 0.96;\ n = 130) \text{ .... [Eq. 3]}$$

$$\text{Tree Biomass} = 1.8131\ (\text{DCL}) + (-5.5415\text{ E-0.3})\ \text{Height} -5.371807$$
$$(r^2 = 0.83;\ n = 130) \text{ .... [Eq. 4]}$$

Where, DBH = Diameter at breast height (cm).
DCL = Diameter at collar level (cm).

Eq. 1 was used for estimating tree biomass as affected by the experimental variables, as breast height measurements are conventionally used for such estimations. Furthermore, it gave a reasonably good fit (r^2 = 0.91; See : Appendix VI) and also is easier to make.

4.4.2 <u>Biomass estimates</u>

The highest total biomass was recorded for the high site class (6.19 kg tree^{-1} in May), and it also differed significantly from the low and medium site classes at all stages of observation (315 per cent and 37 per cent higher than low and medium classes respectively; Table 4; Fig.6 a, b, c: Appendix V) Nwoboshi (1984) also observed that teak biomass production was generally higher on the more productive sites. Furthermore, heavy thinning (4.46 kg/tree during May 1991) and heavy fertilization (4.46 kg/tree during May 1991) also resulted in very high mean biomass yields per tree. However, the total biomass production on a stand basis in these treatments were relatively lower (Table 4). Interaction between site quality - thinning and site quality - fertilization were statistically significant (Table 4a). *The* combination óf high site qulity with heavy thinning recorded highest total biomass (7.31 kg/tree during May 1991). Regarding the site quality-fertization interaction, high sites in conjunction with medium levels of fertilizers consistently recorded the highest biomass yields.

Increase in mean tree biomass in response to thinning is well documented in the literature (Pratt and Knight, 1971; Walker et al., 1972; Besale, 1973; Prichett, 1978; Arauja Filho et al., 1982; Kirmse et al., 1987). However, as a result of thinning, particularly in the high thinning intensities, there is a reduction in the total biomass on a unit area basis (Fig.6b), which might be compensated eventually by the faster growth of the survivors. Thinning eliminates intraspecific competition, which reduces growth of individuals below their potential and is responsible for the faster growth rate/higher biomass production of the survivors.

FIG.6a- Effect of site quality on total biomass.

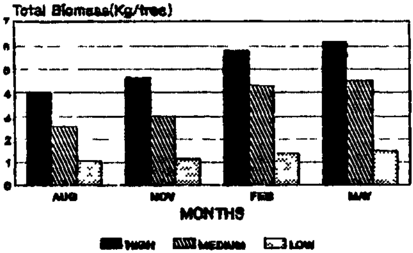


FIG.6b- Effect of thinning intensities on total biomass.

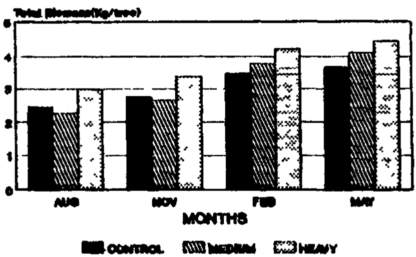


FIG.6c- Effect of fertilization on total biomass.

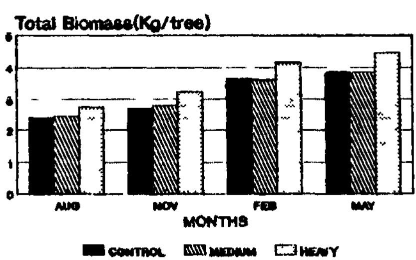


Table 4 Effect of site quality , thinning intensites and Fertilizers on total above ground biomass.

Treatments	Total Biomass (kg/tree)				Stand density	Total Standing Biomass (Kg ha^{-1})
	Aug 90	Nov 90	Feb 91	May 91	(trees ha^{-1})	during May 1991
I <u>site quality</u>						
High	4.03	4.63	5.82	6.19	2716	16812
Medium	2.57	3.00	4.27	4.52	2785	12588
Low	1.06	1.15	1.38	1.49	3032	4518
F-test	**	**	**	**	-	-
SEM (±)	0.27	0.33	0.41	0.45	-	-
CD (0.05)	0.61	0.75	0.94	1.03	-	-
II <u>Thinning Intensities</u>						
Control (no thinning)	2.45	2.75	3.46	3.64	3889	14156
Medium	2.25	2.64	3.78	4.00	2585	10573
Heavy	2.97	3.38	4.23	4.46	2060	9188
F-test	NS	NS	NS	NS	-	-
SEM (±)	0.27	0.33	0.41	0.45	-	-
CD (0.05)	-	-	-	-	-	-
III <u>Fertilization</u>						
Control (no fertilizer)	2.42	2.72	3.68	3.87	3017	11676
Medium	2.47	2.82	3.63	3.86	2978	11495
Heavy	2.77	3.24	4.16	4.46	2377	10601
F-test	NS	NS	NS	NS	-	-
SEM (±)	0.27	0.33	0.41	0.45	-	-
CD (0.05)	-	-	-	-	-	-

Table 4a Effect of site quality x thinning and site quality x fertilization on tree biomass

Aug. 90 Interaction	Thinning: Control (no thinning)	Medium	Heavy
Site Quality			
High	4 3	2 77	5 03
Medium	2.26	3 09	2 37
Low	0 79	0 88	1 50
F-test	*		
SEM (±)	0 46		
CD (0 05)	1.07		

Nov. 90 Interaction	Thinning: Control (no thinning)	Medium	Heavy
Site Quality			
High	5 03	3 17	5 70
Medium	2 4	3 80	2 79
Low	0.84	0 95	1 66
F-test	*		
SEM (±)	0.6		
CD (0 05)	1 38		

Feb. 91 Interaction	Thinning: Control (no thinning)	Medium	Heavy
Site Quality			
High	6.53	4 00	6 94
Medium	2.90	6 23	3 67
Low	0.95	1 11	2 08
F-test	**		
SEM (±)	0 70		
CD (0 05)	1.62		

May 91 Interaction	Thinning: Control (no thinning)	Medium	Heavy
Site Quality			
High	6.95	4.30	7.31
Medium	2 98	6.69	3 90
Low	0 98	1.30	2 17
F-test	**		
SEM (±)	0.77		
CD (0.05)	1.79		

Nov. 90 Interaction	Fertilization: Control (no ferti.)	Medium	Heavy
Site Quality			
High	4 65	6 51	6.30
Medium	5 23	2 83	4.73
Low	1 15	1 56	1 43
F-test	*		
SEM (±)	0 70		
CD (0 05)	1 62		

May 91 Interaction	Fertilization: Control (no ferti.)	Medium	Heavy
Site Quality			
High	4.86	6.96	6 73
Medium	5.57	3 00	5.00
Low	1.19	1.62	1.66
F-test	*		
SEM (±)	0 77		
CD (0 05)	1.79		

* Significant at 5 per cent level
** Significant at 1 per cent level

Application of chemical fertilizers also increased the mean tree biomass (Fig. 6c). Duffy (1977) observed that NPK fertilizers increased biomass production by 1.6 times over control. Knockart and Mandauri (1980) showed a 35 per cent increase in above ground biomass by NPK fertilization in Eucalyptus camaldulensis. The high mean tree biomass yield in the high sites and in response to fertilization and thinning can be attributed to the cumulative effect of their favourable effects on various tree growth parameters such as height, diameter and foliage area/biomass.

4.4.3 Foliage area and foliage biomass

4.4.3.1 Sapwood cross sectional area, Leaf area and Leaf weight relationships.

Many stand processes such as transpiration competition, growth, and self-thinning are thought to be affected by total stand leaf area (Whitehead and Jarvis, 1981; Waring, 1983; Long and Smith, 1984; Dean and Long, 1985). To assess the relation between leaf area and these processes, accurate estimates of stand leaf area are required. Leaf area in trees, however, is exceedingly difficult to measure directly and its determination is very time consuming and cumbersome.

Sapwood cross sectional area is often used to predict leaf area and leaf weight, consequent on the discovery of apparently consistent species specific relationship between leaf area and sapwood cross sectional area at breast height. Linear relationships between sapwood cross sectional area and leaf area have been explained on the basis of the "pipe model" theory (Shinozaki et al., 1964). The "pipe model" conceptualises the plant stems as an assemblage of pipes in which one unit of pipe supports one unit of leaf area. The technique was popularised by various workers such as Heinsdorf, 1967; Dixon, 1971; Rangnekar and Forward, 1973; Grier and Logan, 1978; Snell and Brown, 1978; Waring et al., 1978; Rogers and Hinckley, 1979; Kaufmann and Troendle, 1981; Waring et al., 1982; Binkley and Reid, 1984; Magnussen et al., 1986. However, leaf area/leaf weight-sapwood cross-sectional area relationships have not been quantified for teak in the past. Therefore, an attempt was made to characterise the sapwood cross sectional area, leaf area and leaf weight relations for teak. (This was done utilizing the felled trees from the thinned plots : see section III.2.3.).

Four linear regression models were developed. These models explain the relationships among foliage area (Figs. 7a and c), foliage dry weight (Figs. 7b and d) and sapwood cross-sectional areas at breast height and collar levels. The sapwood cross sectional area-foliage area relations gave a reasonably good fit (r^2 = 0.89 and 0.84 repectively at breast height and collar). The sapwood cross sectional area-foliage weight relations, however, exhibited a high degree of scatter (See: Fig. 7b and d).

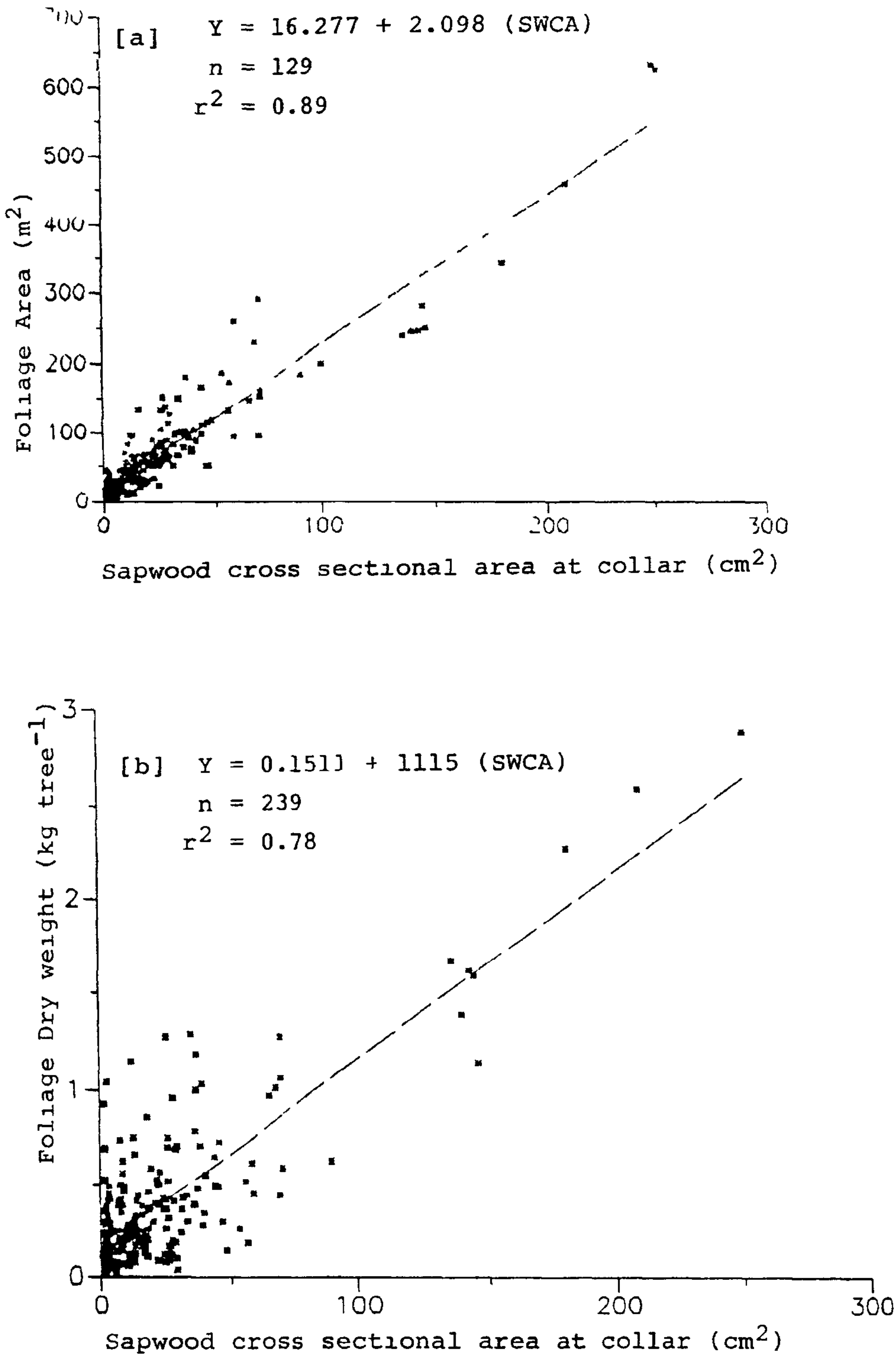
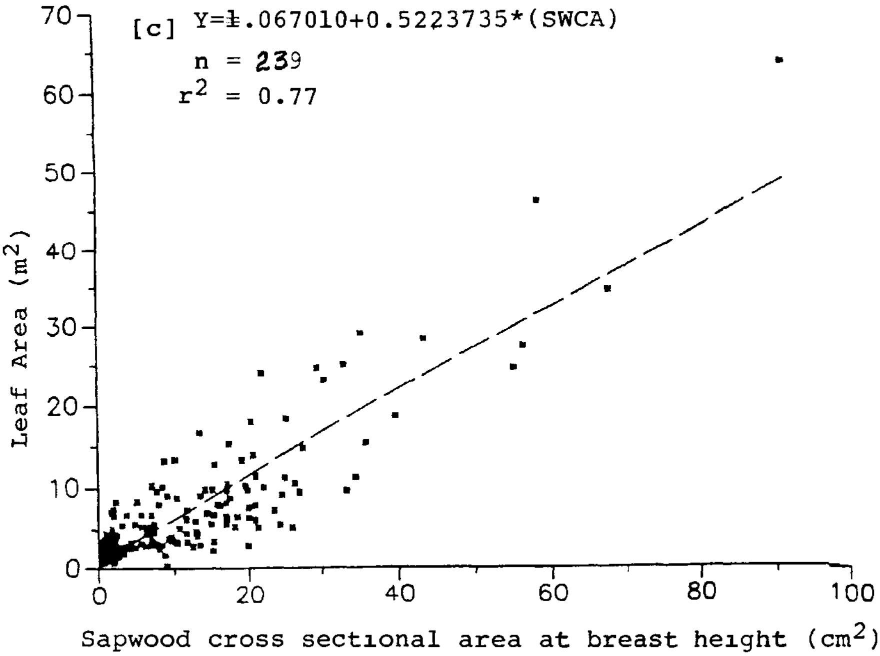


Fig. 7. Relationship between sapwood cross sectional area at collar (SWCA) and (a) Foliage area (b) dry weight of foliage.



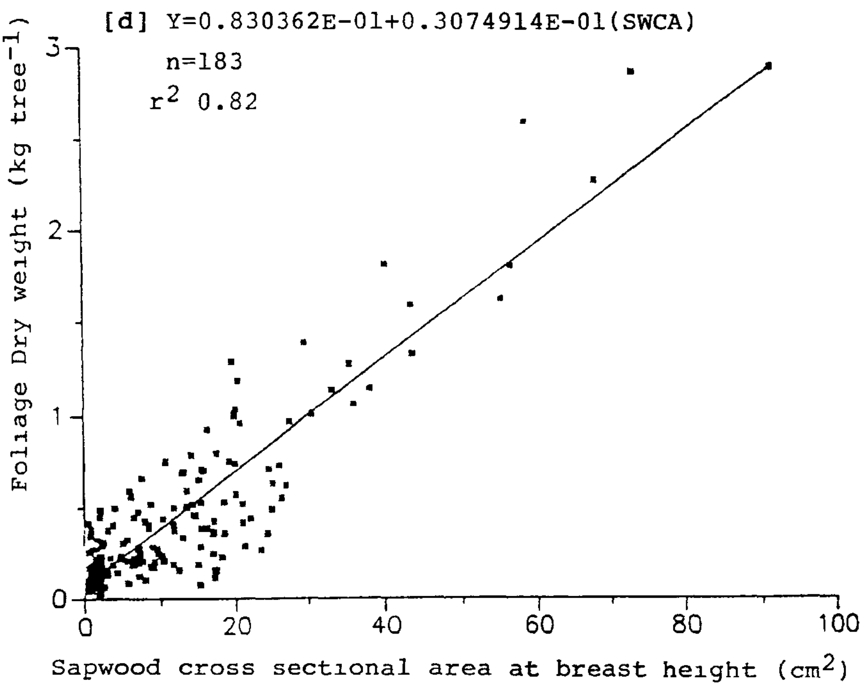
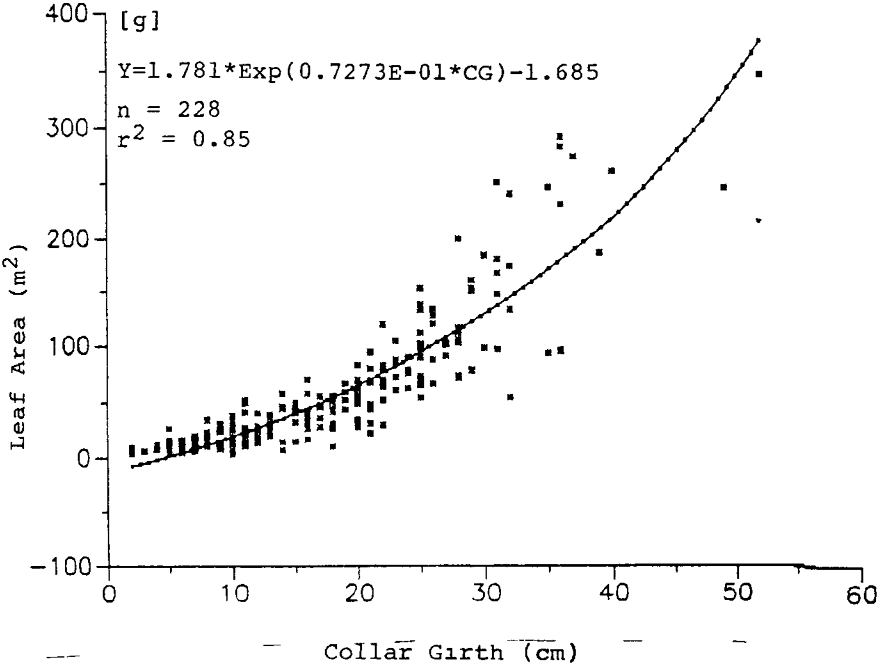


Fig.7. Relationship between sapwood cross sectional area at breast height and (c) Leaf Area (d) Foliage Dry weight.



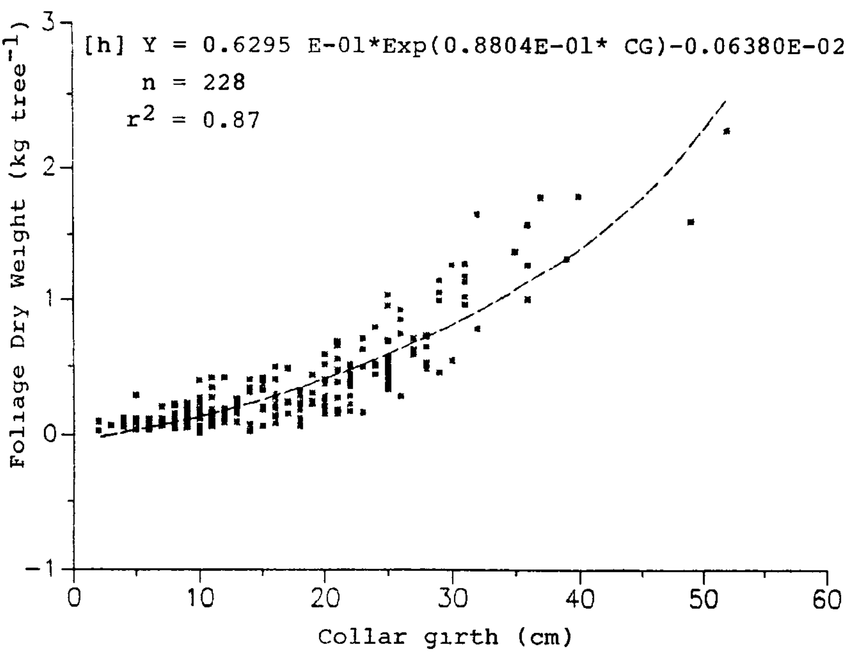


Fig.7. Relationship between collar girth and (c) Leaf Area and (d) Foliage Dry Weight

FIG.8a- Effect of site quality on Leaf Area.

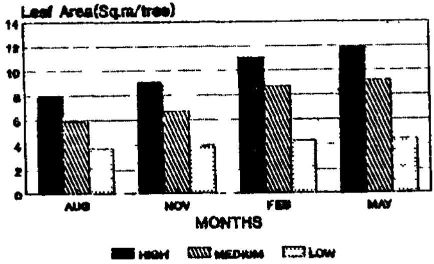


FIG.8b- Effect of thinning intensities on Leaf Area.

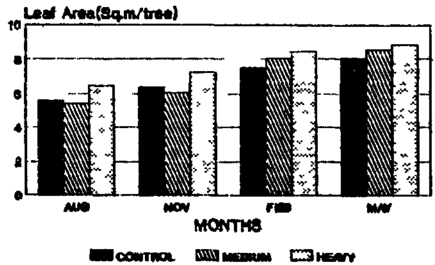


FIG.8c- Effect of fertilization on Leaf Area.

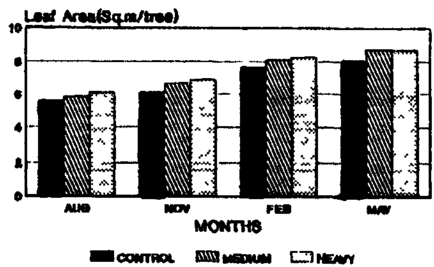


Table 5. Effect of Site quality, thinning treatments and fertilizers on estimates of stand Leaf Area, Leaf Area Index and Foliage dry weight.

Treatments	Leaf Area (sq m/tree)				Leaf Area Index				Foliage Dry Weight (kg/tree)			
	AUG 90	NOV 90	FEB 91	MAY 91	AUG 90	NOV 90	FEB 91	MAY 91	AUG 90	NOV 90	FEB 91	MAY 91
I <u>Site Quality</u>												
High	7.85	9.08	11.01	11.84	2.12	2.50	3.06	3.32	0.47	0.53	0.63	0.67
Medium	5.93	6.69	8.72	9.20	2.62	1.81	2.34	2.46	0.36	0.41	0.51	0.53
Low	3.71	3.87	4.30	4.43	1.07	1.11	1.23	1.26	0.24	0.25	0.27	0.28
F-test	**	**	**	**	**	**	*	*	**	**	**	**
SEM(±)	0.49	0.83	1.20	1.44	0.18	0.33	0.45	0.57	0.03	0.04	0.06	0.07
CD(0.05)	1.13	1.92	2.76	3.33	0.42	0.76	1.06	1.30	0.06	0.09	0.13	0.15
II <u>Thinning intensities</u>												
Control(no thinning)	5.59	6.39	7.54	8.07	2.12	2.44	2.87	3.07	0.34	0.38	0.44	0.46
Medium	5.41	6.04	8.06	8.56	1.37	1.52	2.04	2.17	0.37	0.37	0.48	0.50
Heavy	6.49	7.22	8.43	8.84	1.31	1.46	1.71	1.79	0.39	0.44	0.50	0.52
F-test	NS	NS	NS	NS	**	*	NS	NS	NS	NS	NS	NS
SEM(±)	0.49	0.83	1.20	1.44	0.18	0.33	0.45	0.57	0.03	0.04	0.06	0.07
CD(0.05)	-	-	-	-	0.42	0.76	-	-	-	-	-	-
III <u>Fertilization</u>												
Control(no ferti)	5.55	6.07	7.67	8.05	1.55	1.69	2.12	2.22	0.34	0.37	0.45	0.47
Medium	5.83	6.68	8.10	8.72	1.81	2.11	2.58	2.79	0.35	0.40	0.47	0.50
Heavy	6.11	6.90	8.26	8.69	1.44	1.62	1.93	2.03	0.37	0.42	0.49	0.51
F-test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SEM(±)	0.49	0.83	1.20	1.44	0.42	0.33	0.45	0.57	0.03	0.04	0.06	0.07
CD(0.05)	-	-	-	-	-	-	-	-	-	-	-	-

* Significant at 5 per cent level
** Significant at 1 per cent level
NS Not significant

Table 5a. Effect of site quality x thinning interaction on stand leaf area

Aug. 90 Interaction	Thinning: Control (no thinning)	Medium	Heavy
Site Quality			
High	8.21	5.89	9.45
Medium	5.42	6.89	5.47
Low	3.12	3.45	4.55
F-test	*		
SEM (+)	0.85		
CD (0.05)	1.96		

Feb. 91 Interaction	Thinning: Control	Medium	Heavy
Site Quality			
High	13.02	7.45	12.58
Medium	6.13	12.77	7.25
Low	3.47	3.96	5.47
F-test	*		
SEM (+)	2.07		
CD (0.05)	4.78		

May 91 Interaction	Thinning: Control	Medium	Heavy
Site Quality			
High	14.41	7.85	13.27
Medium	6.27	13.69	7.63
Low	3.53	4.13	5.62
F-test	*		
SEM (+)	2.50		
CD (0.05)	5.77		

* Significant at 5 per cent level

LAI (LAI: 3.32 during May, 1991) at all stages of observation (Table 5). Thinning reduced LAI very substantially, for example, control (no thinning) plots recorded 41 per cent and 71 per cent higher LAI than moderately and heavily thinned plots respectively during May 1991. Evans (1982) also reported that thinning reduced leaf area and consequently the productive capabilities of trees. He further added that the extra space produced by thinning is utilized for producing more foliage and roots. Therefore, the trees in the thinnned plots would exhibit a higher relative growth rate. However, in the present study moderately thinned plots showed a faster recovery rate for leaves than heavily thinned ones, as evident from the relatively higher LAI increment.

Application of chemical fertilizers only had moderate influences on leaf area expansion. Moderate levels of fertilizers recorded relatively higher LAI (LAI: 2.79) than heavy doses (LAI:2.03) in May 1991. Site quality-thinning and site quality-fertilization interactions were statistically significant (Table 5b). No thinning in combination with high site quality was superior. Medium and heavy doses of fertilizers in conjunction with high site quality also registered high LAI (2.88 and 1.73 respectively during February 1991). On high sites improvement in LAI consequent on application of moderate doses of fertilizers was obvious. Nwoboshi (1984) also reported that in

Table 5b. Effect of site quality x thinning and site quality x fertilization interactions on Leaf Area Index

Aug. 90 Interaction	Fertilization: Control (no Ferti.)	Fertilization: Medium	Fertilization: Heavy	Feb. 91 Interaction	Thinning: Control (no thinning)	Thinning: Medium	Thinning: Heavy
Site quality				Site Quality			
High	1.78	2.88	1.73	High	4.92	1.82	2.43
Medium	1.89	1.32	1.69	Medium	2.23	3.25	1.54
Low	1.00	1.25	0.96	Low	1.46	1.07	1.16
F-test	*			F-test	*		
SEM (±)	0.32			SEM (±)	0.79		
CD (0.05)	0.72			CD (0.05)	1.83		

* Significant at 5 per cent level

teak, on more productive site's leaf area and foliage biomass were higher.

4.4.6 Leaf Biomass

Leaf biomass estimates were obtained from DBH (diameter at breast height)-leaf biomass regression equation (Eq. 10, Appendix IV) for various periods and are presented in Table 5. High sites consistently recorded the highest foliage weight per tree. Thinning intensities and fertilization levels although did not exert a profound influence on these parameters, heavy fertilizer dose and heavy thinning intensity registered higher values of foliage dry weight at all stages of observation.

Site quality x thinning interaction was significant at all stages of observation (Table 5c). Combinations involving high site quality with heavy thinning (0.76 kg/tree of mean foliage biomass during May 1991) and medium site quality with medium thinning (0.76 kg/tree during May 1991) were superior to others. Thinning improved the leaf biomass production. It is well established that exogenous supply of nutrients stimulate both cell division and cell expansion, as a result of higher photosynthetic production. Foliage being a primary sink, derives a substantial portion of the assimilates. Similarly thinning alters the light regimes in the stand and consequently favour stand photosynthesis. Duffy (1977) reported that NPK fertilization enhanced total foliage production in *Pinus taeda*.

Table 5c Effect of site quality x thinning and site quality x fertilization interactions on foliage dry weight

Aug 90 Interaction	Thinning: Control (no thinning)	Medium	Heavy
Site Quality			
High	4 88	0 37	0 56
Medium	0 33	0 42	0 34
Low	0 20	0 22	0 28
F-test	*		
SEM (±)	0 04		
CD (0 05)	0.10		

Nov. 90 Interaction	Thinning: Control (no thinning)	Medium	Heavy
Site Quality			
High	0 58	0 39	0 62
Medium	0 35	0 49	0 38
Low	0 21	0 23	0 30
F-test	*		
SEM (±)	0 07		
CD (0 05)	0 16		

May. 91 Interaction	Thinning: Control (no thinning)	Medium	Heavy
Site Quality			
High	0.78	0 48	0 76
Medium	0 38	0 76	0 46
Low	0 23	0 26	0 35
F-test	*		
SEM (±)	0.12		
CD (0 05)	0 27		

Feb 91 Interaction	Thinning: Control (no thinning)	Medium	Heavy
Site quality			
High	0.72	0.46	0.73
Medium	0 37	0 71	0 44
Low	0 22	0 25	0.34
F-test	*		
SEM (±)	0.1		
CD (0 05)	0 23		

* Significant at 5 per cent level

Aussenac et al. (1982) reported that in Douglas-fir thinning improved foliage dry weight production upto 13 per cent. In caatinga forests, Schacht et al. (1988) observed that moderate thinnings resulted in better foliage production.

4.5 Foliage nutrient levels

Seasonal variations in foliar nutrient levels are evident from Table 6. A general increase in foliar nitrogen content is seen during the summer season (May). However, foliage nitrogen contents declined during August. Leaf nitrogen accumulation during summer occurs, presumably as a component of the photosynthetic enzymes. The fresh foliage produced following summer showers are, perhaps, nutritionally richer also. A similar accumulation of leaf nitrogen has been observed by Woodwell (1974) in the case of a temperate deciduous species (scarlet oak; Quercus coccinea).

Moreover, once leaves are fully expanded, seasonal changes in the nutrient content per unit leaf area indicate the pattern of nutrient movements between the foliage and stem and/or nutrient leaching from the leaf surface through rainfall. The latter explanation perhaps is logical as the data presented in Table 6 depict a reduction in both nitrogen and potassium contents during August. Both nitrogen and potassium are highly soluble and concentrated in the cells near the leaf surface (Waring and Schlesinger, 1985). However, there was no

Table 6. Effect of site quality, thinning treatments and fertilizers on leaf nitrogen, phosphorus and potassium contents of teak saplings

Treatments	Nitrogen (%)				Phosphorus (%)				Potassium (%)			
	AUG 90	NOV 90	FEB 91	MAY 91	AUG 90	NOV 90	FEB 91	MAY 91	AUG 90	NOV 90	FEL 91	MAY 91
I <u>Site quality</u>												
High	1.16	1 13	1 38	1 51	0 09	0 11	0 10	0 07	1 31	1 30	1 18	1 29
Medium	1 24	1 33	1 52	1 49	0 10	0 08	0.08	0 07	1 23	1 25	1 32	1 44
Low	1 09	1 58	1 51	1 58	0 08	0 06	0 06	0 06	1 06	0 89	1 37	1.33
F-test	NS	*	NS	NS	NS	*	**	NS	NS	**	NS	NS
SEM (+)	0 07	0 10	0 04	0 12	0.01	0.01	7.5E-03	3 7E-03	0 09	0.07	0.06	0.05
CD (0.05)	-	0.33	-	-	-	0 03	0.02	-	-	0 22	-	-
II <u>Thinning intensities</u>												
Control (No thinning)	1 28	1.45	1.45	1 53	0.08	0.05	0 06	0.06	0.87	0 97	1 15	1 27
Medium	1 18	1 36	1 51	1 59	0.09	0 13	0.10	0 07	1 43	1.23	1 39	1 42
Heavy	1 03	1 23	1.46	1 46	0.09	0 09	0 08	0 07	1 30	1.23	1.32	1.37
F-test	NS	NS	NS	NS	NS	**	**	NS	**	*	NS	NS
SEM (+)	0.07	0.10	0 04	0 12	0 01	0 01	7.5E-03	3 7E-03	0 09	0 07	0 06	0 05
CD (0 05)	-	-	-	-	-	0 03	0 02	-	0 21	0 22	-	-
III <u>Fertilization</u>												
Control (No fertilizer)	1 07	1 19	1 20	1 27	0 07	0 09	0 08	0 06	1 23	1 21	1 24	1 38
Medium	1 19	1 50	1 62	1 60	0 11	0 09	0 09	0 08	1 21	1 14	1 27	1 31
Heavy	1.23	1 35	1 59	1 72	0 08	0 08	0 07	0 07	1 16	1 08	1 36	1 36
F-test	NS	NS	**	NS	NS	NS	NS	**	NS	NS	NS	NS
SEM (+)	0 07	0 10	0 04	0 12	0 01	0 01	7 5E-03	3 7E-03	0 09	0 07	0 06	0 05
CD (0 05)	-		0 13	-	-	-	-	0 01	-	-	-	-

** = Significant at 1 per cent level
* - Significant at 5 per cent level
NS - Not significant

concomittant reduction in leaf phophorus content during August, which in turn, is contrary to the observations of Waring and Schlesinger (1985). They found that the magnitude of nutrient loss followed the order : K > P > N > Ca for temperate species. In fact, our observations indicate that foliar phosphorus content was least during May 1991. Therefore, phosphorus being a structural component of the tissues, probably does not follow the generalized pattern of nitrogen and potassium leaching.

Yet another plausible explanation for the high nutrient content of teak foliage during summer season is the deposition of atmospheric aerosols (dry fall), which are generally low during the rainy period or immediately thereafter. The atmospheric aerosols are generally poor in terms of phosphorus as the atmospheric sources of phosphorus are generally scarce.

Regarding the experimental variables, site quality effect on tissue nitrogen levels was significant only during November 1990 and fertilizers during February 1991. Surprisingly, nitrogen content of the foliage was consistently high in the low site quality plots (1.58 per cent during November 1990 and May 1991), followed by medium and high. This might be due to the high biomass production in the high sites and the consequent nutrient dilution effect as leaf tissues accumulate more carbohydrates and cellulose. As regards to foliar phosphorus, in general, high site quality recorded higher values and the differences were significant in November 1990 and February 1991 (Table 6). Foliar potassium content was highest in high plots during November 1990 (1.30 per cent) and it was significantly superior to the low site quality, which in turn was at par with the medium site quality.

Thinning intensities did not influence leaf nitrogen content significantly. Removal of alternate diagonal rows, however, recorded the highest nitrogen levels especially towards the later stages of experiment (during May 1991 : 1.59 per cent and February 1991 : 1.51 per cent). Heavy and moderate thinning intensities were markedly superior to the unthinned plots in terms of foliar phosphorus content. Thinning treatments (both medium and heavy) also favoured accumulation of potassium in the teak foliage as is evident from the higher values reported (Table 6). These probably are the effects of reduced competition for site resources.

Regarding fertilizers, 100:50:50 kg ha^{-1} N, P_2O_5 and K_2O recorded the highest nitrogen content (1.72 per cent) in May 1991. During February and May 1991, it was seen that the medium and heavy doses of fertilizers were significantly superior to the control ($p = 0.01$) in terms of foliar nitrogen and phosphorus contents.

Site quality-fertilizer interaction was significant in respect of foliar nitrogen (Table 6a). In general, application of fertilizers stimulated foliar nitrogen status in any given site quality class (Table 6a). When nutrients are added to the

Table 6a. Effect of site quality x fertilization and thinning x fertilization interactions on leaf nitrogen content during February 1991.

	Fertilization		
	Control (no ferti.)	Medium	Heavy
Site Quality			
High	0.79	1.79	1.57
Medium	1.52	1.45	1.61
Low	1.30	1.63	1.60
F-test	**		
SEM (+)	0.07		
CD (0.05)	0.23		
Thinning			
Control (no thinning)	1.12	1.74	1.49
Medium	1.32	1.70	1.50
Heavy	1.17	1.42	1.79
F-test	*		
SEM (+)	0.07		
CD (0.05)	0.23		

Table 6c. Effect of site quality x thinning interaction on leaf potassium content during February 1991.

	Thinning		
	Control (no thinning)	Medium	Heavy
Site Quality			
High	0.76	1.35	1.41
Medium	1.18	1.42	1.36
Low	1.49	1.39	1.22
F-test	*		
SEM (+)	0.11		
CD (0.05)	0.35		

* Significant at 5 per cent level
** Significant at 1 per cent level

deficient soils (See: Table 8), the relative growth rate of trees may increase, so that no increase in foliar nutrient concentration is observed. However, when factors such as light or reduced water availability restricts photosynthetic production, nutrients may pile up in the foliage. In this context, it is significant that the site quality - fertilization was significant only during February 1991, when perhaps the restricted soil moisture availability (See: Fig. 1) retarded tree growth rates.

Similarly the interaction between site quality and thinning, intensities also was significant with respect to foliage phosphorus and potassium levels (Table 6b and c). High and medium intensity (with the exception of May 1991) thinning levels on high sites recorded higher values for foliage phosphorus and potassium contents. Interestingly on low sites control (no thinning) recorded the highest potassium levels in foliage.

Thinning-fertilization interaction was significant for nitrogen and phosphorus (Table 6a and b). Here again, heavy and medium fertilization levels in conjunction with heavy and medium thinning intensities recorded relatively higher values for N (1.79 and 1.70 per cent ; Table 6a) on the whole. The higher nutrient levels consequent on application of chemical fertilizer either in heavily/moderately thinned plots or high/medium sites implies that unless fertilizers are applied in conjunction with thinning especially on reasonably 'good' sites, its potential

Table 6b. Effect of site quality x thinning and thinning x fertilization interaction on leaf phosphorus content.

Interaction Feb. 91	Thinning Control (no thinning)	Thinning Medium	Thinning Heavy
Site Quality			
High	0.05	0.13	0.12
Medium	0.08	0.07	0.08
Low	0.05	0.10	0.04
F-test	*		
SEM (±)	0.01		
CD (0.05)	0.04		
May 91			
Site Quality			
High	0.05	0.06	0.10
Medium	0.09	0.06	0.07
Low	0.05	0.09	0.04
F-test	*		
SEM (±)	6.5E-03		
CD (0.05)	0.02		
May 91			
Fertilization			
Control (no fert.)	0.06	0.08	0.05
Medium	0.04	0.07	0.10
Heavy	0.06	0.06	0.09
F-test	*		
SEM (±)	6.5E-03		
CD (0.05)	0.02		

* Significant at 5 per cent level

Table 6d. Nutrient content in different tree components in young teak saplings as a fuction of site quality (n = 6)

Site quality	Nitrogen (%)				Phosphorus (%)				Potassium (%)			
	Mean	Minimum	Maximum	SE	Mean	Minimum	Maximum	SE	Mean	Minimum	Maximum	SE
I. <u>STEM WOOD</u>												
High	0.33	0.14	0.40	0.11	0.04	0.02	0.06	0.01	0.72	0.56	0.80	0.10
Medium	0.20	0.14	0.40	0.10	0 03	0.01	0.05	0.01	0.81	0.55	0.18	0.29
Low	0.18	0.12	0.27	0.07	0.04	0.01	0.05	0.01	0.72	0.51	0.96	0.17
II. <u>BRANCH WOOD</u>												
High	0.24	0.11	0.40	0.10	0.07	0.06	0.09	0.01	0.95	0.38	1.25	0.30
Medium	0.29	0.14	0.40	0.12	0.05	0.03	0.10	0.03	1.11	0.73	1.82	0.43
Low	0.21	0.14	0.40	0.10	0.06	0.02	0.10	0.03	1.26	1.03	1.48	0.15

SE = standard error.

benefits are restricted, provided that the higher nutrient levels do not result from impeded growth/biomass accumulation consequent of an episode of water stress or any other environmental factors. Nwoboshi (1984) also reported that nutrient contents like biomass production were generally higher on the more productive sites. This underscores the need for fertilizing plantation particularly on "good sites". He further added that nutrient content was affected by stocking. In teak, Zech et al.(1989) reported that health, growth and vigour of teak differ considerably according to site. The high potassium content in the low sites - no thinning combination is probably an artifact of the lower amount of total and foliage biomass observed in these treatments.

4.5.1 Branch wood and stem wood nutrient levels in teak

Miller (1980) reported that much of the nutrient storage occur in foliage. Nitrogen content of stem wood was highly variable in different site qualities (Table 6d). High sites recorded higher mean stem wood nitrogen nitrogen content (0.33 per cent). Phosphorus and potassium content of stemwood was, however, less variable (range : 0.03 - 0.04 per cent P and 0.72 - 0.81 per cent K). N, P and K status of the branch wood exhibited a relative lower magnitude of divergence.

High sites registered relatively higher stem wood and branch wood nitrogen contents which can be attributed to the high site nutrient capital. However, soil nutrient analysis (see Table 8) did not manifest any similar pattern of nutrient availability which probably suggest the insensitivity of the soil analysis to characterize forest site quality. Suprisingly potassium content was greatest in low sites, signifying luxury consumption of this element. In general, the trend concerning nutrient contents of different tree organs followed the order leaves> stemwood> branch wood. However, Nwoboshi (1984) reported a slightly different pattern viz. leaves> branches> bolewood.

4.5.2 Stemwood and branchwood biomass

Dry weight of stemwood was highly variable in different site qualities (range : 0.05 - 17.77 kg tree^{-1} in high and 0.16-12.62 kg tree^{-1} in medium, Table 7). High site consistently recorded higher mean stemwood, branch wood and foliage dry weight (3.22, 0.93,0.52 kg tree^{-1}) respectively. Dry weight of the branch and foliage exhibited a relatively lower magnitude of divergence.

Higher stemwood, branchwood and foliage dry weight in the high sites can possibly be attributed to the better growth conditions existing there. Nwoboshi (1971) also reported that on more productive sites biomass and foliage production were generally higher.

Table 7. Dry weight of various components (Kg/tree) as affected by site quality.

Site Quality	Stemwood				Branchwood				Foliage			
	Mean	Minimum	Maximum	SE	Mean	Minimum	Maximum	SE	Mean	Minimum	Maximum	SE
High	3.22 (88)	0.05	17.77	3.78	0.93 (88)	0.05	9.37	1.53	0.52 (88)	0.02	2.89	0.61
Medium	2.47 (72)	0.16	12.62	2.68	0.62 (70)	0.06	2.89	0.60	0.45 (72)	0.08	1.33	0.37
Low	0.55 (81)	0.06	4.90	0.98	0.25 (71)	0.03	1.69	0.31	0.23 (81)	0.04	1.04	0.24

Figures in parentheses indicate number of observations (n).

SE = Standard Error.

4.6 Soil nutrient levels

Soil nutrient levels were not substantially different among the treatments (Table 8; Appendix V). Low site quality recorded slightly higher amount of soil P and organic matter. However, nitrogen and potassium content was higher in the medium site class. Neither thinning nor fertilizer application substantially modified the soil nutrient scenario implying that short term interventions such as fertilizer application or thinning intensities are, thus incapable of bringing about pronounced alterations in the nutrient capital of the site.

Table 8. Effect of site quality, thinning treatments and fertilizers on soil nutrient levels.

Treatments	Nitrogen (%)	Phosphorus (ppm)	Potassium (ppm)	Organic matter (%)
I. Site quality				
High	0.12	70.56	21.06	2.01
Medium	0.15	78.89	23.11	1.98
Low	0.12	103.33	22.22	2.22
F-test	NS	NS	NS	NS
SEM (±)	0.02	27.76	1.51	0.14
CD (0.05)	-	-	-	-
II. Thinning Intensities				
Control (No thinning)	0.12	57.78	21.42	1.94
Medium	0.12	106.11	23.69	2.21
Heavy	0.14	88.89	21.28	2.06
F-test	NS	NS	NS	NS
SEM (±)	0.02	27.76	1.51	0.14
CD (0.05)	-	-	-	-
III. Fertilization				
Control (No fertilizer)	0.11	67.78	22.84	2.02
Medium	0.14	71.11	23.41	2.15
Heavy	0.13	113.89	20.13	2.04
F-test	NS	NS	NS	NS
SEM (±)	0.02	27.76	1.51	0.14
CD (0.05)	-	-	-	-

NS = Not significant.

Summary

V. SUMMARY

Forest plantation management in India, has received only scant attention in the past. Proper management of plantations, however, is essential especially in view of the rising demand for timber and other forest products. Traditional forestry practices with little or no change are still in vogue in most parts of our country. As a result, productivity of our plantations are generally very low. Standardization of cultural practices such as thinning and fertilization are means to increase productivity of forest plantations either by replenishing the site nutrient capital or redistributing the site resources among a fewer, desired number of trees and/or by controlling competition.

With the objective of standardizing the stand density manipulation and fertilization strategies an experiment was conducted at Vellanikkara during 1990-91. The experimental variables consisted of factorial combinations of three thinning intensities [T_0 = control (no thinning); T_1 = removal of alternate diagonal rows and T_2 = removal of every third diagonal row] and three fertilizer levels [F_0 = no fertilizer, F_1 = 50:25:25 Kg of N, P_2O_5 and K_2O ha^{-1} yr^{-1} and F_2 = 100:50:50 kg of N, P_2O_5 and K_2O ha^{-1} yr^{-1} together with three different site quality blocks (high, medium and low). Fertilizers were applied after thinning in the basins around each tree during July 1990. Observations on height and girth of trees were recorded at three monthly intervals, besides initial observations on tree biomass, sapwood cross sectional area, foliage area and foliage weight. The salient findings are summarized below:

1. Mean tree height was strongly influenced by density manipulation. Moderate and heavy thinnings were superior to the unthinned ones in terms of mean tree height. High sites in combination with high and medium doses of fertilizers also recorded higher values for tree heights, implying the beneficial effects of fertilization on the better quality sites, in promoting tree growth.

2. The effects of site quality, thinning and fertilizer application on quadratic mean diameter, basal area, basal area increment and height increments were however not marked. Nevertheless, high sites, moderate levels of thinning and medium and high fertilizer doses in general performed better.

3. Linear regression equations linking foliage area with sapwood cross sectional area at breast height/collar level gave reasonably good r^2 values, indicating the suitability of such equations for estimating foliage area/biomass of trees. Furthermore, radial growth parameters (DBH/Girth) can act surrogates for sapwood cross sectional areas in leaf area/biomass estimates of young trees. Variations in tree biomass production also were found to be profoundly influenced by the allometry of the trees.

4. The estimates of leaf area and foliage dry weight showed significant differences with site quality at all stages of observations. High site quality consistently recorded higher values for leaf area and foliage biomass. Similarly, medium and heavy thinning intensity and fertilizer dozes were markedly superior to the control.

5. The combination of high site quality and heavy thinning alongwith moderate thinning and medium site quality recorded higher mean leaf area and leaf biomass production per tree indicating the favourable effects of these combinations on leaf area expansion and assimilate production.

6. As generally expected thinning reduced the stand leaf area index and high site recorded higher LAI. Chemical fertilizers had only a moderate influence on leaf area expansion on a stand basis. Interaction effect of high site quality with no thinning and high site quality in conjunction with medium and heavy fertilizer doses recorded high LAI.

7. The estimated mean tree biomass (using D^2H relationship) was highest for the high site class. Similarly, heavy thinning and application of moderate doses of fertilizers also improved tree biomass production.

8. Interaction effects showed that, the combination of high site quality with heavy thinning and high site with medium doses of

fertilizers consistently recorded high biomass yield . This underscores the potential advantages of thinning and fertilization applied in conjunction, especially on the better quality sites.

9. A general increase in foliar nitrogen was seen during summer season (May) and it declined during August. Nitrogen content of the foliage was relatively higher in the low site quality plots which may be due to the nutrient dilution effect consequent to the higher biomass production in the high plots. Foliar phosphorus and potassium in general were also higher on high sites. Regarding fertilizers, medium and heavy doses recorded highest N,P and K contents implying the benefit of ferilizers on trees rather than on the site.

10. Soil nutrient analysis showed that neither fertilizer nor thinning substantially modified the soil nutrient scenerio implying that short term interventions such as fertilizer application or thinning are, thus incapable of bringing pronounced alterations in the nutrient capital of the site.

11. In general the trend concerning nutrient contents of different tree organs followed the order leaves> stemwood> branchwood. Branchwood and stemwood N levels were higher on high sites. Potassium content was, however greatest, in the low sites, signifying possible luxuary consumption of this element.

References

VI. REFERENCES

Abayomi, J.O. Ekee, B.A. and Mwaigbo, L.C. 1985. 15th Annual Conference of Forestry Association of Nigeria. Yola, 25-29-November 1985:290-299.

Auchmoody, L.R. and Filip, S.M. 1973. Forest fertilization in the eastern united states: hard woods. In: Forest Ferti. symp. proc., 211-225. USDA Forest serv. Gen. Tech. Rep. NE-3,:246. Upper Darby, Pa.

Adiyodi, P.N. 1973. The seventh working plan for Wynad forest division (1974-75 to 1983-84). State Forest Department, Government of Kerala, Trivandrum, 150p.

Agrawal, V.P. 1985. Forest in India, Environmental and production Forestry Oxford and IBH Pub. Co., New Delhi, 341 p.

Anoop, E.V. Kumar, B.M. and Abraham, C.T. 1991. Teak growth in resonse to weed control treatments. (In review).

Attiwill, P.M. 1980. Nutrient Cycling in a Eucalyptus obliqua (L'Herit.) Forest. III growth, biomass and net primary production. Aust. J. Bot., 27:439-458.

Araujo Filho, J.A. and Gadelha, J.A. 1982. Relatorio anual das atividades tecnicas administrativas do convenio BNB/FCPC-Pastoreio combinado, bovino, ovino e caprino. Banco do Nordeste do Brasil S.A., Fortaleza, 35 pp.

Aussenac, G. Granier, A. and Nand, R. 1982. Influence of thinning on growth and water balance of a young plantation of Douglas-fir. Can. J. For. Res., 2(12):222-231.

Badan, R. Bardet, L. and Jeantet, G. 1977. Thoughts on forest fertilizing. Foret (Fr) Serv. des. For., Lausanne, Switzerland, 30(2):29-33.

Ballard, R. 1980. Forest plantations, the shape of the future. (Eds). Wotton. M.J. and Lloyd D.D., Weyerhaeuser Company, Washington. p.159-200.

Ballard, R. Lea, R. and Nakat, C. 1981. Paper presented at Division I, 17th IUFRO World Congress, Kyoto, Japan.

Ballard, R. 1984. Fertilization of plantation. In: Nutrition of Plantation Forests. (Ed). G.D. Bowen and E.K.S. Nambiar, Academic Press, New York, 327-860.

Banerjee, A.K. 1973. Nutritional experiment of Tectona grandis in laterite soils of West Bengal. 50: For. Conf. from 6-10th Dec. 1973. Forest Res. Inst. Dehra Dun.

Barger, R.L. and Ffolliott, P.F. 1970. Evaluating product potential in standing timber. USDA For. serv. Res. Pap. RM-57.

Barton, I.L. and Madguick, H.A.I. 1987. Response of a kauri stand to fertilizer addition and thinning. New Zealand Forestry, 2:19-21.

Baskerville, G.L. 1965. Estimation of dry weight of tree components and total standing crop in conifer stands. Ecology, 46:867-869.

Baule, H. 1973. Response of Douglas fir stand to fertilizers. BLV Verlag, Munich.

Baule, H. and Fricker, C. 1970. The fertilizer treatment of Forest Trees, BLV Verlag, Munich.

Bengtson, G.W. 1973. In Proc. Inter Natl. Symp. on Forest Fertilization, FAO/IUFRO, Paris. pp. 97-153.

Bengtson, G.W. 1976. Paper presented at Division 1, 6th IUFRO World Congress, 0510.

Besale, I.F. 1973. Tree density effect on yields of herbage and tree components in south west Queensland mulga (Acacia aneura F. Muell.) scrub. Trop. Grassl., 7:135-142.

Beumee, J.G.B. 1922. Results of remeasuring of 40 permanent sample plots reserved for the investigations regarding thinning and yield of Teak plantations, Tectona. 15: 1-76.

Bhatnagar, H.P., Gupta, B.B., Rauthan, B.S. and Joshi, D.N. 1969. Preliminary studies on the nutritional requirements of Teak (Tectona grandis). Indian For., 95:488-495.

Binkely, D. and Reid, P. 1984. Long term responses of stem growth and leaf area to thinning and fertilization in a Douglas-fir plantation. Can.J. For. Res. 14 :656-666.

Blanford, H.R. 1923. Thinnings in Teak plantation. Burma For. Bull., 9:1-8.

Bolghari, H.A. 1980. Growth of a fir/spruce stand South-east of Quebee following thinning and fertilization. Naturalistic Canadian, 107(3): 135-149.

Bolstand, P.V. and Allen, H.L. 1987. Height and growth responses in loblolly pine stand following fertilization . For. Sci., 33(3):644-653.

Bower, D.R. 1965. Precommercial thinning accelerate diameter growth of loblolly pine. J. For., 63(3):210-214.

Briscoe, C.B. and Raul Ybarra-Coronado. 1972. Increasing growth of established Teak. Commonwealth Forestry Rev., 51:290-294.

CFC 1984. Central Forest Commission (CFC), 1984. India's Forest. MOA. FRI, Dehra Dun.

*Ciancio, O. and Martire, F. 1974. Fertilizer trials on plantations of Silver fir and weymouth pine in calabrica, Annali dell'Instituto sperimentle per la selvicoltura, Arezzo., 5:37-59.

Dean, T.J. and Long, J.N. 1985. Variation in sapwood Area-Leaf Area Relations within Two stands of Lodgepole Pine. Forest Sci., 32: 749-758.

De Bell, D.S., Mallonee, E.H. and Alford, L.T. 1975. Effect of N fertilizer on growth, form, and wood quality of Eastern cotton wood. Forestry Research Note, Crown Zelleubach., 4 : 6 pp.

Dixon, A.F.G. 1971. The role of aphids in wood formation. The effect of the sycamore aphid. Drepanosiphum plantanades (Schr.) (Aphidae) on the growth of Sycamore Acer pseudoplantanus (L.). J. Appl.Ecol. 8: 165-179.

Donald, D.G.M. and Schultz, C.J. 1977. The response of Eucalyptus grandis to fertilizer application at planting: Louw's creek trial. South African For. 102: 23-28.

Duffy, P.D. 1977. Fertilizer to accelerate loblolly pine foliage growth for eroision control. Research Note, Southern For. Expt. stn. No. SO-230: 4 pp.

Evans, J. 1982. Plantation Forestry in the Tropics. Oxford University Press, Oxford, 472 pp.

Fahlroth, S. 1969. Diameter increases in stands where fertilizers have been applied. Skogen, 8(56): 238-239.

Forest Department, A.P., India (FDAP), 1964. A note on manurial trials on teak plantations (unpub.).

Forest Research Institute (F.R.I.), 1955. Teak manurial experiments in Nilambur. Forest Research in India Part II, 1954-55, FRI Dehra Dun., 74 pp.

Fownes, J.H. and Harrington, H.A. 1990. Modelling growth and optimal rotations of tropical multipurpose trees using unit leaf rate and LAI. J. Appl. Ecol., 27: 886-896.

Frison, G. 1976. Effect of mineral fertilizers on the growth of Poplar. Cellulosa carta., 27(5):3-20.

Gambi, G. 1979. Experiments on the use of fertilizers in the forest. Annali dell' Instituto Sperimentale fer la selvicoltura, Arezzo 2: 163-198.

Gholz, H.L., Grier, A.G., Campbell, C. and Brown, A.T. 1979. Equations for estimating biomass and leaf area of plants in the Pacific Northwest-Oregon State University Forest Research Laboratory Research Paper 41: 39 p.

Grah, R.F. 1961. Relationship between tree spacing, Knot size and log quality in young Douglas-fir stands. J. For , 59:270-272.

Graney, D.L. 1983. Effects of thinning and fertilization on growth of upland oak stands in Boston mountains of Arkanas: 7-year results. General Technical Report, USDA Forest Service:269-274.

Grier, C.C. and Logan R.S. 1978. Old growth Douglas-fir communities of a western oregon watershed: biomass distribution and production budget. Ecol. Monogr., 47: 373-400.

Grier, C.C. and Running, S.W 1978. Leaf area of mature north western coniferous forests: relation to a site water balance, Ecology, 58: 893-899.

Groot, A., Brown, K.M., Morrison, I.K and Barker, J.E. 1984 A-10-year tree and stand response of Jack pine to urea fertiloization and low thinning. Can. J For. Res., 14(1):44-50.

Haapanen, J., Hari P. and Kellomaki, S. 1979. Effect of fertilization and thinning on radial growth of scot pine. Silva Fennica., 13(2):184-189.

Hamamoto, M. 1981. Paper presented at Division 1, 17th IUFRO World Congress, Kyoto, Japan.

Hase, H. and Foelster, H. 1983. Impact of plantation forestry with Teak (Tectona grandis) on the nutrient status of young alluvial soils in west Venezuela. For. Ecol. Manage., 6:33-57.

Heinsdorf, D. 1967. The effect of mineral fertilizing on sandy soils in the low lands of northeast Germany. V. Dry matter production, increased nutrient uptake and nutrient accumulation of pine plantations after fertilizing. Arch Forstw., 16(3): 183-201.

Hemter, I.R. and Hay, G.F. 1983. Growth and nutrition of Pinus radiata on a recent coastal sand as affected by nitrogen fertilizer. New Zealand J. For. Sci., 13(1):3-13.

Hocker, H.W. 1982. Effects of thinning on biomass growth in young Populus tremuloides plots. Can. J. For Res , 12:731-737.

Hoyle, M.C. 1970. Growth and nutrition of yellow birch as affected by the nutrient status of a podzol soil. In: Tree Growth and Forest soils (Ed.) Youngberg, C.T. and Davey C.B: 221-233. Oreg. State Univ. Press, Corvallis 527.

Iyer, M.K.C. 1982. Third working plan for the Punalur Forest Division. State Forest Department, Government of Kerala, Trivandrum, 96p.

Jackson, M L. 1967. Soil Chemical Analysis Prentice-Hall of India, New Delhi

Jackson, J.K. 1973. Some results from fertilizer experiments in plantations in Nigeria. Research paper (Savanna series) Federal Department of Forest Research, Nigeria No. 23

Kadambi, K. 1972. Siliviculture and Management of teak. School of Forestry, Stephen Austin State Univ Nacogdo ches, Texas : 1-7

Kalaghe, A.G. and Mwinomeke, S.T. 1983. The Influence of first thinning on growth of *Pinus patula* Schl. and cham at West Kilimanjaro, Tanzania: an interim report Tanzania silivculture technical note., 55:11 pp.

Kanwana, A and Leaf, A.L. 1974. Maintenance of productivity under short rotations in Japan. J. For., 72(8):486-487.

Kaufmann, M.R. and Troendle, C.A. 1981. The relationship of area and foliage biomass to sapwood conducting area in four subalpine forest tree species. Forest science, 27: 447-482.

Kaul, O.N., Gupta, A.C. and Negi, J.D.S. 1972 Diagnosis of mineral deficiencies in teak (*Tectona grandis*) seedlings. Indian For., 98(3):173-177.

Karunakaran, C.K. 1970 Second working plan for the Kottayam Forest Division (1970-71 to 1984-85) State Forest Department, Government of Kerala, Trivandrum, 115 p

Khanna L.S. 1984. Tending In: Principles and Practice of Silviculture (3rd ed.) Khanna Bandu publication, Dehra dun, India. 414-457.

Kirmse, R.D., Provenza, F.D. and Malechek, J.C. 1987. Clearcutting Caatinga assessment of tradiational forest grazing management practice. Agrofor. Syst.,5:429-441

Kishore, N. 1987. Preliminary studies on the effect of P fertilizers on teak plantations. Indian For., 113 (6): 391-394.

Knockert, C. and Mandouri, T. 1980. Aerial biomass of *Eucalyptus camandulensis* plantations, Lake Albacutya provenance at three years old with and without fertilizer treatment. Annales dela Recherch Forestiere au Maroc. 20:388-404.

Kramer, P.J. 1986. The role of physiology in forestry Tree Phys , 2:11-16

KSFD, 1990. Forest statistics, Kerala State Forest Department, Trivandrum, Kerala.

Laing F.M., Sendak, P.E., Aleong, J. 1985. Species trials for biomass production on abandoned farmland. Northern J of Appl. Forestry, 2(2): 43-47.

Lanner, R.M 1985. On the insensitivity of height growth to spacing. For. Ecol. Manage., 13: 143-148.

Larson, P.R. 1969. Wood formation and the concept of wood quality Yale Univ. Sch. Bull. For., 74:54 pp.

Larson, B.C and Zaman, M N. 1985. Thinning guidelines for teak (Tectona grandis L) Malaysian Forester, 48(3-4) : 288-297

Lim, M.T. 1988. Studies in Acacia mangium in Kemasul Forest Malaysia, 1 Biomass and productivity J Appl. Ecol 4: 293-302.

Liu, J R. 1984. Preliminary study on relationship between mean diameter and stand density. For. Sci. Technol 3: 17-21

Lloyd, W.J 1955. Alder thinning progress report USDA Soil Conserv Tech. Notes Woodland and conservation 3: 6 pp

Long J N and Smith, F W 1984 Relation between size and density in developing stands: A description and possible mechanisms. Forest Ecol. and Manage , 7: 191-206

Long, J.N and Smith F W. 1989 Estimating leaf area of Abies lasiocarpa across ranges of stand density and site quality Can J For. Res 19:930-932

Louppe, D. 1985. Improvement of Forest productivity by fertilizer application. Example of Madagascar. Bulletin des Recherches Agronomiques de Gembloux, 20 (3-4 part 2): 851-865.

Lozano, F.C. 1975. Soil moisture, diameter growth, foliar nutrients, and plant moisture stress in a thinned and fertilized Red oak (Quercus rubra) stand Disseration abstracts International, 35(9):4304-5

Mader, D.L., Thompson, D.W and Wells, J.P 1969 Influence of nitrogen on sugar maple decline, Univ Mass Agric. Exp Stn. Bull. 582: 24 pp.

Mader, D.L. 1973. Fertilizer needs and treatment responses for wood fibre production: field assessment In: Forest Fert. Symp. Proc.: 140-154. USDA Forest serv Gen Tech. Rep Ne-3 :246 Upper Darby pa

agnussen, S., Smith, V G and Yeatman, C W 1986. Foliage and canopy characteristics in relation to above ground dry matter increment of seven jack pine provenances Can J For Res , 16: 464-470.

Maun, M M. 1977. Survival and growth of four reforestration species applied with slow release tablet fertilizer Sylvatrop., 2(3):219-222

Miller, H G. and Miller. J D 1976 Effect of nitrogen supply on net primary production in corsican pine J Appl Ecol., 13:249-56

Miller, H G. 1980. Forest Fertilization: Some Guiding Concepts Forestry, 54(2): 157-167

Miller, R E., Reukema, D L and Williamson, R L. 1981 Response to fertilization in thinned and unthinned Douglas-fir stands. In: Proceedings, Forest Fertilization conference (Ed). Gssel, S.P Kenady, R.M , Atkinson W A Washington, U S A 150-157

Louppe, D. 1985. Improvement of Forest productivity by fertilizer application. Example of Madagascar. Bulletin des Recherches Agronomiques de Gembloux, 20 (3-4 part 2): 851-865.

Lozano, F.C. 1975. Soil moisture, diameter growth, foliar nutrients, and plant moisture stress in a thinned and fertilized Red oak (Quercus rubra) stand Disseration abstracts International, 35(9):4304-5.

Mader, D.L., Thompson, D.W and Wells, J.P 1969 Influence of nitrogen on sugar maple decline, Univ Mass. Agric. Exp. Stn. Bull. 582: 24 pp.

Mader, D L. 1973. Fertilizer needs and treatment responses for wood fibre production: field assessment In: Forest Fert. Symp Proc.: 140-154. USDA Forest serv Gen Tech. Rep. Ne-3,:246 Upper Darby pa.

agnussen, S , Smith, V G and Yeatman, C W 1986 Foliage and canopy characteristics in relation to above ground dry matter increment of seven jack pine provenances Can J For. Res , 16: 464-470

Maun, M M. 1977 Survival and growth of four reforestration species applied with slow release tablet fertilizer Sylvatrop., 2(3):219-222

Miller, H G. and Miller. J D. 1976 Effect of nitrogen supply on net primary production in corsican pine J Appl Ecol., 13:249-56

Miller, H G. 1980 Forest Fertilization: Some Guiding Concepts Forestry, 54(2): 157-167.

Miller, R E., Reukema, D L and Williamson, R L 1981 Response to fertilization in thinned and unthinned Douglas-fir stands. In: Proceedings, Forest Fertilization conference (Ed). Gssel, S P Kenady, R.M , Atkinson W A Washington, U S A 150-157

Miller, H.G. 1984. Dynamics of nutrient cycling in plantation forest ecosystem . In: G.D. Bower and E K S Nambiar (Ed.) Nutrition of plantation Forests Academic Press New York., 53-78.

*Moller, C.M 1945. Untrrsuchung uber laubmenge, staffverlust and stoffverlust and stoffproduktion des Waldes Forstl Forsogsv, Danmark, 17:1-287.

Mooney, H.A 1972 The carbon balance of plants. Ann. Rev Ecol Syst , 3: 315-346

Morozov, V.A. Shimanskii, P S and Usenya, V.V 1985 Growth of scots pine in relation to initial plantation density and fertilizer application Lesnoe Khozyaistva , 3: 41-43

Nebeker, T.E., Hodges, J D Karr, B.K and Moehring D M 1985 Thinning practices in Southern pines-with pest management recommendations United states Dept of Agriculture Forest Service. Technical Bulletin No 1703 33 pp

*Newbould, R M 1967 The development of stand model for Douglas-fir Faculty of Forestry, University of British Columbia, Vancouver Ph D. thesis 201 pp.

*Nwoboshi L.C 1971 A preliminary report on the application of row, elecctric and basal area thinnings on an 8-Year-old teak stand Research Notes Dept of Forestry Ibdadan University 1(1):1-4

Nwoboshi L C. 1984 Growth and Nutrient Requirements in a teak plantation Age series in Vigeria II Nutrient accumulation and minimum annual requirements Forest Sci. 30(1): 35-40

Orallo, C.A. 1985 Thinning a natural sapling stand of Benguet pine (Pinus Kesiya Royle ex Gordon) Sylvatrop 10(1):1-8

Ovington, J D. 1957 The composition of tree leaves Forestry, 1(29): 22-28.

Ovington, J.D , Heitkamp, D. and Lawernce, D. B. 1963 Plant biomass and productivity of praire savanna, oak wood and field ecosystems in Central Minnesota. Ecology, 44: 52-63

Paovilainen, E. 1975. The response of Norway spruce to fertilizer treatment on peatland sites Folia Forestalia, institutum Forestale Fenniae , 239:10.

Paovilainen E 1976 Nitrogen fertilization on shallow peats with sedges and pines. Typpilannnoitum ohutturpeisilla piensaravameilla. Folia Forestalia Institutum, 16:272

Pongsopha Ch 1962 Comparison of Teak growth resulting from different degree of thinning. Thesis of Faculty of Forestry (1961-62), Kasetsart University Bangkong Thailand (Thai) pp 171

Prasad, R 1982 A practical manual for soil fertility Division of Agronomy Indian Agricultural Research Institute New Delhi

Prasoon Kumar 1990 Stand Density Regulation in Even Aged Teak Plantations M Sc Dissertation Kerala Agricultural University Vellanikkara: 1-72

Pratt D J and Knight,J 1971 Brush control studies in the dryer areas of Kenya V Effects of controlled burning and grazing management on Tarconanthus/Acacia thicket J Appl Ecol 8: 217-237

Pritchett W.I 1978 Site preparation and fertilization of slash pine on a wet savanna soil South J Appl. For 3: 86-90

Pritchett W L 1979 Properties and Management of Forest Soils, John Wiley and sons N Y pp 74

Putz, F E. Parkar, G. and Archibald, M. 1984 Mechanical abrasion and intercrown spacing. Am Midl Nat 112:24-28.

Ram Prasad 1973. Limitation of formula thinning in Teak Forest of M P paper No (81) In: the Forestry Conference (silvicultural conference) from 6 to 10th December 1973 at For. Res Inst D. Dun (U.P). under the subject forest Management (i) Management and Mensuration pp

Ram Prasad Sha A.K and Bhandari 1986 Fertilizer trials in ten and twenty year old teak plantations in Madhya Pradesh Trop For 2(1):47-52

Rana B.S Singh S P and Singh R P 1989 Biomass and net primary productivity in central Himalayan Forests along an altitudinal Gradient. Forest Ecol Manage 27: 199-218

Rangnekar P V and Forward D F 1973 Foliar nutrition and wood growth in red pine: effects of darkening and defoliation on the distribution of ^{14}C-photosynthate in young trees. Can J Bot 51: 103-108

Ranwell, J.F., Kirk, R D and Mullins A J 1974 A preliminary study on the response of timber in Transkei to fertilization Fertilzer Society of South Africa J 1:45-46.

Rogers, R and Hinckley T M. 1979 Foliar weight and area related to current sapwood area in oak Forest Science 25: 298-303

Ryden J C McLaughlin J R and Syers J K 1977 Mechanisms of phosphate sorption by soils and hydrous ferric oxide gel J Soil Sci 28:72-92

Safford L O 1973 Fertilization increases diameter growth of birch-beech-maple trees in New Hampshire USDA Forest Serv Res Note NE-182:4

Salonie P.O and Mackay, A.W. 1980. Ten-Year-growth response of a spruce-fir fertilization Trials (in Nova Scotia) Information Report Maritimes For Res. Cen Canada, 5p

Sarlin, P 1966 The first thinning in Teak plantation Bois For Trop 28(108):5-20.

Schacht W H , Long, J N. and Malecheck, J C. 1988 Above-ground production in cleared and thinned stands of semiarid tropical woodland, Brazil. For. Ecol Manage , 23: 201-214.

Schubert J H Strand R F Cole, T G. and Mac Duttie, K E 1988 Equations for predicting biomass of six introduced tree species, Island of Hawaii, USDA Forest Service. Research Note, PSW-401

Schuster C J 1982 Fertilizing planted Kauri (Eucalyptus deversicolor F Muell.) seedlings Research paper Forest Dept Western Australia 70:11

Scott S L Barker J E Morrison, I.K Foster N W 1982 Basic density of jack pine wood influenced by fertilization and thinning Forestry Chron 58(1): 44-46

Shafii B Moore J A Olson, J R 1989 Effects of nitrogen fertilization on growth of grand fir and Douglas-fit stands in northern Idaho. Western J Appl. Forestry, 4(2): 54-57

Shetron, S G. 1976. Effect of fertilization on the tree form of sugar maple (Acer saccharum M). Research Note, Ford Forestry center, Michigan Techno, Univ , 22:7

Shinozaki, K Yoda K Hozumi, K and Kira, T 1964 A quantitative analysis of plant form - the pipe model theory I Basic analyses. Jap. J. Ecol , 14: 97-104

Shoulders, E. and Tiarks, A.E. 1980. Fertilizer fate in a 13-year-old slash pine plantation. Soil Sci. Soc. America J , 44(5):1085-1089.

Smith, D.M. 1962. The practice of silviculture John Wiley Publisher, New York, Ny. 56 pp.

Snell, J.A K. and Brown, J.K. 1978. Comparison of tree biomass estimators-dbh and sapwood area. Forest Sci., 24: 455-457.

Stone, D M 1977. Fertilising and thinning northern hardwood in the lake states USDA Forest Service Res Paper. North Central Forest Expt. Station. No NC-141:7pp

Stone, D M. 1982. Fertilization of sugar maple: Long term Proceeding, Indian Acadamy of Science, 91:590-594

Stone, D M , Shetron, S G and Peryam, J 1982 Fertilization fails to increase diameter growth of sawlog-sized northern hardwoods in upper Michigan Forestry chron 58(5):207-209.

Sunderalingam, P. 1982 Some preliminary studies on the fertilizer rquirements of Teak Malaysian Forester, 45(3):361-366.

*Suvorov, V.I 1973 Effect of mineral fertilizers on Norway Spruce plantations Lesone khozyaistvo., 7:20-25

Thaiutsa, B., choob, K , Wisut, S.P., Wasan, K and Somporm, C 1976 Soil properties of Teak plantation after thinning Forest Research Bulletin, Faculty of Forestry Kasetsart Univ , Thailand, 37: 27-30

Tiarks, A E and Haywood, J D 1986. Pinus taeda L response to fertilization, herbaceous plant control annd woody plant control For Ecol manage , 14:103--112

Timofeev, A.F. 1974. Fertilizer application in scots pine plantations on old peat workings. Lesnoe Khozycustvo. No. 10: 4477.

Walker, L.C. and Morcock, J.C. Jr. 1965. Fertilization of 21-year-old slash pine stand. Castanea., 30(1): 84-84.

Walker, J , Moore,R.M. and Robertson, J.A. 1972. Herbage reponse to tree and shrub thinning in <u>Eucalyptus populnea</u> shrub woodlands. Aust. J. Agric. Res., 23: 405-410

Waring R.H., Thies, W G and Muscato, D. 1978 Stem growth per Unit of Leaf Area: A Measure of Tree Vigor Forest Sci., 26: 125-130.

Waring R H., Schroeder, P.E. and Orens, 1982. Application of the pipe model to predict canopy leaf area. Can J Forest. Res , 12(12): 556-560.

Waring R.H 1983 Estimating forest growth and efficiency in relation to canopy leaf area. Adv Eco Res (A MacFadyen, E.D Ford, eds), 13:327-354

Waring R H. and Schleisinger, W.H. 1985. Forest ecosystems: Concept and Management Academic Press, New York, 340 pp

*Werner, G.H 1987. Development of regenerated stands of rauli after thinning. Ciencia e Investigacion , Forestal, 1(2): 31-43.

Whitehead, D. and Jarvis, P G 1981 Coniferous forest and plantations. In: Water deficits and Plant growth, Vol VI (T.T Kozlowski, ed) Academic Press, New York, p 44-152.

Winston, D.A. 1977 Height and diameter growth response of 10--year-old Jack pine to thinning and fertilization Bi-Monthly Research Notes , 3(5):34-36.

Wollum, A. G. II and Davey, C.B. 1975. Forest Soils and Forest Land management. (eds) Barnier B, and Winget, C.H., Univ. Laval Press, (Quebec.). Pages 67-106.

Woodwell, G.M. 1974. Variation in the nutrient content of leaves of Quercus alba, Quercus coccinea and Pinus rigida in the Brookhaven forest from budbreak to abscission. Am. J. Bot., 61: 749-753.

Woollons, R.C. 1980. Importance of experimental design and plot maintenance in forest field experiments in Australasia. Aust. For. Res., 10:71-82.

Woollons, R.C. 1985. Problems associated with Analyses of Long-term Pinus Sp. Fertilizer x Thinning Experiments. Aust. For. Res., 15:495-507.

Woollons, R.C. and Will, G.M. 1975. Increasing growth in high production radia pine stands by nitrogen fertilizers. New Zealand. J. For., 29:243-253.

Yost, R.S., De Bell, D.S., Whitesell, C.D. and Miyasaka, S.C. 1987. Early growth and Nutrient status of Eucalyptus saligna as affected by Nitrogen and phosphorus fertilization. Aust. For. Res., 17(3): 203.

Zavitkovski, J. and Dawson, D.H. 1977. USDA Forest Service Res. Paper-NC 157 North Control Forest Exp. Sta. Forest Service, USDA 1992. Folwell Avenue St. Paul Mimesota 55108. pp 1-15.

*Zech, W., Elz,D., Pancel, L. and Drechsel. 1989. Auswirkungen und Erfolgsbedingungen von Aufforstungsmatnahmen in Entwicklungslandern. Forschungsbericht des BMZ Band 93 Weltforum Verlag, Kohn, 348 pp.

Zech, W. and Drechsel P. 1991. Relationships between growth mineral nutrition and site factors of teak (Tectona grandis) plantations in the rain forest zone of Liberia For. Ecol. Manage., 41:221-235

* Originals not seen.

Appendices

APPENDIX -I

Abstract of ANACOVA tables for Quadratic Mean Diameter (Dq), Basal Area and Basal Area Increment

Source of Variation	DF	Quadratic mean diameter NOV 90	Quadratic mean diameter FEB 91	Quadratic mean diameter MAY 91	Basal Area NOV 90	Basal Area FEB 91	Basal Area MAY 91	Basal area increment (With respect to Aug 1990) NOV 90	Basal area increment (With respect to Aug 1990) FEB 91	Basal area increment (With respect to Aug 1990) MAY 91
Covariates Dq-Aug/BA-Aug/BAI-Aug#	1	33 04	40 94	41 95	136 59	217 47	232 70	1 07	16 88	21 31
Site quality (SQ)	2	0 01	0 19	0 19	0 01	1 12	1 24	0 01	1 12	1.34
Thinning	2	0 01	0 18	0 28	0 08	1 41	2 15	0 08	1 44	2 15
Fertilization	2	0 02	0 01	0 02	0 07	0.07	0.20	0 07	0 07	0 20
<u>Interactions</u>										
SQ x Thinning	4	0 02	0 18	0.20	0 05	0.89	1.06	0 05	0.89	1 06
SQ x Fertilization	4	0 01	0.10	0 13	0 04	0.48	0.65	0 04	0 48	0 65
Thinning x Fertilization	4	0 002	0 012	0 019	0 01	0 22	0 29	0 012	0 23	0.30
Residuals	7	0 01	0 08	0 010	0 04	0 58	0 74	0 04	0 58	0 74

\# Dq-Aug – Quadratic mean diameter of August 1990
BA-Aug = Basal Area of August 1990
BAI-Aug – Basal Area Increment of August 1990

APPENDIX - II

Abstract of ANACOVA Tables for Mean Tree Height and Height Increment

Source of variation	DF	Mean Square: Mean tree height NOV 90	FEB 91	MAY 91	Height increment (With respect to Aug. 1990) NOV 90	FEB 91	MAY 91
Covariates MH-Aug/HI-Aug	1	26.98	31.220	31.86	71.40	790.80	974.39
Site Quality (SQ)	2	0.005	0.14	0.14	7.01	228.82	048.47
Thinning	2	0.03*	0.13	0.23*	35.18	167.85	300.09
Fertilization	2	0.011	0.03	0.05	12.02	29.63	62.27
Interactions							
SQ x Thinning	4	0.018	0.093	0.13	27.97	141.23	181.38
SQ x Fertilization	4	0.020*	0.076	0.12	29.04	121.28	182.28
Thinning x Fertilization	4	0.004	0.009	0.01	9.99	60.74	65.97
Residual	7	0.005	0.38	0.042	9.33	63.50	81.34

* Significant at 5 per cent level.
MH-Aug = Mean Height for August 1990.
HI-Aug = Height Increment for August 1990.

APPENDIX - III

Abstract of ANOVA tables for leaf area, leaf area index and foliage dry weight

Source of Variation	DF	Mean Square											
		Leaf Area				Leaf Area Index				Foliage dry weight			
		AUG 90	NOV 90	FEB 91	MAY 91	AUG 90	NOV 90	FEB 91	MAY 91	AUG 90	NOV 90	FEB 91	MAY 91
Site Quality(SQ)	2	38 72**	61 21**	104 77**	127 13**	2 51**	4 31**	7 64*	9 56*	0.12**	0.18**	0 30**	0.35**
Thinning	2	3.01	3 26	1.81	1 36	1 84**	2 69*	3.21	3.30	8.9E-03	1.1E-02	8.8E-03	8.2E-03
Fertilization	2	0.69	1 67	0 87	1 30	0 34	0 64	1 01	1 41	2.2E-03	4.7E-03	3 4E-03	3 7E-03
<u>Interactions</u>													
SQ x Thinning	4	5.27*	10.41	34.05*	42 86*	0 50	1.24	3.63*	4 82	1 5E-02*	2.8E-02*	8 5E 02*	0 10*
SQ x Ferti	4	3 89	7 79	19 81	26 36	0 63*	1 29	2 88	3 87	1 01E-02	1 8E-02	4 6E-02	5 7E-02
Thinning x Ferti	4	1 50	4 12	10 01	14 05	0 29	0 66	1 49	2 09	4 7E-03	9 9E-03	2 2E-02	3 0E-02
Residual	8	1 08	3 13	6 44	9 38	0 15	0 49	0.95	1 44	2 98E-03	6.9E-03	1 5E-02	2 0E-02

* - Significant at 5 per cent level

** - Significant at 1 per cent level

APPENDIX IV

Abstract of ANOVA tables for Leaf Nitrogen, Phosphorus and potassium nutri nt content

Source of variation	DF	Mean Square											
		Nitrogen				Phosphorus				Potassium			
		AUG 90	NOV 90	FEB 91	MAY 91	AUG 90	NOV 90	FEB 91	MAY 91	AUG 90	NOV 90	FEB 91	MAY 91
Site Quality	2	0 05	0 46*	0 06	0 02	0 001	0 005*	0 003*	0 001	0 15	0 45**	0 09	0 05
Thinning	2	0 15	0 11	0 01	0 04	5E-04	0 014**	0 004*	0 000	0 77**	0 20*	0.14	0 05
Fertilization	2	0 06	0 21	0 49**	0 49	0 003	5E-04	5E-04	0 001*	0.01	0.04	0.04	0.01
Interactions													
SQ X Thinning	4	0 05	0 02	0 04	0 04	0 001	0 004	0 003*	0 002**	0 31	0 11	0 17*	0 03
SQ X Fertilization	4	0 01	0 18	0 23**	0 16	0 001	0 001	2 5E-04	2 5E-04	0 28	0 10	0 08	0 02
Thinning X Fertilization	4	0 04	0 12	0 10*	0 17	0 001	2 5E-04	0.001	0 001**	0 04	0.03	0 09	0 06
Residual	8	0 05	0 10	0 02	0 13	0 002	0 001	5E-04	1 25E-04	0 082	0 04	0 04	0 02

* Significant at 5 per cent level
** Significant at 1 per cent level

APPENDIX - V

Abstract of ANOVA tables for soil nutrient levels and total above ground biomass

Source of Variation	DF	Mean Square				Total Biomass			
		Nitrogen	Phosphorus	Potassium	Organic matter	Aug 90	Nov 90	Feb 91	May 91
Site Quality (SQ)	2	0 004	4654 63	9 57	0 158	19 95**	27 35**	45 70**	51 09
Thinning	2	0 001	2612 04	16 46	0 165	1 23	1 44	1 34	1.54
Fertilization	2	0 002	5400 93	27 62	0 043	0 31	0 69	0 76	1.07
<u>Interactions</u>									
SQ x Thinning	4	0 007	2381.48	34 58	0 026	1 92*	2 95*	8 25**	9 44**
SQ x Fertilization	4	0 005	1789 82	9 60	0 033	0 91	1 43	3.66*	4.29*
Thinning x Fert	4	0 003	5324 54	32 98	0 029	0.33	0 54	0.94	1 05
Residual	8	0 005	6934 26	20.45	0 165	0 32	0 48	0 74	0 09

APPENDIX VI

Linear Regression Analysis

[Equation No.: 1]

MODEL	: Y = B(o) + B (1)* X
Dependent variable	: Total biomass
Independent variable	: $(DBH)^2$ x Height
coefficient of determination	: 0.91
Correlation	: 0.95

Analysis of Variance

	DF	Sum of Squares	Mean square	F value
Regression	1	2882.883	2882.883	1400
Residual	147	302.61510	2.058606	

F-statistic = 64.156 Significance = P < 01

Variable in Equation

Variable	Regression coefficient	SE	Student T-value	Sig. T
B(0)	0.2669759	0.14505	1.84	0.07
B(1)	0.23897E-03	0.6385E-05	37.42	0.00

APPENDIX VII

Linear Regression Analysis

[Equation No.: 2]

MODEL : $Y = a\ x_1 + b\ x_2 + c.$

Dependent variable : Total biomass

Independent variables : DBH (Diameter at breast height) and height

Multiple R : 0.72

R Square : 0.52

Adjusted R Square : 0.52

Standard Error : 143.445

Analysis of Variance

	DF	Sum of Square	Mean Square	F	Signi. F
Regression	2	4369754.55	2184877.28	106.18	P < 01
Residual	195	4012402.73	20576.42		
Total	197	8382157.29			

Variables in Equation

Variable	regression Coefficient	Standard Error	student T-value	sig.T
DBH	5.3908	5.9464	9.066	0.000
Height	2.7557	3.2674	0.843	0.40

Intercept = 58.982508

APPENDIX VIII

Linear Regression Analysis

[Equation No.: 3]

MODEL	: Y = B(o) + B (1)* X
Dependent variable	: Total biomass
Independent variable	: $(\text{Collar Diameter})^2$ x Height
Coefficient of determination	: 0.96
Correlation	: 0.98

Analysis of Variance

	DF	Sum of Squares	Mean square	F value
Regression	1	3514.363	3514.363	2688
Residual	128	167.36820	1.307564	

F statistic = 81.150 Significance = 0.08

Variable in Equation

Variable	Regression coefficient	SE	Student T-value	Sig. T
B(0)	0.5371948	0.1277	4.20	0.00
B(1)	0.13931E-03	0.2687E-05	51.84	0.00

APPENDIX IX

Linear Regression Analysis

[Equation No.: 4]

MODEL	: $Y = a x_1 + b x_2 + c.$
Dependent variable	: Total biomass
Independent variables	: Collar Diameter and height
Multiple R	: 0.91
R Square	: 0.83
Adjusted R Square	: 0.83
Standard Error	: 2.23

Analysis of Variance

	DF	Sum of Square	Mean Square
Regression	2	3052.752380	1526.37619
Residual	127	628.978902	4.952259
Total	129	3681.731282	

F Statistic = 308.20 Significance = P < 01

Variables in Equation

Variable	Regression coefficient	Standard Error	Student T-value	sig.T
DBH	1.8131	1.8389 E - 01	9.860	0.000
Height	-5.5415 E - 03	2.9913 E - 03	-1.890	0.000

Intercept = -5.371807

APPENDIX - X

Linear Regression Analysis

[Equation No.: 5]

MODEL	: Y = a + bx
Dependent Variable	: leaf Area
Independent Variable	: Sapwood cross-sectional Area at Collar (SWCA)
Multiple R	: 0.94
R Square	: 0.89
Adjusted R square	: 0.89
Standard Error	: 27.72

Analysis of Variance

	DF	Sum of square	Mean square
Regression	1	1475870.38	1475870.38
Residual	238	182913.92	768.55

F Statistic = 1920.3413 Significance = P < 01

Variable in the equation.

Variable	B	SE B	Beta	T	Sig. T
SWCA	2.098	0.048	0.943	43.52	0.000
(Constant)	16.277	2.114		7.69	0.000

APPENDIX XI

Linear Regression Analysis

[Equation No.:6]

MODEL : Y = a + b x.

Dependent Variable : Dry weight of foliage

Independent Variable : Sapwood cross-sectional Area at Collar (SWCA)

Multiple R : 0.88

R Square : 0.78

Adjusted R Square : 0.78

Standard Error : 0.2169

Analysis of Variance

	DF	Sum of Square	Mean Square
Regression	1	39.3944	39.3944
Residual	238	11.2048	0.0470

F statistic = 836.771 Significance = P < 01

Variables in the equation

Variable	B	SE B	Beta	T	Sig. T
SWCA	0.1115	3.85329E-04	0.88236	28.927	0.0000
(Constant)	0.1511	0.01655		9.130	0.0000

APPENDIX XII

Linear Regression Analysis

[Equation No.:7]

MODEL : Y = B(0) + B(1) * X.

Dependent Variable : Leaf Area.

Independent Variable : Sapwood cross-sectional Area at breast height.

R Square : 0.77

Analysis of Variance

	DF	Sum of Square	Mean Square	F value
Regression	1	8721.324	8721.324	592.7
Residual	179	2633.809	14.714	

F statistic = 2.0950 Significance = P < 01

Variables in the equation

Variable	Regression coefficient	SE	Student T-value	Sig. T
B(0)	1.067010	0.37541	2.84	0.00
B(1)	0.5223735	0.22145E-01	24.35	0.00

APPENDIX - XIII

Linear Regression Analysis

[Equation No.: 8]

MODEL : Y = B(0) + B(1) * X.

Dependent Variable : Dry weight of foliage

Independent Variable : Sapwood cross-sectional Area at breast height.

Co-efficient of Determination: 0.82

Analysis of Variance

	DF	Sum of square	Mean square	F value
Regrassion	1	34.49919	34.49919	811
Residual	183	7.784413	0.4253778E-01	

F Statistic = 2.7580 Significance = P < 01

Variable in the equation.

Variable	Regression coefficient	SE	Student T-value	Sig. T
B(0)	0.8303624E-01	0.197477E-01	4.21	0.00
B(1)	0.3074914E-01	0.107970E-02	28.48	0.00

APPENDIX -XV

Non-Linear Regression Analysis

[Equation No.: 10]

MODEL	: Y = B(1) * EXP (B(2) * X) + B(3)
Dependent Variable	: Foliage Dry Weight.
Independent Variable	: DBH (Diameter at breast height).
Coefficient of Determination	: 0.84

LACK OF FIT TEST

	DF	Sum of Square	Error Mean Square	Standard Deviation
Replication	161	4.9261730	0.305973E-01	0.174921
Residual	191	6.9179240	0.362195E-01	0.190314

F-statistic = 2.1699 Significance = 0.001

Variable in the equation

Variable	B(1)	B(2)	B(3)
DBH	0.834777E-01	0.2997445	0.2265572E-01
SE	0.173175E-01	0.18394E-01	0.4075779E-01

APPENDIX - XIV

Non-Linear Regression Analysis

[Equation No.: 9]

MODEL : Y = B(1) * EXP (B(2) * X) + B(3)

Dependent Variable : Leaf Area.

Independent Variable : DBH (Diameter at Breast Height)

Coefficient of Determination : 0.85

LACK OF FIT TEST

	DF	Sum of square	Error Mean Square	Standard Deviation
Replication	166	1760.0740	10.60285	3.2562
Residual	196	2267.1890	11.56729	3.40107

F Statistic = 1.5943 Significant = 0.03

Variable in Equation

Variable	B(1)	B(2)	B(3)
DBH	1.06757	0.3337238	0.5580229
SE	0.2154364	0.1801581E-01	0.619644

APPENDIX -XVI

Non-Linear Regression Analysis

[Equation No.: 11]

MODEL	: Y = B(1) * EXP (B(2) * X) + B(3)
Dependent Variable	: Leaf Area (Y)
Independent Variable	: Collar Girth (x)
Coefficient of Determination	: 0.85

LACK OF FIT TEST

	DF	Sum of Square	Error Mean Square	Standard Deviation
Replication	194	828.0630	4.268366	2.0660
Residual	227	1101.8040	4.853763	2.203

F-statistic = 1.9434   Significance = 0.0030

Variable in the equation

Variable	B(1)	B(2)	B(3)
Girth (collar)	1.781	0.7273E-01	-1.685

APPENDIX - XVII

Non-Linear Regression Analysis

[Equation No.: 12]

MODEL	: Y = B(1) * EXP (B(2) * X) + B(3)
Dependent Variable	: Dry weight of foliage (Y)
Independent Variable	: Collar Girth (X)
Coefficient of Determination	: 0.87

LACK OF FIT TEST

	DF	Sum of square	Error Mean Square	Standard Deviation
Replication	192	4.91149	0.255807E-01	0.1599
Residual	227	5.90927	0.260320E-01	0.1613

F Statistic = 1.1144 Significant = 0.3153

Variable in Equation

Variable	B(1)	B(2)	B(3)
Girth (collar)	0.6295 E-01	0.8804E-01	-0.06380E-02

STAND DENSITY MANIPULATION AND FERTILIZATION STUDIES ON TEAK

By

SANJAY R. GAWANDE

Abstract of a

THESIS

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE

MASTER OF SCIENCE IN FORESTRY

KERALA AGRICULTURAL UNIVERSITY

FACULTY OF AGRICULTURE

COLLEGE OF FORESTRY

VELLANIKKARA - THRISSUR

1991

ABSTRACT

With the object of standardizing the density manipulation and fertilization strategies for teak, a study was carried out at Vellanikkara during 1990-91. The experimental variables consisted of high, medium and low site quality classes (classified on basis of tree heights), three thinning intensities (control, 30 per cent density reduction and 50 per cent density reduction) and three fertilizer levels (control, 50:25:25 kg of N, P_2O_5 and K_2O ha^{-1} yr^{-1}, 100:50:50 kg of N, P_2O_5 and K_2O ha^{-1} yr^{-1}).

The results indicate that mean height of trees was strongly influenced by density manipulation. The combination of high site quality with medium and heavy fertilizer doses also significantly increased the mean height of trees. However quadratic mean diameter, stand basal area, basal area increment and height increment were not substantially different among the thinning site quality and fertilization regimes.

Tree biomass, foliage area and leaf weight allometry were examined for the first time in teak. The results suggest that leaf area and the biomass yield are strongly dependent on the allometry of trees. High sites consistently recorded higher values for estimates of leaf area, leaf biomass and tree biomass

Combinations of high site quality with medium and heavy thinning as well as medium and heavy fertilization recorded high tree biomass yield , foliage area and leaf area followed by medium and low site quality classes.

Foliar analyses showed a general increase in leaf nitrogen during summer (May) and a gradual decline of the same during the fall season (August). High site quality with medium and heavy fertilization recorded highest nitrogen content. Thinning on higher sites significantly increased foliage phosphorus and potassium levels.

In general the trend concerning nutrient contents of different tree organs followed the order leaves> stemwood> branchwood. Branch wood and stem wood N levels were relatively higher on high sites. Potassium content was, however, greatest in the low sites. Soil nutrient analysis did not indicate any substantial changes in the soil physico-chemical properties consequent to thinning and fertilization which incidentally substantiates Miller's hypothesis on forest fertilization that fertilizers benefits only the trees and not the sites.