MORPHOLOGICAL AND ANATOMICAL PROPERTIES OF TEAK (*Tectona grandis* Linn. f.) SEEDLINGS AS INFLUENCED BY NURSERY TECHNIQUES

By

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THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Morphological and anatomical properties of teak (*Tectona grandis* Linn. f.) seedlings as influenced by nursery techniques"** 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, fellowship or any other similar title, of any other University or Society.

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Certified that the thesis entitled **"Morphological and anatomical properties of teak (*Tectona grandis* Linn. f.) seedlings as influenced by nursery techniques"** is a record of research work done independently by **Ms. Girija Pushpom, R.P.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Dedicated to

My Parents and Husband

Introduction

INTRODUCTION

Teak is the paragon among oriental timbers. Brandis (1879) aptly described it as a "jewel that shines and shimmers in the diadem of tropical trees". Endowed with the characteristic of most versatile use, teak is extensively used in shipbuilding, house construction, bridge and wharf, furniture and for most of the common purposes for which wood is used (Champion and Griffith, 1960).

The natural habitat of teak is in the Indian subcontinent between 10° North and 25° North and in Southeast 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 its natural habitat, teak forms a part of the moist and dry deciduous forests.

In India, the principal states growing teak are Kerala, Madhya Pradesh, Maharashtra, Gujarat, Karnataka, Andhra Pradesh, Tamil Nadu, Rajasthan, West Bengal, Bihar, Orissa and Andamans covering a total area of about 7.1 m ha (CFC; 1984). In Kerala, teak has been raised as plantations since 1844. The major expansion in area under teak in the state occurred during the period 1960-1980. As a result, nearly 50 per cent of the area under forest plantations in the state is occupied by teak. The Kerala Forest Department has about 78,000 ha of teak plantations at present (KFRI, 1992).

To meet the requirement of the plantations, both natural as well as artificial, regeneration methods can be used. Natural regeneration of teak depends on a number of biotic factors, which are often beyond the control of silviculturist. Artificial regeneration is resorted to get quick and uniform germination, which is very important in establishing teak plantations. The basis of successful teak plantation is good planting stock. To raise good planting stock, appropriate nursery techniques should be found out. In order to get good planting stock in lesser time in the nursery, appreciable growth should be there, for which appropriate sowing and nutrient combinations have to be devised.

Growth characteristics and anatomical properties of the seedlings contribute tremendously to the quality of the seedlings and stumps. It is a known fact that diameter growth of trees is brought about by the addition of new cells derived from the cambium. Intensive management of nursery seedlings will produce vigorous seedlings and thereby it will produce good quality stumps in less time. An evaluation of the different nutrient treatments and sowing methods of seeds with reference to the growth parameters will help to find out the appropriate nursery practices for the production of good quality teak stumps.

The present study was taken up at College of Forestry, Kerala Agricultural University, Vellanikkara to evaluate the growth characteristics and wood formation of teak seedlings as affected by nutrient status of nursery beds. The study also aims at finding out the best nutrient levels and sowing methods required for the production of good quality stumps based on anatomical properties of the seedlings with particular reference to wood formation.

Review of Literature

REVIEW OF LITERATURE

Being a commercially important species, teak has attracted the attention of wood users all over the world. Teak produces one of the most valuable timbers of the world. It has a long history as a plantation species. Today it occupies a prime position in many plantation programmes throughout the tropical world. The total area of teak plantations world over is three million hectares, in more than 50 countries. Conolly and Chathumenon raised first successful teak plantation in 1842. 1255 ha of teak plantation was raised by the system of transplanting four months old seedlings from nurseries raised in dry weather by Conolly and Chathumenon. Bourdillon found that the seedlings were of large size and so he stumped them and planted in Arienkavu. This marked, a significant development in the technique of raising teak plantations. Teak seedling require about 680 mg Nitrogen (N) and Potassium (K) and 45 mg of Phosphorous (P) per plant for good growth (Nandakumar, 1991). Different nutrient treatments and espacements influence the growth parameters. A comparative study of seedlings raised in seed beds with root trainer was also done. Morphological, anatomical and physiological characteristics of the teak seedlings contribute greatly to the quality of the planting material.

2.1 INFLUENCE OF NURSERY TECHNIQUES IN THE PRODUCTION OF TEAK STUMPS

Different processes, beginning from the collection of good quality seeds will affect the quality of the teak seedlings. Good quality planting materials were the gateway for a good plantation. Nutrient and sowing methods influence the growth and vigour of the nursery seedlings greatly.

2.1.1 Nutrient

Paul and Hossain (1996) studied the growth response of *Acacia mangium* seedlings to cow dung and NPK fertilizers and found that the best growth was obtained with cow dung without NPK fertilizers at a soil/cow dung ratio of 3:1.

Mohan *et al.* (1995) studied the effect of different rooting media on seed germination and seedling growth. They found that growth of *Acacia nilotica* was found to be slightly higher when grown in a mixture of soil, sand and Farm Yard Manure (FYM) in 1:2:1,1:3:1 and 1:1:1 proportions compared to forest soils alone. Suguki (1990) explained that with respect to *Eucalyptus camaldulensis*, germination and growth in terms of height were greater when grown in a potting mixture of soil, sand, garbage and cow dung compared to other combinations. He also found that a combination of soil, sand and FYM in the ratio 1:1:1 increased the height and dry matter production of seedlings of *Swietenia macrophylla* and *Dalbergia latifolia*.

Hossain (1995) showed that cow dung mixtures significantly increased the growth of *Dalbergia sissoo* seedlings in comparison with control and inorganic fertilizer treatments. Harvested seedlings from different soil and cow dung mixtures attained significantly high root collar diameter, root diameter and oven dry weight of shoot and root in comparison with control seedlings. The initial field growth performance of the seedlings raised in soil cow dung mixtures also showed significantly higher height and collar diameter growth than both control and inorganic fertilizer treatments.

Chattopadhyay and Mohanta (1988) also found that height growth of Tamarindus seedlings was best in cow dung followed by sand and cow dung. Sharma and Tiwari (1996) reported that use of neem cake in rice gave the highest grain yield. KAU (2002) reported that the nutrient content of farm yard manure and neemcake in percentage is N 1.0, P_2O_5 0.5, K_2O 1.0 and N 5.0, P_2O_5 1.0, K_2O 1.5 respectively.

Takur *et al.* (2000) studied the effect of potting media on growth of *Albizzia lebbeck* and found that the best performance was in sand + soil + FYM in one year old seedlings followed by sand + soil and pure sand. Shoot length was 46.1 cm in sand : soil : FYM, root length 27.66 cm and dry weight of shoot (2.924 g) and dry weight of root 1.44 g.

Sekar *et al.* (1996) studied the effect of biofertilizers on six month old seedlings of shola tree species. The results indicated that the combined inoculation of Azospirillum, Phosphobacteria and Vescicular Arbuscular-mycorrhizal fungi significantly increased the shoot length, diameter of shoot at collar and root length in all the tree species compared to other combined or individual inoculations or uninoculated control.

Fagbenro and Agboola (1993) conducted a green house experiment to study the effect of humic acid on the growth and nutrient uptake of teak seedlings. The results reveal that humic acid was beneficial to the growth and nutrient uptake of teak seedlings. Plant monthly growth rates and height and total dry matter yield increased significantly over the controls in the two soils at three humic acid application levels. Sharma *et al.* (1997) studied the effect of different soil mixtures on the development and quality of teak seedlings in the nursery and found that 1:1:1 soil + sand + FYM mixes gave good results for the loam soil with respect to shoot and root development and biomass production; it also gave the maximum seedling drought resistance, quality index and vigour.

2.1.2 Sowing Methods

Sowing methods greatly influence the production of stumpable plants in teak. Intensity of sowing has a direct effect on the early growth of plants and on the stumpable plants available for planting. High intensity of sowing is considered as wasteful, especially when selected seeds are available in small quantities. Line sowing in the nursery or pricking out the seedlings from seedbeds at 10-15 cm gives the best results both in number and size of stumpable plants. In Andhra Pradesh, germinating seedlings with one to two pair of leaves are pricked out with a small ball of earth at 10- 15 cm spacing into prepared standard bed, preferably on a cloudy day, with light drizzling. Watering is done whenever necessary and a yield of 600 to 800 uniform sized planting stocks per bed obtained. In Maharashtra, line sowing or transplanting at 10 cm x 10 cm spacing in secondary beds give 1000 uniformly spaced and well developed seedlings per bed (Tewari, 1992).

Bahuguna *et al.* (1990) reported that height, collar diameter and number of branches in 150 day old seedlings of *Priotropis cytisoides* were best in dibbling treatments. Similar observations were reported by Bahuguna *et al* (1989); Bahuguna *et al.* (1992); Maithani *et al.* (1992); and Lal *et al.* (1999).

Islam and Siddiqi (1987) reported that seeds sown by broad casting gave significantly better performance than dibbling in *Sonneratia apetalae* nursery. Maithani *et al* (1990) reported that germination and plant percentage were best in the line sowing treatment combined with twice daily irrigation in *Dalbergia sissoo* seedlings. Mughal (1996) reported that optimum shoot and root development was attained in open nursery beds in Deodar and Cupressus seedlings.

Masilamani and Dharmalingam (1998) reported that teak seeds treated by alternate soaking and drying for 6 days at 12 hrs intervals, and then sown in sand in pots at 1.5, 3 and 5 cm depths with the scar end in inverted, upright and horizontal positions. The pots which were kept in open sunlight placing the drupes with the scar end up or horizontally at a depth of 1.5 to 3.0 cm resulted in early and higher germination, more seedlings/100 drupes, higher root and shoot length and greater dry matter production and vigour. Saini *et al.* (1999) studied the effect of 13 pre-sowing water treatments imposed on teak seeds collected from mature trees near Haldwani in Uttar Pradesh. The seeds were sown 5 cm apart in lines 10 cm apart in 20 cm raised nursery beds and covered with 1 cm sand. The beds have a 5 cm top layer of sand containing well rotted FYM. The maximum germination percentage (60.5) and germination value of 0.75 were recorded in seeds dipped for 6 minutes in hot water at 50°C + 10 minutes air cooling + 6 minutes hot water + 10 minutes air cooling + 6 minutes hot water dipping before sowing.

Spacing studies can provide useful information about juvenile growth, mortality and density effects on height and diameter growth of tree species. It has been reported that spacing has pronounced effect on the growth of tree species, especially on diameter growth (Ever, 1971; Hamilton and Christie, 1974; Sjolte – Jorgensen, 1967; Malimburi *et al.*, 1992 and Tewari and Wais, 1996).

An experiment conducted at Teak Improvement Centre, Thailand with different sowing methods viz. a) broad-cast sowing, b) Dibbling seeds at a spacing of 5 cm x 5 cm and c) Dibbling seeds at a spacing of 10 cm x 10 cm. After 84 days dibbling seeds at the espacement of 10 cm x 10 cm gave higher germination and survival percentage than broad-cast sowing. Further because of higher frequency of small diameter plants in broad-cast sowing plots a greater percentage of usable plants was obtained in dibbling at 10 cm x 10 cm espacement plots. The probable reason for the low germinations and survival in the broad- cast sowing was shading by the earlier germinated seeds which prevent further germination and also affected survival. Line sowing or dibbling although gives a lesser sowing rate per sq m have the advantage of better germination and survival percentages and advantage of obtaining uniform sized stumps and more planting stock. With improved seed available it is better to adopt line sowings of 5 x 10 cm or 10 x 10 cm for better results (Tewari 1992).

Jamwall (1931) practiced different sowing methods with deodar seeds. The best results were obtained for broadcast sowing of deodar seeds in the forests in late autumn, while in case of nursery beds the earliest spring sowings are preferable to early autumn or late spring sowing. Indira and Basha (1999) reported that through proper management of the nursery, the proportion of plantable sized seedlings can be raised to about 90 per cent of the seedlings in the nursery.

Kapoor (1992) reported very good growth of teak seedlings raised by direct sowing in the nursery. He found that seedlings from May sowing had an average height of 75 cm in September. Jadhev *et al.* (1995) reported that one year old seedlings of teak transplanted at a spacing of 2 x 1 m, 2 x 2 m and 1 x 1 m in July 1990 and sprayed separately with gibberellin in August 1991 and 1992 increased in height and diameter. Subramanian *et al.* (1995) reported that diameter at breast height (dbh), number of branches, total height, basal area, basic density and some strength properties were significantly affected by spacing. The diameter at breast height and number of branches increased with increasing spacing, while basal area decreased.

Murugesh et al. (1998) described a method for estimating leaf is of teak using the product of length and breadth multiplied by a constant (K). The value of K for teak leaf lets was 0.66. The estimated leaf area obtained by the proposed linear measurement method using K, varied by only 3.6 per cent from the actual leaf area. Saju *et al.* (2000) reported that growth performance of teak was better in full sunlight than in shade with height, diameter, leaf area, leaf size, root weight, shoot weight, leaf weight and chlorophyll content all higher under full sunlight.

Rajendrudu and Naidu (1998) studied three month old seedlings of teak grown after transplantation to fertile soil for 5-6 months at Tirupathi and were subjected to water stress by with holding watering continuously for 3 weeks. The growth rates of height and length of developing leaves were unaffected during the first weeks after withholding watering, but they were decreased by about 50 per cent during the second week and became negligible during the third week of water stress treatment. However, after rewatering, these plants regained growth potential and exhibited high rates of leaf expansion and plant growth comparable to those of sufficiently watered plants. The diurnal course of net photosynthetic rate (PN) of plants subjected to water stress for two weeks was similar to that of sufficiently watered plants. However PN of plants subjected to water stress was reduced in the afternoon. Similarly stomatal conductance (gs) and transfer rate (E) of plants experiencing a three week water stress were decreased in the afternoon. Soon after rewatering, PN, gs and E reached similar values to those of sufficiently watered plants.

Genere (1997) studied the production of bare-rooted planting stock of good physiological quality in red oak (*Quercus rubra*), laricio pine (*Pinus nigra*) and Douglas fir (*Pseudotsuga menziessi*). Nursery techniques and post-lifting treatments both affect seedling quality. Post planting weather conditions are also factors which should be considered in the supply of planting stock.

Rajendrudu and Naidu (1997) studied about leaf gas exchange patterns in relation to leaf positions on stems in teak during first year growth under intensive culture plantations and found that differences in stomatal conductance and the rate of transpiration were not apparent between leaves after full expansion.

Suresh *et al.* (1998) studied the effect of grading teak fruits on stump quality and optimal sowing density for different sizes of fruits. There was a positive and significant correlation between fruit size and the number of stumps recovered. The sowing density for maximum production of plantable stumps for a seed lot was 0.5 kg m^{-2} for large fruits, 0.5-1 kg m^{-2} for medium sized fruits and 2 kg m^{-2} for small fruits. For the bulk seed used in this study, a sowing density of 1-1.5 kg m^{-2} appeared optimal.

2.2 TEAK STUMP VS. ROOT TRAINER RAISED PLANTS

Khedkar and Subramanian (1997) compared the teak seedlings raised in root trainers and stumps. The teak seedlings raised in root trainers had given better lateral root development than the normal stump stock and also produced multiple tap roots in contrast to the stump stock which retains a long tap root and forks only occasionally. The comparative growth performance of 75 days old root trainer planting stock and one year old stump origin stock at the out planting site is reported. The root trainer plants were sturdier, healthier and has a large collar girth than stump origin plants.

Josiah and Jones (1992) recommended root trainer technology for raising plants in forest nurseries. In modern forestry, it is important to produce quality seedlings by inducing morphological changes in the plants for making them competent enough to bear the shock of field planting and enhance their productivity. Root trainer technology is widely accepted for raising plants in nurseries. This technology was adopted in western countries as early as in the 1940's but majority of forest nurseries in India are deprived of this technology even in late 1990's (Nanhorya *et al.*, 1999).

Tin Tun (2000) reported the role of stump in the initial establishment of teak plantation. Rapid initial establishment, particularly in the very first year of teak plantation, can be secured by adopting stump as it is capable of seedling out shoot with height and vigour more satisfactorily than the fresh stump.

Ginwal *et al.* (2002) conducted experiments to standardize appropriate potting medium for raising *Dalbergia sissoo* seedlings under root trainer seedling production system. The seedlings achieved significantly better growth, biomass and quality parameters when raised in sand, soil and compost than when raised in the potting mixture containing charcoal and rice husk.

Murugesh *et al.* (1997) conducted a study on the optimal age of container seedlings and stumps of teak for best field performance under irrigated condition. The optimal ages for container seedlings and stumps were found to be three and seven months respectively. Container seedlings have a higher survival (96-100 %) than stumps (58.96 %) but early basal diameter and shoot height increments 0.65 cm and 23.10 cm respectively at seven months was superior in stumps. Container seedlings were also characterized by root coiling and multiple shoot formation, the management of which is not cost effective. So the result favours the use of stumps and the optimal size of stumps was between 1 and 2 cm which is obtained at seven months age. In *Eucalyptus* it was found that the root trainer seedlings either direct sowing or transplanting from nursery beds were taller than those from direct sowing but roots were coiled in transplanted plants and straight in direct sown plants. So direct sowing is recommended on the basis of root quality and cost effectiveness.

Gopikumar and Mahoto (1993) studied the germination percentage and seedling growth of 10 trees species and found that height and number of leaves were significantly correlated with root length and numbers. Khedkar and Subramanian (1997) reported that the comparative growth performance of 75 days old root trainer planting stock and one year old stump origin stock at the out planting site. The root trainer plants were sturdier, healthier and had a longer collar girth than stump origin plants. Rajendrudu *et al.* (1999) reported that two teak phenotypes (seedlings grown from stumps) were subjected to water stress by withholding water supply for three weeks

Mohan *et al.* (1995) found that planting stumps in crow bar holes on mini-terraces formed on sloping areas in the Western Ghats of Maharashtra performed a water conservation function and growth of the mini-terrace plantings was better, with the height and girth of 2 years old plants exceeding traditionally planted ones at 3 years old.

Rajesh *et al.* (1998) reported that best potting mixture combination obtained for Eucalyptus hybrid seedlings raised in a root trainer nursery was compost, sand and soil in the ratio 2:1:2. Khedker (1999) reported that root trainer plants have a shorter nursery period (60-90 days compared with 12-13 months for stump plants).

2.3 EFFECT OF NURSERY TECHNIQUES OF TEAK SEEDLINGS ON ANATOMICAL PROPERTIES

Anatomical characteristics of the teak seedlings contribute greatly to the quality of the stumps. The primary structure of teak seedling contains the epidermis, pericycle, vascular bundles and pith. The vascular bundle lies towards the center and is composed of vessels, wood fibres and wood parenchyma. The xylem or wood parenchyma of secondary wood usually becomes thick walled and lignified. The xylem elements ie, vessels and trachieds, aid in the conduction of water and mineral salts from the roots to the leaves, whereas wood or xylem parenchyma are living tissues that aid in the storage. The wood fibres give mechanical support to the plant body (Pandey, 2001).

Seedling vigour and growth performance is related to anatomical properties such as ring width which depends on its cambial derivatives like vessels, fibres, rays and axial parenchyma. So the stump quality is affected by the silvicultural treatments that modify the growth and vigour of the seedlings and produce good stumps in lesser time similar to the trees rotation period (Larson, 1969; Denne, 1985).

Akachukwu (1982) reported significant variation across the rings and not along the vertical axis of the lumen dimension of vessel in *Quercus rubra*. Fahn (1990) reported that fibres are present in the xylem where they are mainly concerned with the strengthening of the plant body. Parenchyma cells which have storage and other functions also occur in the xylem. The xylem that is produced as a result of the activity of the vascular cambium is called the secondary xylem.

2.3.1 Cambial activity and secondary growth activity

The cambium in teak comprises of vertically elongated fusiform initials and horizontally elongated ray initials and is non-storied. Rao and Dave (1981) observed in teak that during the dormant period, the cambial walls are thick and beaded and dense cytoplasm is conspicuous. In the active period, the walls are less beaded and thin and the cytoplasm is vacuolated. According to them cambial rays in teak are multiseriate and heterogenous and tangential. Dimensions of the ray initials range from 14.2 µm - 31.6 µm. With the result of the tangential (periclinal) divisions of cambium cells the phloem and the xylem are formed. The vascular tissues are formed in two opposite directions, the xylem cells towards the interior of the axis, the phloem cells toward its periphery. The tangential divisions of the cambium initials during the formation of vascular tissues determine the arrangement of cambial derivatives in radial rows. Since the division is tangential, the daughter cells that persist as cambium initials increase in radial diameter only. The new cambium initials formed by transverse divisions increase greatly in length. As the xylem cylinder increases in thickness by secondary growth, the cambial cylinder also grows in circumference. The main cause of this growth is the increase in the number of cells in tangential direction, followed by a tangential expansion of these cells (Bhat *et al.*, 2001).

Priya and Bhat (1997) reported that latewood width was more closely correlated with ring width than early wood width, no significant differences were found in specific gravity, cell wall percentage and diameter and percentage of vessels probably due to the juvenility of the wood. Bhat (1998) studied about the cambial activity and juvenile wood formation in teak. He reported that juvenile wood of teak was characterized by wide growth rings, a wide microfibrillar angle, small diameter and low percentage of vessels and a high percentage of cell wall with short fibres, in comparison with mature wood. Priya and Bhat (1999) reported that irrigation of five year old teak trees led to the loss of typical ring porosity and their first three growth rings were more or less diffuse porous. This is attributed to uninterrupted cambial activity resulting in production of uniform sized vessels.

Noduchi *et al.* (1996) studied the wood formation and properties, anatomy and elemental analysis and was investigated in relation to season, topography, soil moisture content and seasonal changes in leaf area in 22 year old plantation grown teak. Wood formation was investigated using the pin/nail method (to locate the cambium); it started after leaf budding and continued until the end of the rainy season.

Relatively little work has been done on the growth rings in dicotyledons. Most of the research on cambial growth and wood production has gone to the trees of temperate zones (Brown, 1971). Knowledge about the patterns of cambial periodicity and wood formation in tropical trees is meager. Like the temperate trees, cambial activity is more likely to be seasonal or episodic even in the tropical trees (Koriba, 1958). Teak being a tropical tree, knowledge of the effects of environmental conditions and age on growth periodicity is essential in view of increasing plantation programmes in the tropics. Variations in the cambium lead to size variation in the ring width of wood (Srinivas *et al.*, 1998).

It is a known fact that diameter growth of trees is brought about by the addition of new cells derived from the cambium. The growth of vascular cambium in woody plants is never continuous even in evergreen species. Rather, there is a periodicity or rhythm for the growth of cambium with periods of activity alternating with periods of rest or dormancy (Wilcox, 1962).

As early as 1921, Hartig suggested that the cambium is a biseriate layer of cells producing wood and bast cells in opposite directions. Later, Bannan (1962) proposed the concept that cambium is a uniseriate initiating row of cells producing xylem and phloem mother cells on either side. According to Bannan (1955) the initiating layer is functionally uniseriate. Further, the width of the phloem and xylem mother cell layer varies with the time of the year, vigour of growth and the cycle of periclinal division. The cells of the dormant cambium are rectangular in cross section and the radial walls are thick and have a beaded appearance. With the onset of activity the walls become semitransparent and more. Plastic and the protoplasm changes from gel to sol state (Wort, 1962). Both periclinal and anticlinal divisions occur in the cambial zone.

Zimmerman and Brown (1971) reported that tree age influenced the periodicity of cambial activity. Kozlowski (1971) observed that the width and structure of the annual ring on trees are closely related to the amount and duration of shoot growth. Further, cambial activity continued for a lengthier period in the small rapidly growing twigs or shoots that were, late in completing their apical growth Radial growth in tropical trees may be annual, semi – annual, irregular or continuous (Tomlinson and Longman, 1981).

According to Wareing (1951), in ring-porous trees, the first formed vessels were the widest and there evidence of a high initial supply of auxin. Wort (1962) explained that the change from the production of early wood to latewood may be a response to a changed level of auxin reaching the cambium coupled with a specific response to a diminishing hormone supply. Fritts (1976) observed that once the cambial activity initiated and the size of the active zone established, it usually remained more or less of the same size until latewood began to differentiate. He also stated that the changes on growth associating with increasing age varied from site to site.

Busgan and Munch (1929) observed differences in both initiation and cessation of radial growth in conifers. According to them, in the younger trees cambial activity began earlier and was prolonged than the older ones. According to Eames and Mac Daniels (1947) the duration of seasonal cambial activity varied with different ages of the plant and plant parts. As discussed by Alvim and Alvim (1978), tropical species exhibiting rhythmic growth were always asynchronous with regard to growth flushes when they were young, but showed close synchronism in growth behaviour when mature.

Wareing (1951) reported that the presence of a reserve auxin precursor in the cambium of the ring porous species that revealed the rapid spread of wide vessel formation throughout the tree at an early stage of bud development. Amobi (1973) found in trees in low land rain forests in Nigeria that radial growth started either during the dry season or at the beginning of the rainy season. However, the bulk of the wood formed during the rainy season. In many ring porous species, cambial reactivation spread so quickly that it appeared simultaneous through out the tree in twigs, branches and the main stem.

The earliest work in teak dates back to 1856, when Brandis (1879) reported that growth rings are annual. Later on, Chawdhury (1939, 1940) and Rao and Dave (1981) carried out some investigations on the periodicity of cambium in teak. In contrast to many tropical trees, teak being a ring-porous wood, cambium reactivated simultaneously throughout the stem.

Larson (1969) found that the diameter growth of trees is brought about by the addition of new cells derived from the cambium. Knowledge of annual increment/ growth ring formation in trees is essential not only to determine the tree age and growth rate but also wood production in managed forest stands. In such managed plantations, forest managers will aim at maximizing wood production by intensive silvicultural practices which accelerate the tree growth for early harvesting. Brown (1971) reported that most of the research on cambial growth and wood production has gone to the trees of temperate zones. Plant axis grows in girth even after they have ceased to elongate, because of the periodic meristematic activity of cambia. Successive additions of the secondary phloem and xylem derived from the vascular cambium provide new pathways for the transportation of the cell sap and assimilate to parts of the plant and additional cells for mechanical support to the branching and enlarging body of woody plant.

Chawdhury (1940) recorded the time of initiation and cessation of cambial activity of teak grown in three different locations in India. According to him, local temperature rather than rainfall was responsible for the initiation of cambial activity.

Lawton (1972) observed in teak grown in Nigeria that cambial activity began in early March and continued till November thereafter it probably ceased in December to late February during the dry season. Rao and Dave (1981) observed that cambial activity commenced in the first week of June, reached a peak in July and then slowly declined in teak grown in Calcutta. Further, they found that the initiation of cambial activity was associated closely with the opening of the dormant foliar buds in first week of May. This agrees with the observations of Venugopal and Krishnamurthy (1987) where they found a month's interval between the onset of bud breaks and cambial reactivation. They found in twigs of three to five year old teak grown in Tamil Nadu that cambial activity began in July and ceased in March. Tomazello and Careloso (1997) observed a clear relationship between cambial activity and phenological and climatic condition in 31 year old teak trees grown in Brazil. It is clear from the above studies that seasonal variations occur in cambial activity of teak in India.

2.3.2 Vessel characteristics

Vessels are vertical series of cells with open ends placed one above the other, forming a continuous tube, like the section of a drain pipe, running in the direction of the long axis of the tree. Their function is to conduct sap (water and nutrients) from the soil and roots to the crown for which they are structurally well adapted. The size and distribution of rays and vessels in the hard woods have major effects on wood quality and utility. The patterns of vessel production are of great importance in determining the utility of hard woods for a given product (Guiher, 1965). It is a well-known fact that wide vessels conduct large volume of water per unit time (Carlquist, 1985).

Tewari (1992) reported that in teak, early wood vessel diameter ranges from 200-320 µm. Teak vessels are arranged in semi-ring porous pattern. The widest vessel diameter is 270 µm which occur in the ring porous wood; the most common is medium size vessel diameter varies from 230-270 µm which occur in semi-ring porous wood and the smallest ones 230 µm in the semi-diffuse porous samples. Vessels in the late wood abruptly decrease diameters and ranges between 100-70 µm. Vessels in early wood of teak is large distinctly visible to the eye, mostly solitary, oval in outline, partly filled with tyloses and sometimes with white powdery deposits, gradually becoming smaller towards the late wood; late wood vessels moderately large to small, mostly solitary or in radial pairs, round to oval in outline, vessel line of the early wood zone conspicuous on longitudinal surfaces.

Idu and Ijomah (1998) reported that variations in vessel width are significant for identification purposes in closely related species. Vessels are of importance not only for their primary roles but also for impregnation of wood with chemicals for preservation and pulping. Vessel width showed significant variation along the stem vertical axis.

Most of the work pertaining to vessel morphology (vessel diameter, vessel frequency) was mainly restricted to pith to periphery variation. The vessel frequency decreases from pith outwards in *Eucalyptus regnans* (Dadswell, 1958); *Eucalyptus camaldulensis* (Chudnoff and Tischler, 1963); *Eucalyptus grandis* (Bamber and Humphreys, 1972); *Eucalyptus dalrympleana* (Nguyen, 1977) and *Eucalyptus piluaris* (Bamber and Curtin, 1974). Bamber *et al.* (1982) reported that the size of the vessels have become smaller and less numerous and ray volume increase in the fast grown trees. Their findings revealed that fast growth appears to affect physiologically active cells but not the mechanical cells i.e., the fibres. They also revealed that fast grown trees had more vessel volume, although there were more vessels in slow grown trees in eucalypt species. Increase in vessel diameter and decrease in vessel frequency in *Eucalyptus grandis* clones as tree age increased was noticed.

Akachukwu (1987) found that narrow vessels are of smaller lengths than wider vessels; the vessel dimensions increase with stem age. An individual vessel can vary in diameter along its length; the widest portion in *Quercus rubra* is nearly wider than the narrow portions. Ewers and Fisher (1989) reported that liana vessels are considered to be the longest and widest in the plant kingdom. Anatomical examination of certain tropical and subtropical lianas has shown that larger diameter stems tend to have longer as well as wider vessels (*Pithecodenium crucigerum*)

Fahn (1990) reported that large vessels are not obligatory in lianas and quite a significant number possess small vessels, for e.g.: *Carissa ovata* and *Quintinia fawkneri* have mean vessel diameters of 44 µm and 60 µm, respectively. Such a reduction in vessel diameter in lianas is compensated by an increase in vessel frequency so that, the proportion of vessels remains higher on average than in trees.

The presence of small vessels in climbers was also recorded by Carlquist (1984) for the family Lardizabalaceae in which he found mean vessel diameters of 46 µm in *Akebia quinata*, 47 µm in *Holboellia latifolia*, 52 µm in *Stautonia hexaphylla*, 67 µm in *Boquila trifoliate* and 87 µm in *Lardizabala biternata*. Although these vessels average less in diameter than those of large tropical lianas, vessels of lianoid Lardizabalaceae are larger in diameter than those of shrubby Lardizabalaceae and thus they follow a pattern (Carlquist, 1988). Rao and Rajput (2001) reported that length and width of vessel elements in species ranges from 435 – 510 µm and 105 to 415 µm respectively.

2.3.3 Tissue proportion

Rao and Rajput (2001) reported that xylem is composed of vessel elements, fibres and unlignified parenchyma cells. Vessels are exceptionally large, solitary but radial and tangential multiples of 2-4 cells. In teak wood vessels, fibres, wood parenchyma and ray parenchyma is there.

Chudnoff and Tischlr (1963) found that in *Eucalyptus camaldulensis* the fibre, vessel and parenchyma volumes varied between 47 – 62, 13 – 19, 24 – 37 per cent and in another tree it varied between 39 – 40, 11-17, 44 – 49 per cent respectively. Davidson (1972) reported that in *Eucalyptus deglupta* 'the fibres and vertical parenchyma, vessels, and rays were 63.5, 27.9 and 10.5 per cent respectively.

According to Gill and Onuja (1984) various parameters, such as the distribution of the tissues, proportion of thin-walled tracheary elements, the thickness of the fibre walls and their physiological nature are very important characteristics in determining the quality of a timber. Tewari (1992) reported that fibres in teak are 900-

1300 μm long, diameter 15-20 μm, wall thickness about 4 μm, septations of uneven occurrence even with in the same sample, pits with diameter about 2-5 μm including a fine border; broadly scattered.

Guiher (1965) observed that rays are groups or plates of horizontally oriented parenchyma cells, which run in a radial direction from pith or center of the log towards the bark or periphery. The size and distribution of rays and vessels in the hard wood have a major effect on wood quality and utility. Barghoorn (1941) revealed that the decrease in the size of rays with phylogenetic advancement may have been brought about by changes that took place in the cambium. Carlquist (1975) refers to the greater proportion of ray tissues in liana exhibiting normal secondary growth than in other plant forms.

Materials and Methods

MATERIALS AND METHODS

The present investigation to evaluate the growth characteristics and wood formation of teak seedlings as affected by nutrient status of nursery beds and sowing methods was conducted at the College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur, Kerala. The experiment was carried out from January 2002 to December 2002. Geographically, the area is located 40 meters above mean sea level at 10°32' North latitude and 76°26' East longitude. The area experiences warm and humid climate with distinct summer and rainy seasons. The weather data pertaining to the experimental period are given in Appendix-I. The soil of the experimental site is oxisols. The predominant parent material is metamorphic rock of gneiss series. The average soil pH was found to be 5.8. The soils and sub-soils were porous and extremely well drained.

The experimental materials consisted of seeds of teak (*Tectona grandis* Linn.f.) procured from the Research Range and Seed Storage Division, Coimbatore. Winnowing was done to remove the impurities from the seeds. The seeds were graded using a 9 mm sieve. In order to obtain good and uniform germination, seeds were subjected to alternate wetting and drying treatment for a cycle of seven days. The treatment involved immersing the seeds in cold water during nights followed by drying under the sun during day time. Plate 1 shows an overview of the experimental plot.

Nursery beds of standard size (12 m x 1.25 m x 0.3 m) were prepared by clearing the land and ploughing the area. Different treatments were randomly allocated to each plot in factorial combinations following completely randomized design (CRD) with 3 replications. The pretreated seeds were broadcasted / dibbled in the nursery plots at different spacements. The seeds were then covered with a thin layer of sand and soil and mulching was given. Different nutrient treatments were imposed there after.

Plate 1. An overview of experimental plot

3.1 EXPERIMENTAL DETAILS

3.1.1 Main factor A: Nutrients

1. No nutrient
2. Cow dung: Cow dung was applied at the rate of 0.4 kg m^{-2} (i.e., 6 kg / bed as basal application)
3. Cow dung and neem cake: Cow dung was applied at the rate of 0.4 kg m^{-2} (6 kg / bed) and neem cake at the rate of 0.2 kg m^{-2} (i.e., 3 kg per bed) as basal application.

3.1.2 Main factor B: Sowing methods

1. Broadcasting: Seeds were broadcast at the rate of 6kg per bed.
2. Dibbling: Seeds dibbled at a spacing of 4 cm (between lines) x 4 cm (within lines)
3. Dibbling: Seeds dibbled at a spacing of 8 cm (between lines) x 8 cm (within lines)
4. Dibbling: Seeds dibbled at a spacing of 12 cm (between lines) x 12 cm (within lines)

A total of 12 treatment combinations were involved.

3.2 OBSERVATIONS RECORDED

3.2.1 Biometrical observations

The following biometrical observations were recorded for a period of 8 months at fortnightly intervals.

3.2.1.1 Shoot length

Shoot length was measured from the collar to the tip of the growing point using a meter scale and expressed in cm.

3.2.1.2 Collar girth

Collar girth was measured with the help of a digital caliper and expressed in mm.

3.2.1.3 Leaf production

The number of leaves produced by each seedling were counted.

3.2.1.4 Root length

Root length was measured from the collar to the tip of the longest root and expressed in cm. This was done at monthly intervals.

3.2.2 Biomass measurements

One seedling belonging to each treatment was sampled at monthly intervals for estimation of biomass. The shoot and root portion of the seedlings were separated and the following observations were taken.

3.2.2.1 Fresh weight of shoot

The fresh weight (g) of shoot portion was determined separately using a precision balance.

3.2.2.2 Dry weight of shoot

After finding out the fresh weight, the shoot portion was dried in hot air oven at a temperature of 100°C for about 24 hours. The drying and weighing was repeated till constant weights were obtained.

3.2.2.3 Fresh weight of root

Roots were separated carefully from the plant, washed well and the fresh weight (g) was recorded using a precision balance.

3.2.2.4 Dry weight of root

The dry weight of root was found out after oven drying the sample at 100°C for 24 hours. This was repeated till constant weights were obtained.

3.2.3 Anatomical properties

Thin microscopic sections were taken from the collar region of the seedlings at monthly intervals to study anatomical properties. Anatomical properties were studied by taking hand sections (5-10 μm) in the initial stages up to eight months. In the later stages of development, sections (10-15 μm) were taken using a sliding microtome (Leica SM-2000 R). The sections were stained using saffranin following the procedure outlined by Johansen (1940) and permanent slides were prepared. The following anatomical observations were recorded.

3.2.3.1 Tissue proportion

Tissue proportion like fibre, vessel, parenchyma and ray percentages were determined by using the method outlined by Rao *et al.* (1995). For this, an eleven-point ocular micrometer scale was placed tangentially on the cross section from permanent mount and the numbered point on the scale was identified and recorded. The total score of each cell type was obtained by running the slide from one end to the other both in tangential and radial direction. The cell type is expressed in percentage.

3.2.3.2 Vessel diameter

Vessel diameter (μm) was recorded on the permanent sections using a stage and ocular micrometer. The vessel diameter was recorded from an average of 10 observations per slide.

3.2.3.3 Vessel frequency

The frequency of vessel was determined from the average of 5 counts on the permanent sections using a stage and ocular micrometer and it was expressed as number per mm^2.

3.2.3.4 Ring width

The ring width was measured using a microscope with stage and ocular micrometer. The xylem produced was measured from the pith up to cambium and was expressed in micrometres.

3.3 STATISTICAL ANALYSIS

The data collected were subjected to analysis of variance (ANOVA) using SPSS software package to determine differences between treatments. Follow up analysis was conducted using Duncan's Multiple Range Test (DMRT) for pair wise comparison of means. Regression analysis was carried out to findout the relationship between anatomical properties and biometric characters.

Results

RESULTS

Results of the investigations carried out at the College of Forestry, Vellanikkara with the objective of finding out the best nutrient levels and sowing methods required for the production of good quality teak stumps are furnished below. The results are presented in four main sections namely, biometric characters, biomass characteristics, and anatomical properties. Within each main section, effect of treatment combination on various characters have been discussed first, followed by the effect of nutrients and sowing methods, separately.

4.1 BIOMETRIC CHARACTERS

The results pertaining to biometric characters of teak seedlings as affected by different nutrient levels and sowing methods at different intervals of time are presented in Tables 1 to 8 and Figures 1 to 4.

4.1.1 Shoot length

The effect of nutrients and sowing methods on shoot length of teak seedlings are given in Table 1 and illustrated in Figure 1. Levels of nutrients and sowing methods were found to vary significantly with respect to the parameter shoot length. Significant variation was found for this character due to nutrient and sowing methods in the first nine fortnights and then gradually the growth slowed down and there was no significant difference between the treatment interactions in the last seven fortnights. Highest shoot length was obtained for the treatment combination of cowdung 0.4 kg/m^2 and 12 cm x 12 cm spacing between seeds (N_1S_3) in the first ten fortnights. In the subsequent fortnights it was found that no nutrient and broadcasting (N_0S_0) was the best treatment which was followed by N_1S_3 (cowdung 0.4 kg/m^2 and 12 cm x 12 cm spacing between seeds) and N_0S_3 (no nutrient and 12 cm x 12 cm spacing between seeds). Least height growth was obtained for the treatment N_2S_2 (cowdung 0.4 kg/m^2 + neem cake 0.2 kg/m^2 and 8 cm x 8 cm spacing between seeds) in the first eight fortnights. Further periods showed that N_2S_1 (cowdung 0.4 kg/m^2 + neem cake 0.2 kg/m^2 and 4 cm x 4 cm spacing between seeds) had the least height growth. The best performing treatments N_0S_0 (no nutrients and broadcasting) and N_1S_3

Table 1. Effect of combination of nutrients and sowing methods on shoot length (cm) of teak seedlings at fortnightly intervals

Treatment	Treatment details	Fortnights															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
N_0S_0	No nutrients + broadcasting (control)	41.90^{a}	52.45^{b}	65.45^{a}	70.90^{a}	75.10^{a}	77.75^{a}	81.10	84.45^{a}	88.65^{a}	96.15	98.40	98.70	108.60	112.30	115.00	116.95
N_0S_1	No nutrients + spacing 4 x 4 cm	29.55^{b}	34.60^{de}	40.50^{bc}	44.40^{cde}	50.15^{cde}	54.55^{bcd}	57.80	60.30^{bcd}	62.10^{bcd}	63.65	63.70	63.95	70.65	74.50	78.35	79.45
N_0S_2	No nutrients + spacing 8 x 8 cm	17.00^{e}	21.70^{b}	26.00^{d}	29.60^{fg}	35.30^{f}	39.35^{ef}	43.40	44.55^{de}	47.25^{cd}	49.85	50.50	50.60	51.95	52.15	53.75	54.65
N_0S_3	No nutrients + spacing 12 x 12cm	28.65^{b}	37:15de	46.50^{b}	54.75^{bc}	62.60^{bc}	67.00^{ab}	71.85	76.15^{ab}	81.00^{ab}	84.00	86.85	86.30	95.20	100.20	106.25	109.60
N_1S_0	Cowdung + broadcasting	34.05^{b}	45.45^{c}	47.55^{b}	48.65^{bcd}	48.85^{de}	49.45^{de}	49.20	50.65^{cde}	52.50^{cd}	53.45	53.55	53.70	54.95	56.70	62.20	63.75
N_1S_1	Cowdung + spacing 4 x 4 cm	29.25^{b}	37.80^{de}	47.50^{b}	56.50^{b}	62.30^{bc}	64.65^{abc}	66.85	66.90^{abc}	67.35^{bc}	68.50	70.35	70.85	71.25	71.40	71.60	72.25
N_1S_2	Cowdung + spacing 8 x 8 cm	31.10^{b}	40.25^{cd}	48.15^{b}	54.15^{bc}	58.95^{cd}	60.50^{bcd}	63.25	64.40^{bc}	66.30^{bc}	68.05	68.30	68.70	71.35	72.35	73.85	74.80
N_1S_3	Cowdung + spacing 12 x12 cm	44.75^{a}	58.70^{a}	65.60^{a}	71.50^{a}	73.95^{ab}	78.00^{a}	81.85	84.75^{a}	87.75^{a}	89.75	91.30	92.35	95.60	99.20	100.90	102.40
N_2S_0	Cowdung + neem cake + broadcasting	32.00^{b}	39.15^{cd}	43.90^{b}	49.50^{bcd}	55.40^{cd}	58.70^{bcd}	61.25	62.30^{bcd}	65.80^{bc}	66.05	66.15	66.95	68.55	70.75	71.90	72.30
N_2S_1	Cowdung + neem cake + spacing 4 x 4 cm	28.25^{b}	31.70^{e}	33.95^{c}	35.75^{ef}	37.85^{ef}	39.10^{ef}	41.05	41.55^{e}	42.10^{d}	42.75	43.60	43.70	44.75	45.20	46.80	47.10
N_2S_2	Cowdung + neem cake + spacing 8 x 8 cm	11.45^{d}	14.50^{g}	19.00^{d}	23.25^{g}	28.80^{f}	32.60^{f}	37.45	41.45^{e}	47.55^{cd}	51.55	51.95	52.10	55.45	56.90	57.20	56.00
N_2S_3	Cowdung + neem cake + spacing 12 x 12 cm	28.70^{b}	34.10^{de}	39.65^{bc}	43.40^{de}	47.35^{de}	51.15^{cde}	54.35	58.10^{bcde}	6.95^{e}	65.50	67.15	68.70	79.95	80.60	89.80	92.60
F		12.49*	11.20*	11.03*	9.75*	8.03*	6.44*	2.27^{NS}	4.58*	3.91*	3.58^{NS}	3.64^{NS}	3.29^{NS}	2.82^{NS}	2.27^{NS}	1.62^{NS}	1.45^{NS}
SEM		0.74	0.90	1.148	1.39	1.65	1.89	4.66	2.41	2.73	3.08	3.15	3.35	4.01	4.61	5.13	5.44
CD (0.05)		2.77	3.37	4.31	2.41	2.86	3.27	8.07	4.18	4.72	5.33	5.45	5.80	6.94	7.98	8.88	9.43

** Significant at 0.01; * Significant at 0.05; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at P = 0.05

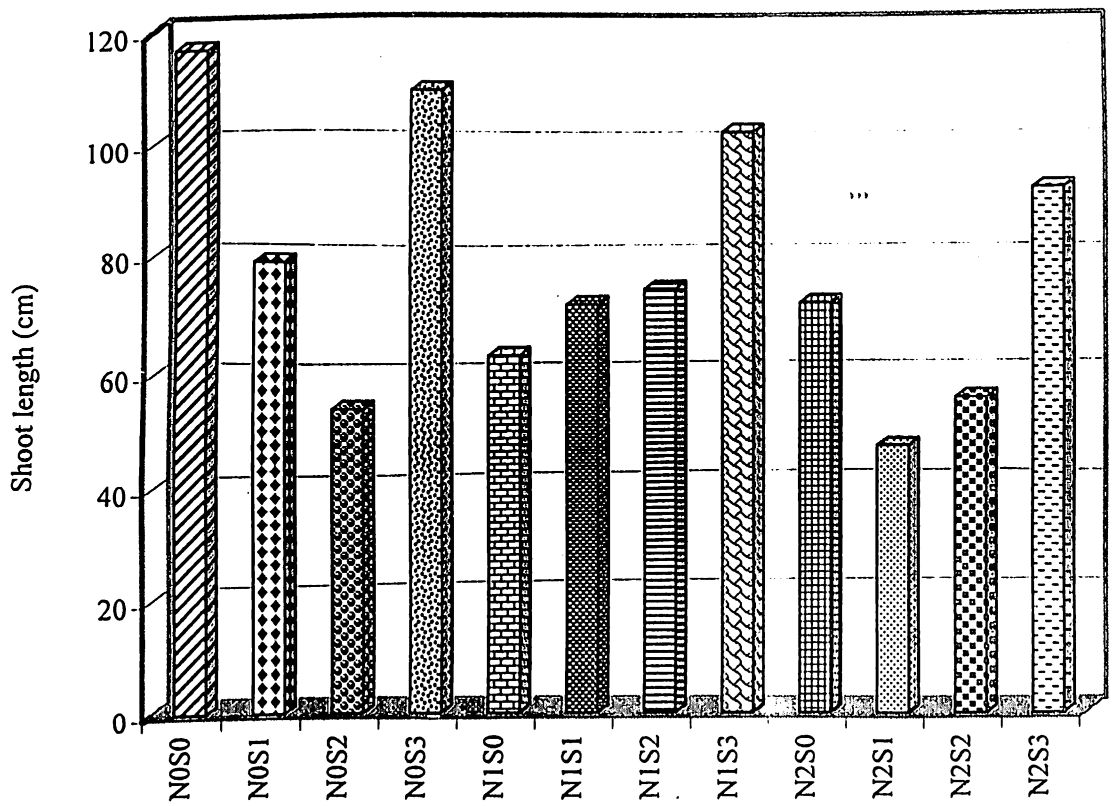

Fig. 1. Effect of nutrients and sowing treatments on shoot length (cm) of teak seedlings at sixteenth fortnight

(cowdung 0.4 kg/m^2 and 12 cm x 12 cm spacing between seeds) were at par as is evident from the Table 2.

Table 2 shows the effect of nutrients on shoot length of seedlings. The treatments were found to be significant throughout the study period. Cowdung 0.4 kg/m^2 was the best treatment followed by no nutrients in the first eight fortnights. However, in the last eight fortnights the no nutrients treatment showed best height growth followed by the cowdung 0.4 kg m^{-2} treatment.

Sowing method were also found to vary significantly with respect to shoot length (Table 2). The best sowing method during the study period was a spacing of 12 cm x 12 cm between seeds and the broadcast sowing method which were at par. Least performing treatments were 4 cm x 4 cm spacing between seeds and the treatment 8 cm x 8 cm which were at par after the initial six fortnights of observation.

4.1.2 Collar girth

The effect of nutrients and spacing on collar girth of seedlings is shown in Table 3 and illustrated in Figure 2. Effect of the combination of the nutrients and sowing methods were found to vary significantly during the six fortnights of initial observation. However, analysis of variance showed that there was no significant difference between different treatments after six fortnight of observation. However the best treatment was N_2S_3 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and 12 cm x 12 cm spacing between seeds) which was followed by N_1S_3 (cowdung 0.4 kg m^{-2} and spacing 12 cm x 12 cm between seeds) which was followed by N_0S_3 (no nutrients and 12 cm x 12 cm spacing between seeds).

Data furnished in Table 4 shows the effect of nutrients and sowing methods on collar girth of seedlings. Levels of nutrients were found to vary significantly with respect to collar girth. The best treatment at the end of the 16th fortnight was the treatment used as control i.e., no nutrient with a collar girth of 12.882 mm which is followed by cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} with a collar girth of 10.338 mm. The best performing treatment during the study period was found to be

Table 2. Effect of nutrients and sowing methods on shoot length (cm) of teak seedlings at fortnightly intervals

Treatment	Fortnight 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Nutrient																
1. No nutrient (control)	29.28^{b}	36.48^{b}	44.61^{b}	49.91^{b}	55.79^{a}	59.66^{a}	63.54^{b}	66.36^{a}	69.75^{a}	73.41^{a}	74.86^{a}	74.89^{a}	81.60^{a}	84.79	88.36	90.16
2. Cowdung	34.79^{a}	45.55^{a}	52.20^{a}	57.70^{a}	61.01^{a}	63.15^{a}	72.79^{a}	66.68^{a}	68.48^{a}	69.94^{a}	70.88^{a}	71.40^{ab}	73.29^{ab}	74.91	77.14	78.30
3. Cowdung + Neem cake	25.10^{c}	29.86^{c}	34.13^{c}	37.98^{c}	42.35^{b}	45.39^{b}	48.53^{c}	50.85^{b}	54.10^{b}	56.46^{b}	57.21^{b}	57.86^{b}	61.43^{b}	63.36	65.95	67.19
F test	28.99*	51.53*	41.65*	34.06*	22.60*	16.54*	4.60*	9.37*	6.77*	5.65*	5.77*	4.82*	4.27*	3.61^{NS}	3.179^{NS}	2.97^{NS}
Sowing methods																
1. Broadcasting (control)	35.98^{a}	45.68^{a}	52.30^{a}	56.35^{a}	59.78^{a}	61.97^{a}	63.85^{b}	65.80^{a}	68.98^{a}	71.88^{a}	72.70^{a}	73.12^{a}	77.37^{a}	79.92^{a}	82.73^{a}	84.33^{a}
2. Spacing 4 cm x 4 cm	29.02^{b}	34.70^{b}	40.65^{b}	45.55^{b}	50.10^{b}	52.77^{b}	55.23^{bc}	56.25^{b}	57.18^{b}	58.30^{b}	59.22^{b}	59.50^{ab}	62.22^{b}	63.70^{b}	65.58^{b}	66.27^{b}
3. Spacing 8 cm x 8 cm	19.85^{c}	25.48^{c}	31.05^{c}	35.67^{c}	41.02^{c}	44.15^{c}	48.03^{c}	50.13^{b}	53.70^{b}	56.48^{b}	56.92^{b}	57.13^{b}	59.58^{b}	60.47^{b}	61.27^{b}	62.07^{b}
4. Spacing 12 cm x 12 cm	34.03^{a}	43.32^{a}	50.58^{a}	56.55^{a}	61.30^{a}	65.38^{a}	79.35^{a}	73.00^{a}	76.57^{a}	79.75^{a}	81.77^{a}	82.45^{a}	89.25^{a}	93.33^{a}	98.98^{a}	101.63^{a}
F test	47.81*	52.52*	36.75*	25.86*	16.27*	12.82*	4.18*	8.79*	7.52*	6.55*	6.92*	6.33*	5.98*	5.47*	5.67*	5.54*
Nutrient vs spacing																
F test	12.49*	11.20*	11.03*	9.75*	8.03*	6.44*	2.26^{NS}	4.58*	3.91*	3.58^{NS}	3.64^{NS}	3.29^{NS}	2.82^{NS}	2.27^{NS}	1.62^{NS}	1.45^{NS}
SEM	0.74	0.90	1.148	1.39	1.65	1.89	4.66	2.41	2.73	3.08	3.15	3.35	4.01	4.61	5.126	5.44

** Significant at 0.01; * Significant at 0.05; NS - Non significant

Values sharing same alphabets within the main treatments do not differ significantly between themselves at $P = 0.05$

Table 3. Effect of combination of nutrients and sowing methods on collar girth (mm) of teak seedlings at fortnightly intervals

Treat-ment	Treatment details	Fortnights															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
N_0S_0	No nutrients + broadcasting (control)	4.84^{abc}	5.44^{bc}	6.91^{ab}	7.53^{ab}	8.23^{ab}	8.58^{ab}	9.02	9.33	9.69	10.41	10.76	11.36	11.68	11.88	12.25	12.30
N_0S_1	No nutrients + spacing 4 x 4 cm	4.50^{bcd}	5.17^{bc}	5.62^{bcd}	6.08^{abcd}	6.78^{abcd}	7.90^{abcd}	8.44	8.844	9.51	10.27	10.68	11.35	11.77	12.04	12.98	13.31
N_0S_2	No nutrients + spacing 8 x 8 cm	4.23^{bcd}	5.01^{bc}	5.52^{bcd}	5.98^{bcde}	6.39^{bcd}	6.86^{bcdef}	7.52	7.956	8.421	9.46	9.96	10.38	10.46	10.74	11.39	11.52
N_0S_3	No nutrients + spacing 12 x 12cm	4.95^{abc}	5.77^{bc}	7.01^{ab}	7.57^{ab}	8.60^{a}	9.14^{a}	9.50	10.02	10.47	11.29	11.88	12.60	12.90	13.37	14.10	14.40
N_1S_0	Cowdung + broadcasting	4.08^{cd}	4.37^{bc}	5.04^{cde}	5.36^{cde}	5.62^{cde}	5.95^{def}	6.51	6.57	6.65	6.93	7.18	7.28	7.31	7.37	7.64	7.71
N_1S_1	Cowdung + spacing 4 x 4 cm	4.09^{cd}	4.85^{bc}	5.67^{bcd}	6.21^{abcd}	7.05^{abc}	7.31^{abcde}	7.70	8.12	8.52	8.84	9.154	9.27	9.31	9.35	9.49	9.53
N_1S_2	Cowdung + spacing 8 x 8 cm	5.27^{ab}	5.65^{bc}	6.23^{ab}	6.74^{abc}	7.49^{abc}	8.04^{abc}	8.59	8.83	9.29	9.86	10.15	10.35	10.86	10.93	11.10	11.17
N_1S_3	Cowdung + spacing 12 x12 cm	5.61^{a}	6.20^{b}	7.16^{a}	7.72^{a}	8.41^{a}	8.95^{ab}	9.356	9.76	10.22	10.72	10.89	11.33	11.72	11.82	12.14	12.35
N_2S_0	Cowdung + neem cake + broadcasting	3.66^{d}	4.10^{bc}	5.26^{cde}	5.55^{cde}	5.95^{cde}	6.50^{cdef}	7.00	7.21	7.44	7.56	7.78	7.93	8.12	8.16	8.40	9.48
N_2S_1	Cowdung + neem cake + spacing 4 x 4 cm	3.65^{d}	4.00^{c}	4.31^{de}	4.64^{de}	5.07^{de}	5.53^{ef}	6.08	6.34	6.54	6.841	6.98	6.99	7.03	7.07	7.23	7.23
N_2S_2	Cowdung + neem cake + spacing 8 x 8 cm	3.44^{d}	3.72^{c}	3.95^{e}	4.34^{e}	4.58^{e}	5.07^{b}	5.53	6.29	6.00	6.848	7.58	8.43	8.80	9.02	9.44	9.66
N_2S_3	Cowdung + neem cake + spacing 12 x 12 cm	5.86^{a}	8.25^{a}	7.03^{ab}	7.59^{ab}	8.20^{ab}	8.80^{ab}	9.26	10.02	10.65	11.38	12.03	12.82	13.75	13.76	14.53	14.96
F		3.15*	2.75*	2.41*	2.32*	2.50*	2.27*	1.82^{NS}	1.57^{NS}	1.98^{NS}	1.49^{NS}	1.28^{NS}	1.19^{NS}	1.51^{NS}	1.26^{NS}	1.23^{NS}	1.25^{NS}
SEM		0.14	0.21	0.19	0.22	0.257	0.27	0.30	0.32	0.35	0.40	0.44	0.49	0.52	0.55	0.59	0.61
CD (0.05)		0.54	0.80	0.72	0.82	0.93	1.00	1.11	1.22	1.30	1.51	1.65	1.85	1.94	2.06	2.20	2.30

** Significant at 0.01; * Significant at 0.05; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at $P = 0.05$

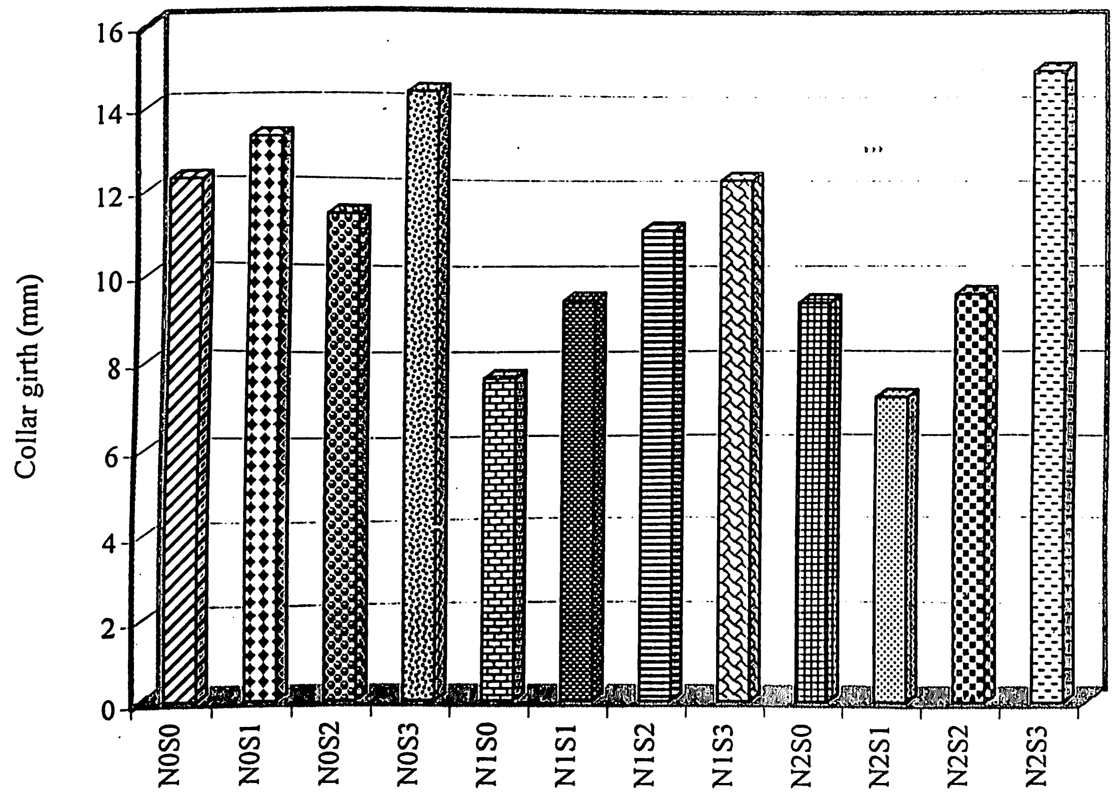

Fig. 2. Effect of nutrients and sowing methods on collar girth (mm) of teak seedlings at sixteenth fortnight

Table 4. Effect of nutrients and sowing methods on collar girth (cm) of teak seedlings at fortnightly intervals

Treatment	Fortnight															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Nutrient																
1. No nutrient (control)	4.63	5.34	6.26^{a}	6.79^{a}	7.50^{a}	8.12^{a}	8.62^{a}	9.04^{a}	9.53^{a}	10.36^{a}	10.82^{a}	11.42^{a}	11.70^{a}	12.00^{a}	12.68^{a}	12.88^{a}
2. Cowdung	4.77	5.23	6.03^{a}	6.51^{a}	7.141^{a}	7.56^{ab}	8.04^{ab}	8.32^{ab}	8.67^{ab}	9.09^{ab}	9.34^{ab}	9.56^{ab}	9.80^{ab}	9.87^{ab}	10.09^{b}	10.19^{b}
3. Cowdung + Neem cake	4.15	5.02	5.14^{b}	5.53^{b}	5.95^{b}	6.47^{b}	6.97^{b}	7.46^{b}	7.66^{b}	8.16^{b}	8.60^{b}	9.04^{b}	9.43^{b}	9.50^{b}	9.90^{b}	10.34^{ab}
F test	3.32^{NS}	0.27^{NS}	6.41*	6.23*	7.22*	6.55*	5.38*	3.95*	4.90*	5.03*	4.85*	4.32*	3.71*	4.06*	4.69*	4.09*
Sowing methods																
1.Broadcasting (control)	4.19^{b}	4.64^{b}	5.74^{b}	6.15^{b}	6.60^{b}	7.01^{b}	7.51^{b}	7.70^{b}	7.93^{b}	8.30^{b}	8.57^{b}	8.85^{b}	9.04^{b}	9.14^{b}	9.43^{b}	9.83^{b}
2. Spacing 4 cm x 4 cm	4.08^{b}	4.68^{b}	5.20^{b}	5.65^{b}	6.31^{b}	6.91^{b}	7.40^{b}	7.77^{b}	8.19^{b}	8.65^{b}	8.94^{b}	9.21^{b}	9.37^{b}	9.49^{b}	9.90^{b}	10.02^{b}
3. Spacing 8 cm x 8 cm	4.31^{b}	4.79^{b}	5.23^{b}	5.69^{b}	6.15^{b}	6.66^{b}	7.22^{b}	7.69^{b}	7.90^{b}	8.72^{b}	9.23^{b}	9.72^{b}	10.04^{b}	10.23^{a}	10.65^{b}	10.79^{b}
4. Spacing 12 cm x 12 cm	5.48^{a}	6.73^{a}	7.07^{a}	7.63^{a}	8.40^{a}	8.96^{a}	9.37^{a}	9.93^{a}	10.45^{a}	11.13^{a}	11.60^{a}	12.25^{a}	12.79^{a}	12.98^{a}	13.59^{a}	13.90^{a}
F test	9.99*	7.24*	10.4*	9.17*	8.94*	7.93*	5.79*	5.83*	6.33*	5.21*	4.42*	4.88*	5.43*	5.06*	5.08*	4.78*
Nutrient vs spacing																
F test	3.15*	2.75*	2.41*	2.32*	2.50*	2.27*	1.82^{NS}	1.57^{NS}	1.98^{NS}	1.48^{NS}	1.28^{NS}	1.19^{NS}	1.51^{NS}	1.26^{NS}	1.23^{NS}	1.25^{NS}
SEM	0.14	0.21	0.19	0.22	0.25	0.27	0.30	0.32	0.35	0.40	0.44	0.49	0.52	0.55	0.59	0.61

** Significant at 0.01; * Significant at 0.05; NS - Non significant

Values sharing same alphabets within the main treatments do not differ significantly between themselves at P = 0.05

cowdung 0.4 kg m^{-2} during the initial period. But in the further period of growth, the control treatment performed better than the other nutrients.

Levels of sowing methods were found to vary significantly with respect to collar girth. The best sowing method during the study period was a spacing of 12 cm x 12 cm between seeds with a collar girth of 13.902 mm at the end of the study period. While considering other sowing methods, the least performing treatment was broadcast sowing method with a collar girth of 9.83 mm at the end of the study period. However all the three treatments viz., broadcasting, spacing 4 cm x 4 cm between seeds, spacing 8 cm x 8 cm between seeds were at par during the study period.

4.1.3 Number of leaves

Analysis of variance revealed that the treatments differed significantly between themselves at all fortnigths of observations except in the last three fortnights. The effect of nutrients and sowing methods on number of leaves produced is shown in Table 5 and illustrated in Figure 3. The number of leaves produced in each fortnight varied significantly between treatments during all fortnights. In the first four fortnights the best treatment was N_0S_0 (control) and in the later fortnights the best treatment was N_2S_3. (cowdung 0.4 kg/m^2 + neem cake 0.2 kg/m^2 and a spacing of 12 cm x 12 cm between seeds). N_0S_0 (control) was the next best treatment with a leaf number of 32.40 at the end of the 13th fortnight. Treatment combinations were non significant from 13th to 16th fortnight. Least performing treatment at the end of the 13th fortnight was N_2S_1 (cowdung 0.4 kg/m^2 + neem cake 0.2 kg/m^2 and a spacing of 4 cm x 4 cm between seeds) with a leaf number of 24.8.

Table 6 shows the effect of nutrients and sowing methods on leaf number of teak seedlings. Levels of nutrients were found to vary significantly with respect to leaf number. Considering the nutrient, the best treatment was the control treatment with a leaf number of 35.65 at the end of the study period which was followed by the treatment cowdung 0.4 kg/m^2 with a leaf number of 33.05. The least performing treatment was cowdung 0.4 kg/m^2 + neem cake 0.2 kg/m^2 with a leaf number of 31.9.

Table 5. Effect of combination of nutrients and sowing methods on leaf number of teak seedlings at fortnightly intervals

Treat-ment	Treatment details	Fortnights															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
N_0S_0	No nutrients + broadcasting (control)	19.2^{a}	20.8^{a}	21.4^{ab}	23.2^{a}	24.4^{ab}	25.6^{a}	26.8^{a}	28.2^{a}	28.8^{a}	29.6^{ab}	30.6^{a}	31.2^{ab}	32.4^{a}	34.6	35.6	35.8
N_0S_1	No nutrients + spacing 4 x 4 cm	17.2^{abc}	19.6^{a}	21.2^{ab}	22.6^{a}	23.8^{ab}	25.4^{a}	27.2^{a}	28.0^{a}	29.2^{a}	30.4^{a}	30.4^{a}	32^{a}	31.8^{ab}	33.6	35.0	36.0
N_0S_2	No nutrients + spacing 8 x 8 cm	16.6^{bcd}	18.6^{ab}	19.6^{bc}	21.4^{ab}	22.6^{abc}	24.2^{ab}	25.4^{ab}	26.6^{a}	27.2^{a}	28.6^{ab}	29.2^{ab}	29.2^{ab}	30.2^{abc}	33.2	35.2	36.4
N_0S_3	No nutrients + spacing 12 x 12cm	14.8^{de}	16.8^{bc}	17.6^{cd}	19.6^{bcd}	21.0^{cd}	22.4^{bcd}	23.6^{bc}	25.2^{ab}	26.2^{ab}	27.2^{abc}	27.8^{ab}	28.4^{abc}	29.6^{abcd}	31.6	33.2	34.4
N_1S_0	Cowdung + broadcasting	18.2^{ab}	19.6^{a}	20.0^{ab}	21.8^{ab}	22.4^{bc}	23.8^{ab}	25.0^{ab}	26.2^{a}	26.8^{ab}	28.4^{ab}	28.4^{ab}	28.4^{abc}	29.6^{abcd}	30.8	32.2	33.0
N_1S_1	Cowdung + spacing 4 x 4 cm	15.2^{cde}	17.0^{bc}	17.2^{cd}	18.8^{cd}	19.6^{d}	21.2^{cd}	21.8^{cd}	23.2^{bc}	23.8^{bc}	24^{cde}	24.2^{cd}	25.2^{cd}	25.8^{de}	27	27.4	28.0
N_1S_2	Cowdung + spacing 8 x 8 cm	18.6^{ab}	20.6^{a}	21.4^{ab}	23.2^{a}	25.0^{a}	25.6^{a}	26.6^{a}	27.6^{a}	28.0^{a}	29.4^{ab}	29.8^{ab}	30.4^{ab}	31.8^{ab}	32.9	34.9	35.7
N_1S_3	Cowdung + spacing 12 x12 cm	18.8^{ab}	20.8^{a}	22.2^{a}	23.2^{a}	24.0^{ab}	25.0^{ab}	25.6^{ab}	26.4^{a}	27.0^{ab}	28.8^{ab}	29.8^{ab}	30.6^{ab}	31.4^{ab}	33.9	34.7	35.5
N_2S_0	Cowdung + neem cake + broadcasting	17.6^{ab}	18.8^{ab}	19.6^{bc}	21.0^{abc}	22.6^{abc}	23.6^{abc}	24.6^{ab}	25.4^{ab}	26.0^{ab}	26.6^{bcd}	26.6^{bc}	27.4^{bcd}	28^{bcde}	28.4	29.6	29.8
N_2S_1	Cowdung + neem cake + spacing 4 x 4 cm	14.4^{e}	16.4^{c}	17.2^{d}	18.2^{de}	19.4^{de}	20.2^{bc}	21.2^{cd}	21.6^{c}	21.8^{c}	22.8^{e}	23.0^{d}	23.8^{d}	24.8^{e}	26.4	27.0	27.0
N_2S_2	Cowdung + neem cake + spacing 8 x 8 cm	11.4^{f}	13.2^{d}	14.6^{e}	16.0^{e}	17.2^{e}	18.4^{e}	19.6^{d}	21.2^{c}	22.8^{c}	23.8^{de}	24.2^{cd}	25.2^{cd}	26.6^{cde}	29.4	30.2	31.2
N_2S_3	Cowdung + neem cake + spacing 12 x 12 cm	18.6^{ab}	20.2^{a}	21.8^{ab}	23.0^{a}	24.4^{ab}	25.8^{a}	26.6^{a}	28.2^{a}	29.2^{a}	30.6^{a}	30.6^{a}	31.4^{ab}	32.6^{a}	35.6	38.2	39.6
F		11.09*	11.17*	11.45*	10.16*	11.42*	9.22*	8.11*	6.96*	5.40*	5.97*	4.91*	4.846*	3.816*	3.16^{NS}	3.408^{NS}	3.231^{NS}
SEM		0.29	0.29	0.32	0.32	0.33	0.35	0.38	0.38	0.19	0.45	0.47	0.507	0.535	0.637	0.707	0.765
CD (0.05)		1.12	1.11	1.21	1.22	1.24	1.33	1.44	1.48	0.73	1.72	1.80	1.934	2.04	2.429	2.696	2.918

** Significant at 0.01; * Significant at 0.05; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at P = 0.05

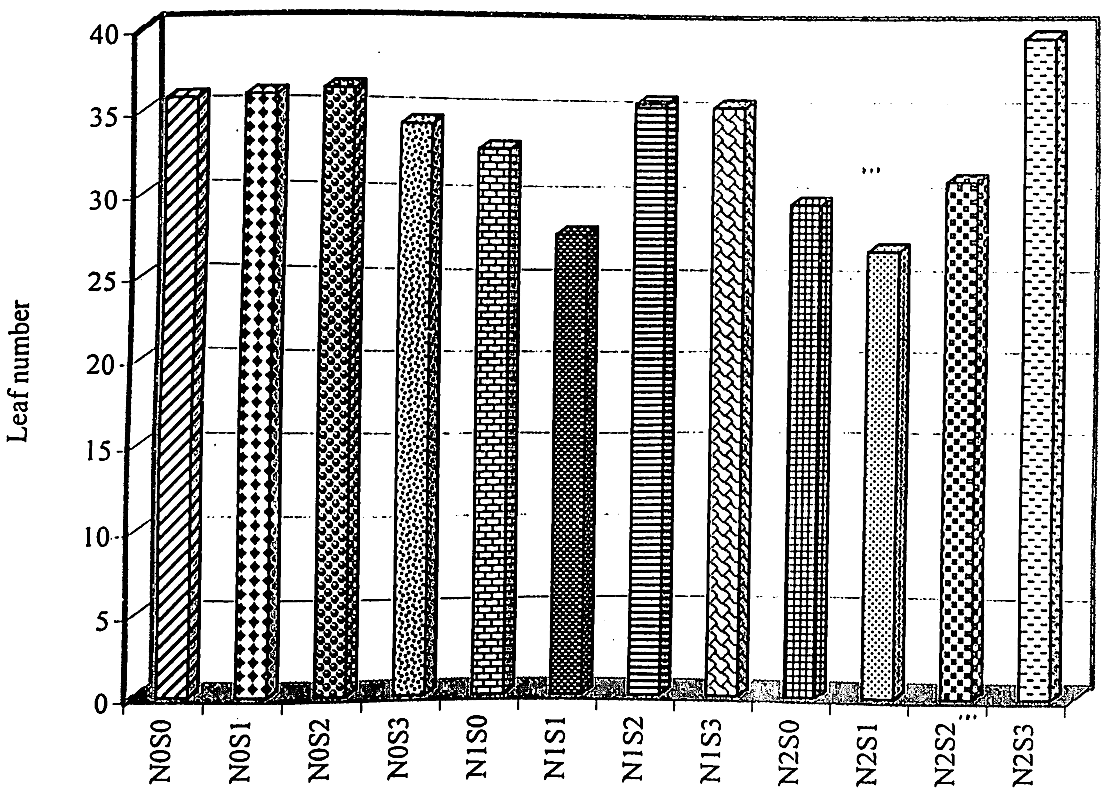

Fig. 3. Effect of nutrients and sowing methods on leaf number of teak seedlings at sixteenth fortnight

Table 6. Effect of nutrients and sowing methods on leaf number of teak seedlings at fortnightly intervals

Treatment	Fortnight															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Nutrient																
1. No nutrient (control)	17.05^{a}	18.95^{a}	19.95^{a}	21.70^{a}	22.95^{a}	24.40^{a}	25.75^{a}	27.00^{a}	27.85^{a}	28.95^{a}	29.50^{a}	30.20^{a}	31.00^{c}	33.25^{a}	34.70^{a}	35.65^{a}
2. Cowdung	17.70^{a}	19.50^{a}	20.20^{a}	21.75^{a}	22.75^{a}	23.90^{a}	24.75^{a}	25.85^{a}	26.40^{ab}	27.65^{ab}	28.05^{ab}	28.65^{ab}	29.65^{a}	31.15^{ab}	32.30^{ab}	33.05^{ab}
3. Cowdung + Neem cake	15.50^{b}	17.15^{b}	18.30^{t}	19.55^{b}	20.90^{b}	22.00^{b}	23.00^{b}	24.10^{b}	24.95^{b}	25.95^{b}	26.10^{b}	26.95^{b}	28.00^{c}	30.00^{b}	31.25^{b}	31.90^{b}
F test	9.88*	11.79*	7.02*	10.25*	8.07*	8.81*	9.03*	9.48*	7.33*	7.38*	8.71*	6.87*	5.27*	4.59*	4.17*	4.20*
Sowing methods																
1.Broadcasting (control)	18.33^{a}	19.73^{a}	20.33^{a}	22.00^{a}	23.13^{a}	24.33^{a}	25.47^{a}	26.60^{a}	27.20^{ab}	28.20^{ab}	28.53^{ab}	29.00^{ab}	30.00^{a}	31.27^{b}	32.40^{b}	32.87^{b}
2. Spacing 4 cm x 4 cm	15.73^{b}	17.67^{b}	18.53^{b}	19.87^{b}	20.93^{b}	22.27^{b}	23.40^{b}	24.27^{b}	24.93^{c}	25.73^{c}	25.87^{c}	27.00^{c}	27.47^{b}	29.00^{c}	29.80^{c}	30.33^{c}
3. Spacing 8 cm x 8 cm	15.53^{b}	17.47^{b}	18.53^{b}	20.20^{b}	21.60^{b}	22.73^{b}	23.87^{b}	25.13^{b}	26.00^{bc}	27.27^{b}	27.73^{b}	28.27^{bc}	29.53^{a}	31.83^{ab}	33.43^{ab}	34.43^{ab}
4. Spacing 12 cm x 12 cm	17.40^{a}	19.27^{a}	20.53^{a}	21.93^{a}	23.13^{a}	24.40^{a}	25.27^{a}	26.60^{a}	27.47^{a}	28.87^{a}	29.40^{a}	30.13^{a}	31.20^{a}	33.70^{a}	35.37^{a}	36.50^{a}
F test	10.52*	7.56*	5.97*	6.17*	5.85*	4.94*	3.65*	4.43*	3.57*	4.51*	5.10*	3.37*	4.24*	4.62*	5.38*	5.78*
Nutrient vs spacing																
F test	11.09*	11.17*	11.45*	10.16*	11.42*	9.22*	8.11*	6.96*	5.40*	5.97*	4.91*	4.85*	3.82*	3.16^{NS}	3.41^{NS}	3.23^{NS}
SEM	0.29	0.29	0.32	0.32	0.33	0.35	0.38	0.38	0.19	0.45	0.47	0.51	0.54	0.64	0.71	0.77

** Significant at 0.01; * Significant at 0.05; NS - Non significant

Values sharing same alphabets within the main treatments do not differ significantly between themselves at P = 0.05

Levels of sowing methods were found to vary significantly with respect to number of leaves produced during the study period. The best sowing method during the study period was the broadcast sowing method with a leaf number of 18.33 at the initial fortnight of observation which was followed by the sowing method with a spacing of 12 cm x 12 cm between seeds. Considering the treatment broadcasting and the widest spacing of 12 cm x 12 cm produced maximum number of leaves during the study period and the treatments were at par also. The least number of leaves was obtained for the lowest spacing treatment 4 cm x 4 cm between seeds with a leaf number of 30.33 at the end of the study period.

4.1.4 Root length

Root length showed significant differences at all stages of observations as is evident from the data furnished in Table 7 and illustrated in Figure 4. In the case of interaction effect of nutrients and spacing the treatment N_0S_0 recorded maximum root length (42.6 cm) and was followed by N_1S_3 (cowdung 0.4 kg/m^2 and a spacing of 12 cm x 12 cm between seeds) and N_1S_2 (cowdung 0.4 kg/m^2 and a spacing of 8 cm x 8 cm between seeds) in the first month of observation. The treatment N_0S_1 (no nutrients and a spacing of 4 cm x 4 cm between seeds) recorded the minimum root length (23.6 cm) which was followed by N_1S_1 (cowdung 0.4 kg/m^2 and a spacing of 4 cm x 4 cm between seeds) in the initial month of observation. In the eighth month of observation the root length was the maximum (85.7 cm) for N_0S_0 (control), which was followed by treatment N_1S_2 (cowdung 0.4 kg/m^2 and a spacing of 8 cm x 8 cm between seeds) with a root length of 85.60 cm. The minimum root length of 49.2 cm was recorded by the treatment N_2S_1 (cowdung 0.4 kg/m^2 + neem cake 0.2 kg/m^2 and a spacing of 4 cm x 4 cm between seeds) which was followed by the treatment N_2S_2 (cowdung 0.4 kg/m^2 + neem cake 0.2 kg/m^2 and a spacing of 8 cm x 8 cm between seeds).

At the eighth month, the treatments N_0S_0 (control), N_1S_2 (cowdung 0.4 kg/m^2 and a spacing of 8 cm x 8 cm between seeds), N_1S_3 (cowdung 0.4 kg/m^2 and a spacing of 12 cm x 12 cm between seeds) were at par with the maximum root

Table 7. Effect of combination of nutrients and sowing methods on root length (cm) of teak seedlings at monthly intervals

Treat-ment	Treatment details	Months							
		1	2	3	4	5	6	7	8
N_0S_0	No nutrients + broadcasting (control)	42.60^{a}	50.60^{a}	57.40^{a}	61.40^{a}	70.90^{a}	76.00^{a}	81.30^{a}	85.70^{a}
N_0S_1	No nutrients + spacing 4 x 4 cm	34.40^{c}	41.40^{b}	45.20^{bc}	49.20^{b}	52.60^{c}	54.20^{cd}	56.60^{de}	60.30^{d}
N_0S_2	No nutrients + spacing 8 x 8 cm	27.70^{de}	31.70^{cde}	35.40^{e}	39.86^{de}	45.50^{de}	49.00^{de}	52.60^{ef}	56.60^{de}
N_0S_3	No nutrients + spacing 12 x 12cm	29.10^{d}	34.90^{cd}	38.50^{de}	42.80^{cd}	46.40^{de}	55.20^{cd}	58.40^{cd}	62.20^{d}
N_1S_0	Cowdung + broadcasting	27.00^{def}	29.50^{ef}	33.70^{ef}	36.80^{ef}	38.90^{fg}	45.20^{ef}	51.10^{fg}	57.60^{de}
N_1S_1	Cowdung + spacing 4 x 4 cm	25.30^{ef}	26.90^{f}	29.70^{f}	32.20^{f}	34.40^{g}	40.00^{f}	46.40^{g}	52.70^{ef}
N_1S_2	Cowdung + spacing 8 x 8 cm	35.66^{bc}	40.30^{b}	46.30^{bc}	60.70^{a}	62.50^{b}	72.00^{a}	79.90^{a}	85.60^{a}
N_1S_3	Cowdung + spacing 12 x12 cm	37.80^{b}	43.40^{b}	48.20^{b}	57.90^{a}	59.50^{b}	65.50^{b}	72.80^{b}	82.90^{a}
N_2S_0	Cowdung + neem cake + broadcasting	26.70^{def}	35.10^{c}	42.80^{cd}	47.80^{bc}	49.70^{cd}	59.30^{c}	68.60^{b}	76.80^{b}
N_2S_1	Cowdung + neem cake + spacing 4 x 4 cm	23.60^{f}	30.60^{cdef}	35.30^{e}	42.10^{de}	44.10^{ef}	45.60^{ef}	47.80^{fg}	49.20^{f}
N_2S_2	Cowdung + neem cake + spacing 8 x 8 cm	27.00^{def}	31.80^{cde}	35.40^{e}	39.10^{de}	41.10^{ef}	43.20^{ef}	45.90^{g}	49.40^{f}
N_2S_3	Cowdung + neem cake + spacing 12 x 12 cm	25.90^{def}	30.40^{def}	34.50^{ef}	38.80^{de}	43.00^{ef}	53.30^{cd}	62.90^{c}	70.50^{c}
F		33.26*	30.21*	30.10*	43.43*	48.59*	37.51*	60.04*	62.32*
SEM		0.44	0.58	0.67	0.74	0.73	0.86	0.74	0.76
CD (0.05)		1.67	2.22	2.55	2.83	2.78	3.26	2.82	2.90

* Significant at 0.05; ** Significant at 0.01; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at P = 0.05

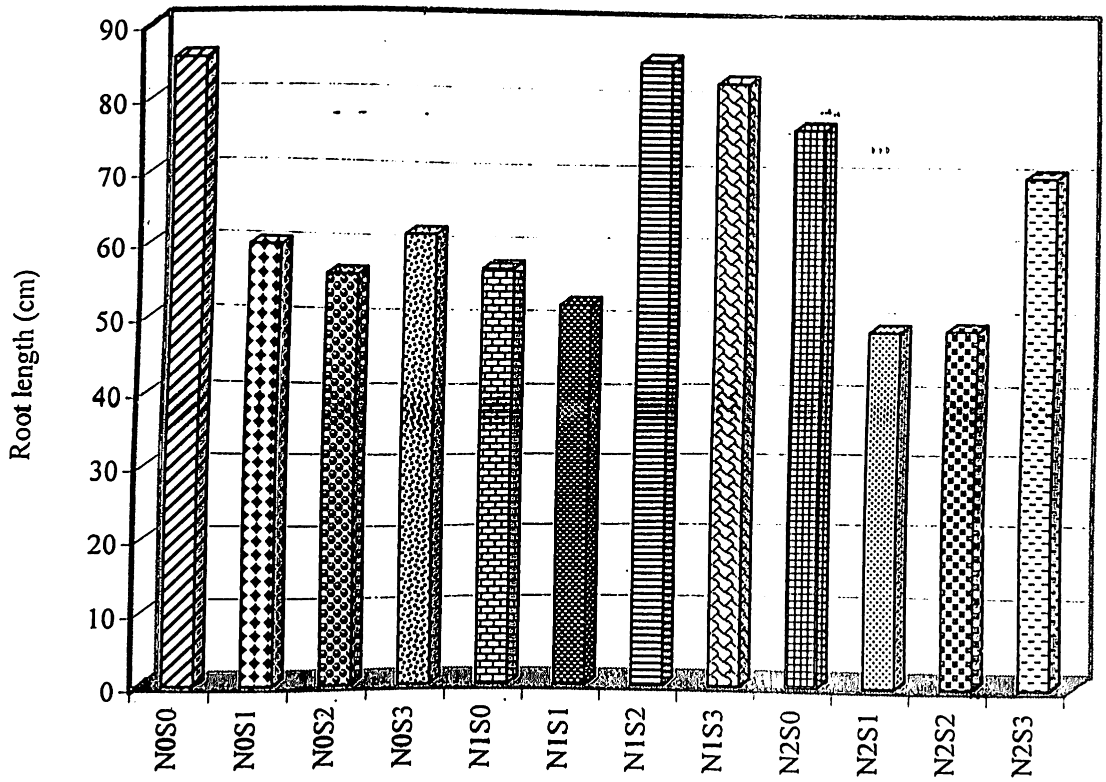

Fig. 4. Effect of nutrients and sowing methods on root length (cm) of teak seedlings at eighth month

length which was followed by the treatments N_2S_0 (cowdung 0.4 kg/m^2 + neem cake 0.2 kg/m^2 and broadcast sowing method) then by N_2S_3 (cowdung 0.4 kg/m^2 + neem cake 0.2 kg/m^2 and a spacing of 12 cm x 12 cm between seeds). The least performing treatments were N_2S_1 (cowdung 0.4 kg/m^2 + neem cake 0.2 kg/m^2 and a spacing of 4 cm x 4 cm between seeds). and N_2S_2 (cowdung 0.4 kg/m^2 + neem cake 0.2 kg/m^2 and a spacing of 8 cm x 8 cm between seeds). The treatments N_0S_0, (control), N_1S_2 (cowdung 0.4 kg/m^2 and a spacing of 8 cm x 8 cm between seeds), N_1S_3 (cowdung 0.4 kg/m^2 and a spacing of 12 cm x 12 cm between seeds) were at par with the maximum root length which was followed by the treatment N_2S_0 (cowdung 0.4 kg/m^2 + neem cake 0.2 kg/m^2 and broadcast sowing method) and N_2S_3 (cowdung 0.4 kg/m^2 + neem cake 0.2 kg/m^2 and a spacing of 12 cm x 12 cm between seeds). The least performing treatments were N_2S_1 (cowdung 0.4 kg/m^2 + neem cake 0.2 kg/m^2 and a spacing of 4 cm x 4 cm between seeds) and N_2S_2 (cowdung 0.4 kg/m^2 + neem cake 0.2 kg/m^2 and a spacing of 8 cm x 8 cm between seeds).

Table 8 shows the effect of nutrients and sowing methods on root length of seedlings. Levels of nutrients were found to vary significantly with respect to root length of teak seedlings. When considering the effect of nutrients..on root length of teak seedlings separately the maximum root length (33.45 cm) was recorded by the control treatment (no nutrients), which was at par with the treatment cowdung 0.4 kg m^{-2} with a root length of 31.44 cm at the first month of observation. This trend continued up to the last month of observation. At the end of the study period the maximum root length of 69.7 cm was recorded by the treatment cowdung 0.4 kg m^{-2}. Minimum root length of 61.48 cm was recorded by the treatment cowdung 0.4 kg m^{-2} and neem cake 0.2 kg m^{-2} at the end of the study period.

Levels of sowing methods were found to vary significantly with respect to the root length. Highest root length of 32.1 cm was recorded by broadcast treatment which was followed by the treatment spacing 12 cm x 12 cm between seeds with 30.933 cm root length in the initial month of observation. Least performance was observed in the spacing treatment of 4 cm x 4 cm between seeds with a root length of 27.767 cm in the first month of study. However, in the eighth month of observation

Table 8. Effect of nutrients and sowing methods on root length (cm) of teak seedlings at monthly intervals

Treatment	Months							
	1	2	3	4	5	6	7	8
Nutrient								
1. No nutrient (control)	33.45^{a}	39.65^{a}	44.13^{b}	48.32^{a}	53.85^{a}	58.60^{a}	62.23^{a}	66.20^{b}
2. Cowdung	31.44^{b}	35.03^{b}	39.48^{a}	46.90^{a}	48.83^{b}	55.68^{a}	62.55^{a}	69.70^{a}
3. Cowdung + Neem cake	25.80^{c}	31.98^{c}	37.00^{a}	41.95^{b}	44.48^{c}	50.35^{b}	56.30^{b}	61.48^{c}
F test	54.79*	29.35*	19.58*	13.48*	27.69*	15.94*	15.13*	19.72*
Sowing methods								
1.Broadcasting (control)	32.10^{a}	38.40^{a}	44.63^{a}	48.67^{a}	53.17^{a}	60.17^{a}	67.00^{a}	73.37^{a}
2. Spacing 4 cm x 4 cm	27.77^{c}	32.97^{c}	36.73^{c}	41.17^{b}	43.70^{c}	46.60^{c}	50.27^{c}	54.07^{c}
3. Spacing 8 cm x 8 cm	30.12^{b}	34.60^{bc}	39.03^{b}	46.55^{a}	49.70^{b}	54.73^{b}	59.47^{b}	63.87^{b}
4. Spacing 12 cm x 12 cm	30.93^{ab}	36.23^{b}	40.40^{b}	46.50^{a}	49.63^{b}	58.00^{a}	64.70^{a}	71.87^{a}
F test	8.77*	7.94*	12.37*	9.27*	14.57*	24.21*	50.58*	65.14*
Nutrient vs spacing								
F test	33.26*	30.21*	30.10*	43.43*	48.59*	37.51*	60.04*	62.32*
SEM	0.44	0.58	0.67	0.74	0.73	0.86	0.74	0.76

* Significant at 0.05; ** Significant at 0.01; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at P = 0.05

the maximum root length (73.37 cm) was recorded by broadcast treatment and minimum root length (54.07 cm) was recorded by the treatment with the spacing of 4 cm x 4 cm between seeds. In the last three months, the broadcast treatment and the spacing treatment of 12 cm x 12 cm between seeds were at par.

4.2 BIOMASS CHARACTERISTICS

Results pertaining to the effect of nutrients and sowing methods on the biomass characteristics of teak seedlings at monthly intervals are presented in Table 9 to 16 and illustrated in Figures 5 to 8.

4.2.1 Shoot fresh weight

Data given in the Table 9 reveal that there is significant difference between treatments in the case of shoot fresh weight throughout the study period. Figure 5 graphically illustrates the shoot fresh weight of the seedlings as influenced by nutrients and sowing methods. The treatment N_0S_0 (control) had consistently higher shoot fresh weight during the initial stages of observation with a maximum shoot fresh weight of 3.9 g. However during the end of the study period maximum shoot fresh weight of 33.05 g was recorded by the treatment N_2S_3 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and a spacing of 12 cm x 12 cm between seeds). At the end of the study period N_1S_1 (cowdung 0.4 kg m^{-2} and a spacing of 4 cm x 4 cm between seeds) recorded lowest shoot fresh weight of 24.85 g at the end of the study period. At this stage however, the treatments N_0S_0 (control), N_1S_3 (cowdung 0.4 kg m^{-2} and a spacing of 12 cm x 12 cm between seeds), N_2S_0 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and broadcast sowing method), N_2S_1 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and a spacing of 4 cm x 4 cm between seeds), N_2S_2 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and a spacing of 8 cm x 8 cm between seeds) and N_2S_3 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and a spacing of 12 cm x 12 cm between seeds) were at par.

Data furnished in Table 10 reveal that there is significant difference between the levels of nutrients on shoot fresh weight of teak seedlings. In the initial

Table 9. Effect of combination of nutrients and sowing methods on shoot fresh weight (g) of teak seedlings at monthly intervals

Treat-ment	Treatment details	Months							
		1	2	3	4	5	6	7	8
N_0S_0	No nutrients + broadcasting (control)	3.90^{a}	6.54^{a}	10.78^{a}	17.76^{a}	23.69^{a}	28.08^{a}	30.184^{a}	31.37^{a}
N_0S_1	No nutrients + spacing 4 x 4 cm	2.63^{bc}	3.80^{cde}	6.17^{de}	10.82^{def}	14.69^{cd}	19.97^{bc}	25.23^{cde}	26.91^{b}
N_0S_2	No nutrients + spacing 8 x 8 cm	2.34^{c}	3.19^{e}	5.62^{e}	10.23^{f}	14.75^{cd}	18.63^{c}	23.67^{e}	25.81^{bc}
N_0S_3	No nutrients + spacing 12 x 12cm	2.35^{c}	3.37^{de}	6.03^{de}	10.84^{def}	15.97^{bc}	20.62^{bc}	23.84^{de}	25.94^{bc}
N_1S_0	Cowdung + broadcasting	2.79^{bc}	4.26^{bcde}	6.29^{cde}	11.09^{cdef}	15.24^{cd}	19.91^{bc}	30.18^{a}	31.40^{a}
N_1S_1	Cowdung + spacing 4 x 4 cm	2.29^{c}	3.18^{e}	6.05^{de}	10.86^{ef}	14.57^{d}	20.27^{bc}	23.21^{e}	24.85^{c}
N_1S_2	Cowdung + spacing 8 x 8 cm	2.36^{c}	3.45^{de}	6.12^{de}	10.94^{def}	14.61^{cd}	20.51^{bc}	23.49^{e}	26.41^{bc}
N_1S_3	Cowdung + spacing 12 x12 cm	2.88^{bc}	4.80^{bc}	7.18^{bcd}	12.28^{bcde}	15.78^{bc}	20.63^{bc}	25.83^{bcd}	31.93^{a}
N_2S_0	Cowdung + neem cake + broadcasting	2.86^{bc}	4.34^{bcde}	7.32^{bc}	12.43^{bcd}	15.39^{cd}	20.34^{bc}	30.16^{a}	31.45^{a}
N_2S_1	Cowdung + neem cake + spacing 4 x 4 cm	3.04^{bc}	4.60^{bcd}	7.40^{b}	12.56^{bc}	15.60^{bcd}	20.36^{bc}	26.74^{bc}	31.54^{a}
N_2S_2	Cowdung + neem cake + spacing 8 x 8 cm	3.05^{bc}	5.30^{b}	7.67^{b}	12.90^{b}	15.96^{bc}	21.48^{b}	26.94^{bc}	32.07^{a}
N_2S_3	Cowdung + neem cake + spacing 12 x 12 cm	3.34^{ab}	5.01^{bc}	8.06^{b}	13.58^{b}	16.95^{b}	21.76^{b}	27.68^{b}	33.05^{a}
F		4.14*	7.89*	17.49*	19.73*	31.56*	19.49*	3.05*	15.15*
SEM		0.10	0.16	0.15	0.20	0.19	0.25	0.28	0.24
CD (0.05)		0.37	0.60	0.56	0.77	0.71	0.94	1.06	0.93

* Significant at 0.05; ** Significant at 0.01; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at P = 0.05

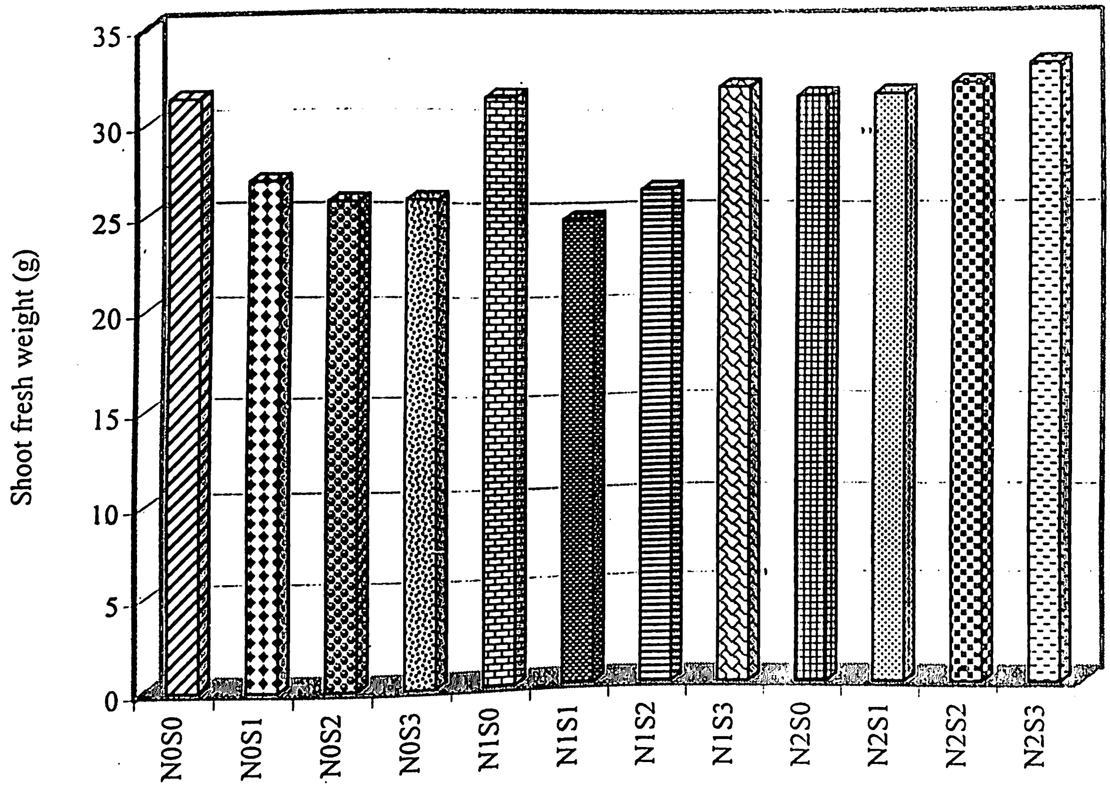

Fig. 5. Effect of nutrients and sowing methods on shoot fresh weight (g) of teak seedlings at eighth month

Table 10. Effect of nutrients and sowing methods on shoot fresh weight (g) of teak seedlings at monthly intervals

Treatment	Months							
	1	2	3	4	5	6	7	8
Nutrient								
1. No nutrient (control)	2.80^{ab}	4.23^{ab}	7.15^{a}	12.41^{a}	17.28^{a}	21.83^{a}	25.73^{b}	27.51^{c}
2. Cowdung	2.58^{b}	3.92^{b}	6.41^{b}	11.29^{b}	15.05^{c}	20.33^{b}	25.68^{b}	28.65^{b}
3. Cowdung + Neem cake	3.07^{a}	4.82^{a}	7.61^{a}	12.87^{a}	15.98^{b}	20.99^{ab}	27.88^{a}	32.03^{a}
F test	4.32*	5.62*	11.40*	10.68*	24.05*	6.13*	13.53*	62.03*
Sowing methods								
1.Broadcasting (control)	3.19^{a}	5.05^{a}	8.13^{a}	13.76^{a}	18.11^{a}	22.78^{a}	30.17^{a}	31.41^{a}
2. Spacing 4 cm x 4 cm	2.65^{b}	3.86^{c}	6.54^{c}	11.41^{c}	14.95^{c}	20.20^{c}	25.06^{bc}	27.76^{c}
3. Spacing 8 cm x 8 cm	2.58^{b}	3.98^{bc}	6.47^{c}	11.36^{c}	15.11^{c}	20.21^{c}	24.70^{c}	28.10^{c}
4. Spacing 12 cm x 12 cm	2.86^{b}	4.40^{b}	7.09^{b}	12.23^{b}	16.24^{b}	21.01^{b}	25.78^{b}	30.31^{b}
F test	3.90*	5.87*	13.63*	15.28*	30.55*	12.03*	41.40*	25.84*
Nutrient vs spacing								
F test	4.14*	7.89*	17.49*	19.73*	31.56*	19.49*	3.05*	15.15*
SEM	0.10	0.16	0.15	0.20	0.19	0.25	0.28	0.24

* Significant at 0.05; ** Significant at 0.01; NS - Non significant
Values sharing same alphabets do not differ significantly between themselves at P = 0.05

stage of study cowdung 0.4 kg m^{-2} and neem cake 0.2 kg m^{-2} nutrient level had the maximum shoot fresh weight of 3.072 g. This trend continued during most of the study period. At the end of the study period also cowdung 0.4 kg m^{-2} and neem cake 0.2 kg m^{-2} treatment obtained the maximum shoot fresh weight of 32.08 g and the least shoot fresh weight was obtained for the control treatment (no nutrients).

Observations given in Table 10 reveals that broadcast sowing method had maximum shoot fresh weight (3.19 g) which was followed by the treatment with a spacing of 12 cm x 12 cm between seeds (2.86 g) at the initial month of study. The least performing treatments were sowing methods with a spacing of 8 cm x 8 cm between seeds and 4 cm x 4 cm between seeds which were at par during the study period. At the end of the study period the maximum shoot fresh weight (31.41 g) was obtained for the broadcast sowing method which was followed by the sowing method with a spacing of 12 cm x 12 cm between seeds with a shoot fresh weight of 30.31 g. However, the sowing methods with a spacing of 4 cm x 4 cm between seeds and 8 cm x 8 cm between seeds were at par.

4.2.2 Shoot dry weight

The data furnished in the Table 11 reveal that there is significant influence of nutrient and sowing methods on shoot dry weight of teak seedlings. Figure 6 graphically illustrates the effect of nutrients and sowing methods on shoot dry weight of teak seedlings. The maximum shoot dry weight of 1.29 g was recorded by the treatment N_2S_3 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and a spacing of 12 cm x 12 cm between seeds) at the initial stage of study period. The minimum shoot dry weight (g) of 0.76 g was found in the treatment N_0S_2 (no nutrients and a spacing of 8 cm x 8 cm between seeds) at the first month of study. Analysis of variance showed significant variation between the combinations of the nutrients and sowing methods on shoot dry weight of teak seedlings. At the end of the study period treatment N_0S_0 (control), shoot dry weight of 19.66 g and N_2S_3 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and a spacing of 12 cm x 12 cm between seeds) with a shoot dry weight of 18.547 g were at par. The least shoot fresh weight was obtained for the treatment N_0S_2

Table 11. Effect of combination of nutrients and sowing methods on shoot dry weight (g) of teak seedlings at monthly intervals

Treat-ment	Treatment details	Months							
		1	2	3	4	5	6	7	8
N_0S_0	No nutrients + broadcasting (control)	1.25^{a}	2.16^{a}	3.85^{a}	8.60^{a}	14.75^{a}	18.41^{a}	19.12^{a}	19.66^{a}
N_0S_1	No nutrients + spacing 4 x 4 cm	0.80^{cd}	1.47^{bcd}	2.17^{d}	4.98^{cde}	6.16^{def}	12.08^{bc}	13.89^{bc}	14.94^{c}
N_0S_2	No nutrients + spacing 8 x 8 cm	0.76^{d}	0.99^{e}	2.10^{d}	3.89^{de}	5.19^{f}	8.13^{f}	9.36^{e}	10.82^{f}
N_0S_3	No nutrients + spacing 12 x 12cm	0.90^{bcd}	1.29^{de}	2.17^{d}	3.95^{cde}	6.05^{ef}	9.05^{ef}	10.94^{d}	12.28^{e}
N_1S_0	Cowdung + broadcasting	1.03^{abcd}	1.54^{bcd}	2.31^{cd}	3.81^{e}	5.41^{f}	8.05^{f}	9.59^{e}	13.42^{d}
N_1S_1	Cowdung + spacing 4 x 4 cm	0.89^{bcd}	1.03^{e}	3.14^{b}	4.86^{cde}	9.24^{b}	12.27^{bc}	13.27^{c}	15.40^{bc}
N_1S_2	Cowdung + spacing 8 x 8 cm	1.04^{abcd}	1.38^{cde}	3.02^{b}	5.33^{bc}	8.96^{b}	10.98^{bcd}	14.31^{bc}	15.63^{bc}
N_1S_3	Cowdung + spacing 12 x12 cm	1.23^{a}	1.82^{abc}	3.12^{b}	5.17^{bcde}	6.72^{cde}	9.98^{de}	14.51^{bc}	19.22^{a}
N_2S_0	Cowdung + neem cake + broadcasting	1.09^{abc}	1.57^{bcd}	2.76^{bc}	5.15^{bcde}	6.84^{cde}	10.17^{de}	14.47^{bc}	15.65^{bc}
N_2S_1	Cowdung + neem cake + spacing 4 x 4 cm	1.14^{ab}	1.68^{bcd}	2.86^{b}	5.16^{bcde}	6.88^{cde}	10.24^{de}	14.62^{b}	15.78^{bc}
N_2S_2	Cowdung + neem cake + spacing 8 x 8 cm	1.23^{a}	1.75^{abc}	2.96^{b}	5.22^{bcd}	7.12^{cd}	10.78^{cd}	14.83^{b}	16.21^{b}
N_2S_3	Cowdung + neem cake + spacing 12 x 12 cm	1.29^{a}	1.85^{ab}	3.07^{b}	6.38^{b}	7.59^{c}	11.57^{bc}	14.98^{b}	18.55^{a}
F		2.61*	7.02*	15.97*	14.31*	96.37*	58.69*	65.25*	65.91*
SEM		0.04	0.06	0.07	0.17	0.13	0.18	0.17	0.16
CD (0.05)		0.15	0.21	0.26	0.66	0.51	0.67	0.65	0.60

* Significant at 0.05; ** Significant at 0.01; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at $P = 0.05$

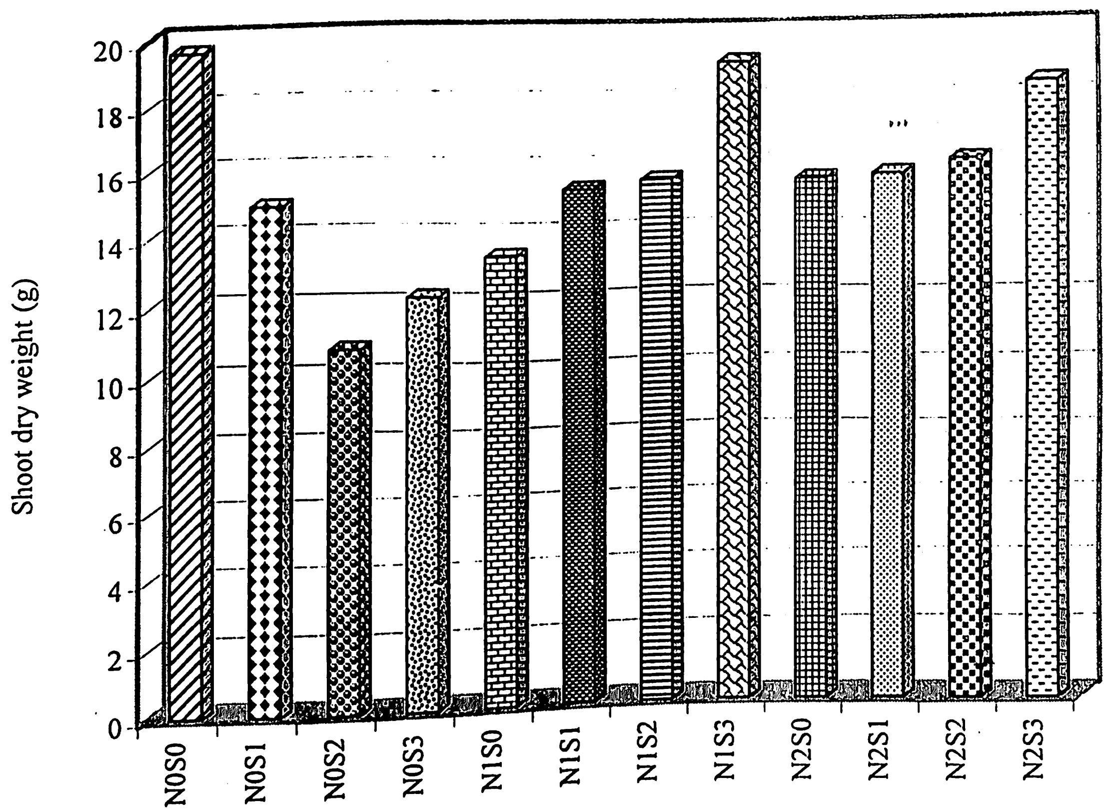

Fig. 6. Effect of nutrients and sowing methods on shoot dry weight (g) of teak seedlings at eighth month

(no nutrients and a spacing of 8 cm x 8 cm between seeds) with a shoot dry weight of 10.80 g at the end of the study period.

Table 12 shows the effect of nutrients and sowing methods on shoot dry weight of teak seedlings. Levels of nutrients were found to vary significantly with respect to shoot dry weight. The maximum shoot dry weight of 1.19 g at the first month of study period was observed by the nutrient level cowdung 0.4 kg m^{-2} and neem cake 0.2 kg m^{-2}. Minimum shoot dry weight of 0.98 g was recorded by the no nutrient level at the initial study period. However at the end of the study period the nutrient level cowdung 0.4 kg m^{-2} and the nutrient level cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} were at par with a shoot dry weight of 15.92 g and 16.55 g respectively.

The levels of sowing methods were found to vary significantly with respect to shoot dry weight. The maximum shoot dry weight of 1.14 g was recorded by the sowing method with a spacing of 12 cm x 12 cm between seedlings during the first month of study. It was followed by the broadcast sowing method with a shoot dry weight of 1.12 g. The minimum shoot dry weight of 0.94 g was recorded by the spacing 4 cm x 4 cm between seeds in the first month of the study period. However at the end of the study period the sowing method with a spacing of 12 cm x 12 cm between seeds (16.68 g) and broadcast sowing method (16.24 g) were at par. The least performing level of sowing method was found to be the spacing of 8 cm x 8 cm between seeds with a shoot dry weight of 14.22 g at the last month of the study period.

4.2.3 Root fresh weight

Data furnished in Table 13 reveal that in teak, the treatments exerted significant influence on fresh weight of roots except for the seventh month. Figure 7 illustrates the effect of nutrients and sowing methods on root fresh weight of seedlings. At the first month of observation maximum root fresh weight of 3.34 g was recorded by the treatment combination N_0S_0 (no nutrients and broadcast sowing method) which was at par with the treatment combination N_2S_3 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and a spacing of 12 cm x 12 cm between seeds) with the root

Table 12. Effect of nutrients and sowing methods on shoot dry weight (g) of teak seedlings at monthly intervals

Treatment	Months							
	1	2	3	4	5	6	7	8
Nutrient								
1. No nutrient (control)	0.93[b]	1.47[c]	2.57[b]	5.35	8.04[a]	11.92[a]	13.33[b]	14.43[b]
2. Cowdung	1.05[ab]	1.44[b]	2.90[a]	4.79	7.58[ab]	10.32[b]	12.92[b]	15.92[a]
3. Cowdung + Neem cake	1.19[a]	1.71[a]	2.91[a]	5.48	7.11[b]	10.69[b]	14.73[a]	16.55[a]
F test	7.14*	4.77*	5.58*	2.95[NS]	8.04*	15.12*	20.87*	32.63*
Sowing methods								
1.Broadcasting (control)	1.12[ab]	1.76[a]	2.97	5.85[a]	9.00[a]	12.21[a]	14.40[a]	16.24[a]
2. Spacing 4 cm x 4 cm	0.94[c]	1.39[b]	2.72	5.00[b]	7.43[b]	11.53[b]	13.93[ab]	15.38[b]
3. Spacing 8 cm x 8 cm	1.01[bc]	1.37[b]	2.69	4.81[b]	7.09[bc]	9.96[c]	12.83[c]	14.22[c]
4. Spacing 12 cm x 12 cm	1.14[a]	1.65[a]	2.79	5.17[b]	6.79[c]	10.20[c]	13.48[b]	16.68[a]
F test	2.90*	5.93*	1.76[NS]	3.45*	26.88*	18.71*	7.75*	24.24*
Nutrient vs spacing								
F test	2.61*	7.02*	15.97*	14.31*	96.37*	58.69*	65.25*	65.91*
SEM	0.10	0.06	0.07	0.17	0.13	0.18	0.17	0.16

* Significant at 0.05; ** Significant at 0.01; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at P = 0.05

Table 13. Effect of combination of nutrients and sowing methods on root fresh weight (g) of teak seedlings at monthly intervals

Treat-ment	Treatment details	Months							
		1	2	3	4	5	6	7	8
N_0S_0	No nutrients + broadcasting (control)	3.34^{a}	5.52^{a}	9.64^{a}	16.70^{a}	22.15^{a}	26.91^{a}	28.96	30.23^{b}
N_0S_1	No nutrients + spacing 4 x 4 cm	1.86^{f}	2.81^{g}	5.19^{e}	9.78^{e}	13.77^{e}	18.80^{d}	22.23	24.52^{c}
N_0S_2	No nutrients + spacing 8 x 8 cm	2.00^{ef}	2.99^{fg}	5.51^{e}	10.01^{e}	14.22^{de}	19.28^{cd}	22.61	25.01^{c}
N_0S_3	No nutrients + spacing 12 x 12cm	2.16^{def}	3.19^{efg}	5.83^{e}	10.61^{e}	15.05^{cde}	20.07^{bcd}	23.60	25.79^{c}
N_1S_0	Cowdung + broadcasting	2.70^{abcde}	4.15^{cdef}	6.20^{cde}	10.96^{cde}	14.70^{cde}	19.75^{cd}	29.98	31.23^{b}
N_1S_1	Cowdung + spacing 4 x 4 cm	2.21^{cdef}	3.25^{efg}	5.94^{e}	10.76^{de}	14.43^{cde}	20.02^{bcd}	23.10	24.54^{c}
N_1S_2	Cowdung + spacing 8 x 8 cm	2.31^{bcdef}	3.36^{defg}	6.04^{de}	10.86^{de}	14.53^{cde}	20.36^{bcd}	23.40	26.33^{c}
N_1S_3	Cowdung + spacing 12 x12 cm	2.75^{abcd}	4.70^{abc}	7.08^{bcd}	12.18^{bcd}	15.70^{bc}	20.63^{bc}	25.70	31.85^{ab}
N_2S_0	Cowdung + neem cake + broadcasting	2.80^{abcd}	4.27^{bcde}	7.22^{bc}	12.31^{bc}	15.28^{cd}	20.14^{bcd}	30.08	31.34^{b}
N_2S_1	Cowdung + neem cake + spacing 4 x 4 cm	2.98^{ab}	4.53^{abcd}	7.32^{b}	12.41^{b}	15.42^{cd}	20.26^{bcd}	26.64	31.45^{b}
N_2S_2	Cowdung + neem cake + spacing 8 x 8 cm	2.94^{abc}	5.20^{abc}	7.62^{b}	12.80^{b}	15.90^{bc}	20.94^{bc}	26.80	31.94^{ab}
N_2S_3	Cowdung + neem cake + spacing 12 x 12 cm	3.27^{a}	5.39^{ab}	7.90^{b}	13.52^{b}	16.83^{b}	21.66^{b}	26.59	33.54^{a}
F		3.18*	5.38*	12.71*	19.60*	28.78*	19.20*	1.79	11.78*
SEM		0.09	0.16	0.15	0.19	0.18	0.22	0.30	0.25
CD (0.05)		0.36	0.60	0.56	0.72	0.70	0.85	1.14	0.96

* Significant at 0.05; ** Significant at 0.01; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at P = 0.05

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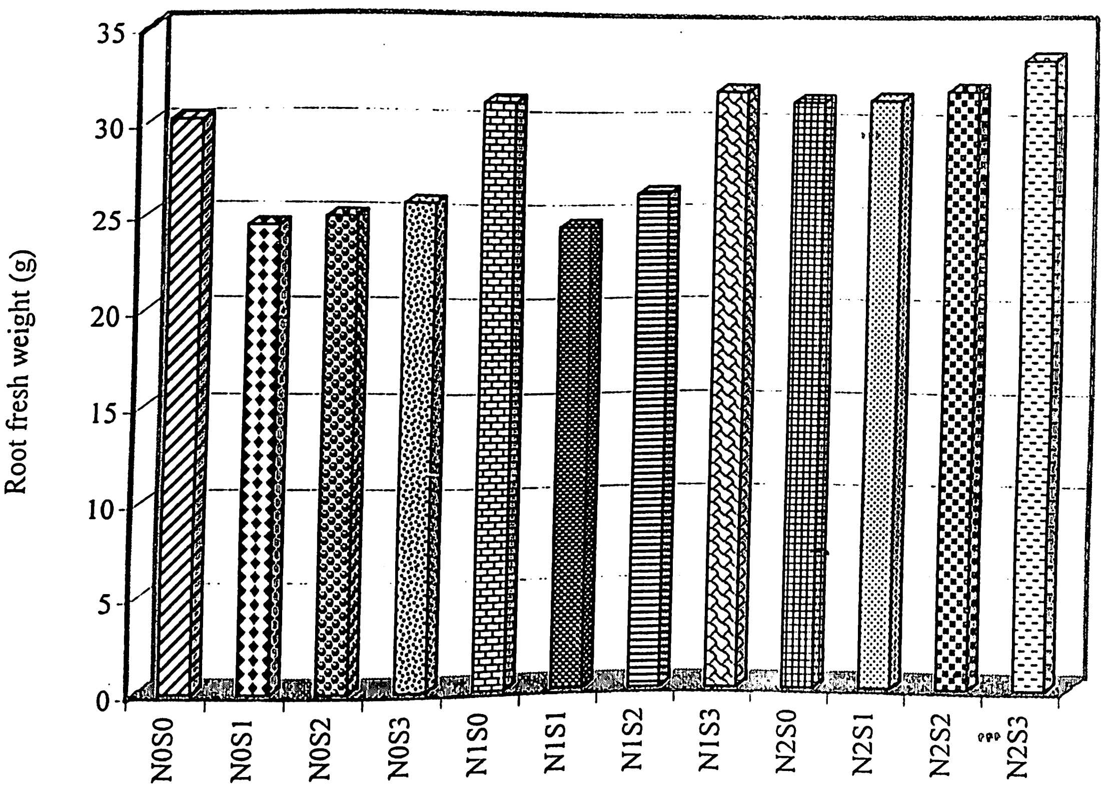

Fig. 7. Effect of nutrients and sowing methods on root fresh weight (g) of teak seedlings at eighth month

fresh weight of 3.27 g. The least performing treatment combinations were N_0S_1 (no nutrients and a spacing of 4 cm x 4 cm between seeds) with 1.86 g root fresh weight. At the end of the eighth month of study, the treatment N_2S_3 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and a spacing of 12 cm x 12 cm between seeds) recorded maximum root fresh weight of 33.54 g and the minimum fresh weight of 24.52 g was recorded by N_0S_1 (no nutrients and a spacing of 4 cm x 4 cm between seeds). It was followed by the treatments N_0S_0 (no nutrients and broadcast sowing method), N_1S_0 (cowdung 0.4 kg m^{-2} and broadcast sowing method), N_2S_0 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and broadcast sowing method) and N_2S_1 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and a spacing of 4 cm x 4 cm between seeds) which were at par. The minimum root fresh weight was showed by the treatments N_0S_1 (no nutrients and a spacing of 4 cm x 4 cm between seeds), N_0S_2 (no nutrients and a spacing of 8 cm x 8 cm between seeds), N_0S_3 (no nutrients and a spacing of 12 cm x 12 cm between seeds), N_1S_1 (cowdung 0.4 kg m^{-2} and a spacing of 4 cm x 4 cm between seeds) and N_1S_2 (cowdung 0.4 kg m^{-2} with a spacing of 8 cm x 8 cm between seeds) which were at par.

The data furnished in Table 14 reveal that the nutrient exerted significant influence on fresh weight of roots. The nutrient treatment cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} recorded maximum root fresh weight (3.00 g) which was followed by cowdung 0.4 kg m^{-2} alone treatment in the first month. The same trend of root fresh weight continued as the study progressed and at the end of eighth month maximum root fresh weight (32.97 g) was recorded by the treatment cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2}. The treatments no nutrients and cowdung 0.4 kg m^{-2} treatments were at par during the first four months of the study period and in the seventh month of observation.

Data furnished in Table 14 reveal that the sowing methods also exerted significant influence on root fresh weight of teak seedlings. Maximum root fresh weight of 2.95 g was recorded by the broadcast sowing method which was followed by 12 cm x 12 cm spacing between seeds in the first month of observation. The minimum root fresh weight of 2.35 g was recorded by the sowing method of 4 cm x

Table 14. Effect of nutrients and sowing methods on root fresh weight (g) of teak seedlings at monthly intervals

Treatment	Months							
	1	2	3	4	5	6	7	8
Nutrient								
1. No nutrient (control)	2.34[b]	3.63[b]	6.54[b]	11.78[b]	16.30[a]	21.27[a]	24.35[b]	26.39[c]
2. Cowdung	2.49[b]	3.87[b]	6.32[b]	11.19[b]	14.84[b]	20.19[b]	25.55[b]	28.49[b]
3. Cowdung + Neem cake	2.10[a]	4.85[a]	7.51[a]	12.76[a]	15.86[a]	20.75[ab]	27.53[a]	32.10[a]
F test	8.88*	11.38*	12.43*	11.89*	11.19*	3.92*	19.35*	86.53*
Sowing methods								
1.Broadcasting (control)	2.95[a]	4.65[a]	7.69[a]	13.32[a]	17.38[c]	22.27[a]	29.67[a]	30.93[a]
2. Spacing 4 cm x 4 cm	2.35[b]	3.53[b]	6.15[c]	10.98[c]	14.54[b]	19.70[c]	23.10[c]	26.84[c]
3. Spacing 8 cm x 8 cm	2.42[b]	3.85[b]	6.39[c]	11.22[c]	14.89[b]	20.19[bc]	24.27[c]	27.76[b]
4. Spacing 12 cm x 12 cm	2.73[a]	4.43[a]	6.94[b]	12.10[b]	15.86[a]	20.79[b]	25.30[b]	30.40[a]
F test	4.37*	5.42*	10.67*	15.86*	24.24*	12.61*	39.23*	31.19*
Nutrient vs spacing								
F test	3.18*	5.38*	12.71*	19.60*	28.78*	19.20*	1.79	11.78*
SEM	0.09	0.16	0.15	0.19	0.18	0.22	0.30	0.25

* Significant at 0.05; ** Significant at 0.01; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at P = 0.05

4 cm between seeds. The same trend continued upto the eighth month of observation with a maximum root fresh weight of 30.93 g in the broadcast sowing method. However the broadcast treatment and spacing 12 cm x 12 cm between seeds were at par during the first two months and last month of observation. The minimum root fresh weight of 26.84 g was recorded by the sowing method with the spacing of 4 cm x 4 cm between seeds in the eighth month of observation.

4.2.4 Root dry weight

The data furnished in Table 15 reveal that the nutrients and sowing methods exerted significant influence on root dry weight of teak seedlings during the study period except in the first month. Figure 8 graphically illustrates the effect of nutrients and sowing methods on root dry weight of teak seedlings. At the second month of observation the maximum root dry weight of 1.76 g was recorded by the treatment N_2S_3 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and a spacing of 12 cm x 12 cm between seeds) and the minimum root dry weight of 0.92 g was recorded by the treatment N_0S_2 (no nutrient and a spacing of 8 cm x 8 cm between seeds) followed by the treatment N_0S_1 (no nutrient and a spacing of 4 cm x 4 cm between seeds) with 0.95 g eventhough both were at par. N_1S_3 (cowdung 0.4 kg m^{-2} and a spacing of 12 cm x 12 cm between seeds) recorded maximum fresh weight of 19.17 g and N_0S_2 (no nutrients and a spacing of 8 cm x 8 cm between seeds) recorded minimum fresh weight of 10.13 g in the last month of observation. The treatments N_0S_0 (control), N_1S_3 (cowdung 0.4 kg m^{-2} and a spacing of 12 cm x 12 cm between seeds) and N_2S_3 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and a spacing of 12 cm x 12 cm between seeds) which were at par, had the maximum root dry weight.

The data furnished in Table 16 shows the effect of nutrients and sowing methods on root dry weight of seedlings. Levels of nutrients were found to vary significantly with respect to root dry weight throughout except in the fifth month of observation. The maximum root dry weight of 1.13 g was recorded by the treatment cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} in the first month of observation which

Table 15. Effect of combination of nutrients and sowing methods on root dry weight (g) of teak seedlings at monthly intervals

Treat-ment	Treatment details	Months 1	2	3	4	5	6	7	8
N_0S_0	No nutrients + broadcasting (control)	1.03	1.64^{ab}	2.88^{a}	6.11^{a}	12.83^{a}	15.24^{a}	18.15^{a}	18.94^{a}
N_0S_1	No nutrients + spacing 4 x 4 cm	0.61	0.95^{d}	1.66^{d}	2.42^{e}	4.53^{f}	8.89^{ef}	11.90^{c}	13.63^{c}
N_0S_2	No nutrients + spacing 8 x 8 cm	0.68	0.93^{d}	1.92^{cd}	3.49^{d}	4.96^{f}	7.22^{g}	8.78^{d}	10.13^{d}
N_0S_3	No nutrients + spacing 12 x 12cm	0.82	1.12^{cd}	1.99^{cd}	3.56^{d}	5.18^{ef}	7.84^{fg}	9.03^{d}	11.03^{d}
N_1S_0	Cowdung + broadcasting	0.94	1.47^{abc}	2.22^{bc}	3.71^{d}	5.33^{ef}	7.95^{fg}	8.97^{d}	13.34^{c}
N_1S_1	Cowdung + spacing 4 x 4 cm	0.86	1.32^{bc}	2.62^{ab}	4.58^{c}	5.96^{de}	9.35^{de}	12.50^{c}	12.99^{c}
N_1S_2	Cowdung + spacing 8 x 8 cm	0.97	1.30^{bc}	2.95^{a}	5.28^{b}	8.88^{b}	10.88^{bc}	14.22^{b}	15.39^{b}
N_1S_3	Cowdung + spacing 12 x12 cm	1.17	1.77^{a}	3.07^{a}	5.11^{bc}	6.57^{cd}	9.90^{cde}	14.43^{b}	19.17^{a}
N_2S_0	Cowdung + neem cake + broadcasting	1.03	1.50^{ab}	2.67^{ab}	5.05^{bc}	6.75^{cd}	10.06^{cde}	14.38^{b}	15.49^{b}
N_2S_1	Cowdung + neem cake + spacing 4 x 4 cm	1.10	1.59^{ab}	2.76^{a}	5.11^{bc}	6.81^{cd}	10.16^{cd}	14.45^{b}	15.41^{b}
N_2S_2	Cowdung + neem cake + spacing 8 x 8 cm	1.16	1.66^{ab}	2.87^{a}	5.17^{b}	6.87^{cd}	10.66^{bc}	14.53^{b}	16.10^{b}
N_2S_3	Cowdung + neem cake + spacing 12 x 12 cm	1.22	1.76^{a}	2.98^{a}	5.26^{b}	6.97^{c}	11.50^{b}	14.85^{b}	18.44^{a}
F		1.85^{NS}	3.92*	7.50*	37.40*	75.40*	44.22*	84.80*	93.86*
SEM		0.04	0.05	0.07	0.08	0.13	0.16	0.16	0.14
CD (0.05)		0.15	0.18	0.25	0.29	0.48	0.62	0.59	0.52

* Significant at 0.05; ** Significant at 0.01; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at P = 0.05

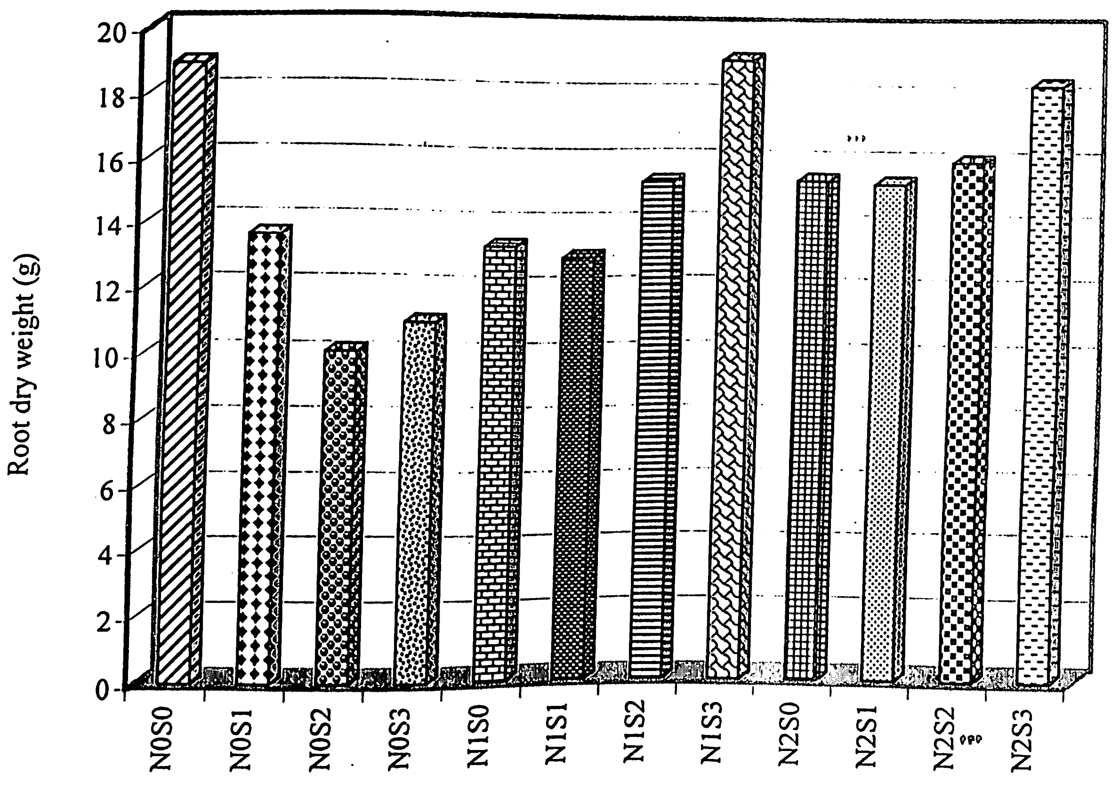

Fig. 8. Effect of nutrients and sowing methods on root dry weight (g) of teak seedlings at eighth month

Table 16. Effect of nutrients and sowing methods on root dry weight (g) of teak seedlings at monthly intervals

Treatment	Months							
	1	2	3	4	5	6	7	8
Nutrient								
1. No nutrient (control)	0.79^{b}	1.15^{b}	2.11^{b}	3.90^{c}	6.88	9.80^{b}	11.96^{b}	13.43^{c}
2. Cowdung	0.99^{a}	1.47^{a}	2.71^{a}	4.67^{b}	6.68	9.52^{b}	12.53^{b}	15.23^{b}
3. Cowdung + Neem cake	1.13^{a}	1.63^{a}	2.82^{a}	5.15^{a}	6.85	10.60^{a}	14.55^{a}	16.36^{a}
F test	12.85*	16.91*	22.60*	47.50*	0.46^{NS}	7.94*	51.34*	77.17*
Sowing methods								
1.Broadcasting (control)	0.10	1.53^{a}	2.59	4.96^{a}	8.30^{a}	11.08^{a}	13.83^{a}	15.92^{a}
2. Spacing 4 cm x 4 cm	0.86	1.29^{b}	2.35	4.04^{c}	5.77^{d}	9.47^{b}	12.95^{b}	14.01^{b}
3. Spacing 8 cm x 8 cm	0.94	1.29^{b}	2.58	4.65^{b}	6.90^{b}	9.59^{b}	12.51^{b}	13.87^{b}
4. Spacing 12 cm x 12 cm	1.07	1.55^{a}	2.68	4.65^{b}	6.24^{c}	9.75^{b}	12.77^{b}	16.21^{a}
F test	2.72^{NS}	4.64*	2.35^{NS}	13.22*	37.82*	10.74*	6.87*	40.52*
Nutrient vs spacing								
F test	1.85	3.92*	7.50*	37.40*	75.40*	44.22*	84.80*	93.86*
SEM	0.04	0.05	0.07	0.08	0.13	0.16	0.16	0.14

* Significant at 0.05; ** Significant at 0.01; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at P = 0.05

was at par with the treatment cowdung 0.4 kg m^{-2} with 0.99 g of root dry weight. The minimum root dry weight of 0.79 g was recorded by the treatment no nutrients.

Data furnished in Table 16 revealed that treatment with cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} treatment had maximum root dry weight of 16.36 g at the end of the study period. The best nutrient combination was found to be cowdung 0.4 kg m^{-2} and neem cake 0.2 kg m^{-2} throughout the study period.

Table 16 reveals that sowing methods also had significant influence on root dry weight. Levels of sowing methods were found to vary significantly with respect to root dry weight except for the first and third month of observation. The best sowing method in the second month of observation was spacing 12 cm x 12 cm between seeds with 1.55 g root dry weight which was at par with broadcast sowing method with 1.53 g root dry weight. The minimum root dry weight 1.29 g was recorded by the spacing 4 cm x 4 cm between seeds and spacing 8 cm x 8 cm between seeds. At the end of the eighth month 16.21 g root dry weight was recorded by the spacing 12 cm x 12 cm between seeds which was at par with the broadcast sowing method with 15.92 g root dry weight. The best sowing method was broadcast sowing method and dibbling in lines 12 cm x 12 cm between seeds were at par.

4.3 ANATOMICAL PROPERTIES

The results of anatomical observations such as tissue proportion, vessel diameter, vessel frequency and ring width of teak seedlings as influenced by nutrients and sowing methods are presented in Table 17 to 30 and Figures 9 to15. Plate 2 shows the initiation of secondary growth in teak seedlings and Plate 3 shows the later stage of wood formation with periderm.

4.3.1 Tissue proportion

The proportion of various tissues such as parenchyma, vessel, ray and fibre percentage were measured and analysis of variance was carried out to find out the effect of nutrients and sowing methods on the tissue proportion of teak seedlings. In

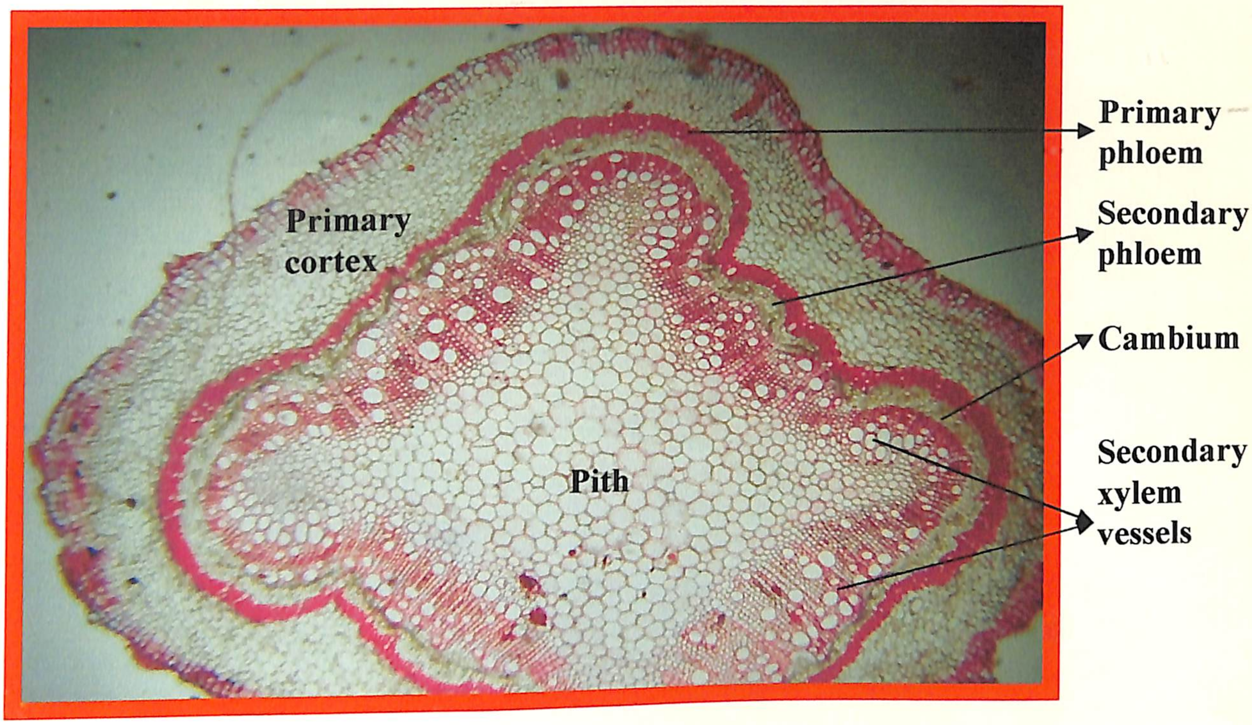

Plate 2. Initiation of secondary growth at first month of observation (T.S. 10x)

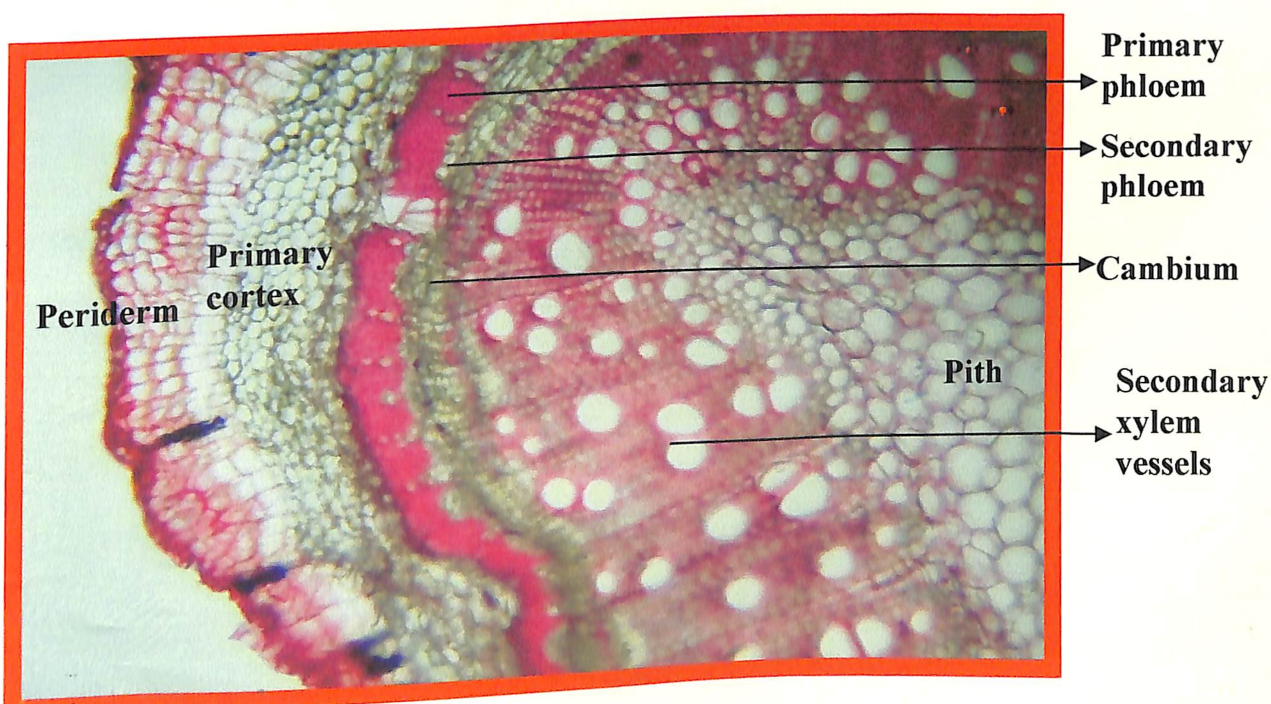

Plate 3. Later stage of wood formation with periderm at sixth month of observation (T.S. 10x)

the first month the proportion of vessel and xylem parenchyma were found to be more compared to the ray parenchyma cells. Gradually when the seedlings matured it was found that the proportion of xylem fibres increased and that of the other xylem tissues reduced proportionately for all the treatments. The effect of nutrients and spacing methods on tissue proportion of teak seedlings are given below.

4.3.1.1 Vessel percentage

Table 17 illustrates the effect of the treatment combinations of nutrients and sowing methods on vessel percentage of teak seedlings. Levels of nutrients and sowing methods were found to vary significantly in the sixth month of observation. In the very first month of observation mean vessel percentage was highest (52 %) for the treatment N_1S_1 (cowdung 0.4 kg m^{-2} and dibbling in lines of 4 cm x 4 cm between seeds) followed by N_2S_1 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and dibbling in lines of 4 cm x 4 cm between seeds). The lowest vessel percentage was shown by N_0S_3 (no nutrients and a spacing of 12 cm x 12 cm between seeds). As the teak seedlings, grew up the proportion of vessels was found reduced. In the first five months vessel percentage differed significantly but in the last three months it was found that there was no significant difference between treatments. The effect of various treatments on vessel percentage is illustrated in Figure 9. At the end of the study period however there was no significant difference between treatments with respect to this character.

Table 18 shows the effect of nutrients and sowing methods on vessel percentage of seedlings. Levels of nutrients were found to vary significantly only during the first third and seventh month of study. In the first month of the study cowdung 0.4 kg m^{-2} recorded maximum vessel percentage of 32 per cent which was at par with the cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} nutrient level with vessel percentage of 29 per cent. Vessel percentage was found more in the cowdung 0.4 kg m^{-2} treatment the value being 13.28 per cent in the seventh month of observation.

Levels of sowing methods were found to vary significantly during the first three months and last two months of observation (Table 18). The sowing method

Table 17. Effect of combination of nutrients and sowing methods on vessel percentage of teak seedlings at monthly intervals

Treat-ment	Treatment details	Months							
		1	2	3	4	5	6	7	8
N_0S_0	No nutrients + broadcasting (control)	20.87^{cd}	30.87^{bc}	40.89^{a}	19.41^{a}	17.82^{a}	14.20	15.07	11.30
N_0S_1	No nutrients + spacing 4 x 4 cm	20.87^{cd}	23.65^{cd}	24.50^{ab}	12.69^{ab}	15.49^{ab}	10.32	10.69	11.41
N_0S_2	No nutrients + spacing 8 x 8 cm	17.31^{d}	17.51^{def}	13.20^{bc}	11.15^{b}	9.19^{b}	10.25	8.77	7.91
N_0S_3	No nutrients + spacing 12 x 12cm	15.23^{d}	12.56^{f}	15.06^{cd}	11.92^{ab}	11.70^{ab}	11.80	11.88	10.47
N_1S_0	Cowdung + broadcasting	16.66^{d}	19.22^{def}	10.74^{de}	11.21^{b}	9.91^{b}	7.57	18.98	11.47
N_1S_1	Cowdung + spacing 4 x 4 cm	52.24^{a}	42.33^{a}	18.28^{def}	12.98^{ab}	12.00^{ab}	11.61	9.65	14.53
N_1S_2	Cowdung + spacing 8 x 8 cm	23.24^{c}	15.14^{ef}	22.08^{def}	18.91^{a}	14.32^{ab}	9.93	11.14	6.94
N_1S_3	Cowdung + spacing 12 x12 cm	36.14^{b}	11.59^{f}	16.22^{def}	15.42^{ab}	18.09^{a}	8.67	13.38	9.03
N_2S_0	Cowdung + neem cake + broadcasting	16.21^{d}	14.77^{ef}	14.67^{ef}	10.69^{b}	12.90^{ab}	12.3	10.43	11.95
N_2S_1	Cowdung + neem cake + spacing 4 x 4 cm	51.50^{a}	35.63^{ab}	23.11^{ef}	13.60^{ab}	17.85^{a}	13.87	11.15	11.16
N_2S_2	Cowdung + neem cake + spacing 8 x 8 cm	25.67^{c}	21.94^{de}	17.73^{f}	12.32^{ab}	14.15^{ab}	10.95	9.96	8.37
N_2S_3	Cowdung + neem cake + spacing 12 x 12 cm	23.96^{c}	19.06^{f}	12.55^{f}	12.72^{ab}	11.51^{ab}	10.24	8.74	9.02
F		19.94*	8.84*	10.98*	2.58*	3.41*	1.60^{NS}	2.23^{NS}	1.61^{NS}
SEM		0.77	1.08	1.12	0.92	0.87	0.60	0.62	0.40
CD (0.05)		2.93	4.10	4.26	3.52	3.33	2.30	2.37	1.54

* Significant at 0.05; ** Significant at 0.01; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at P = 0.05

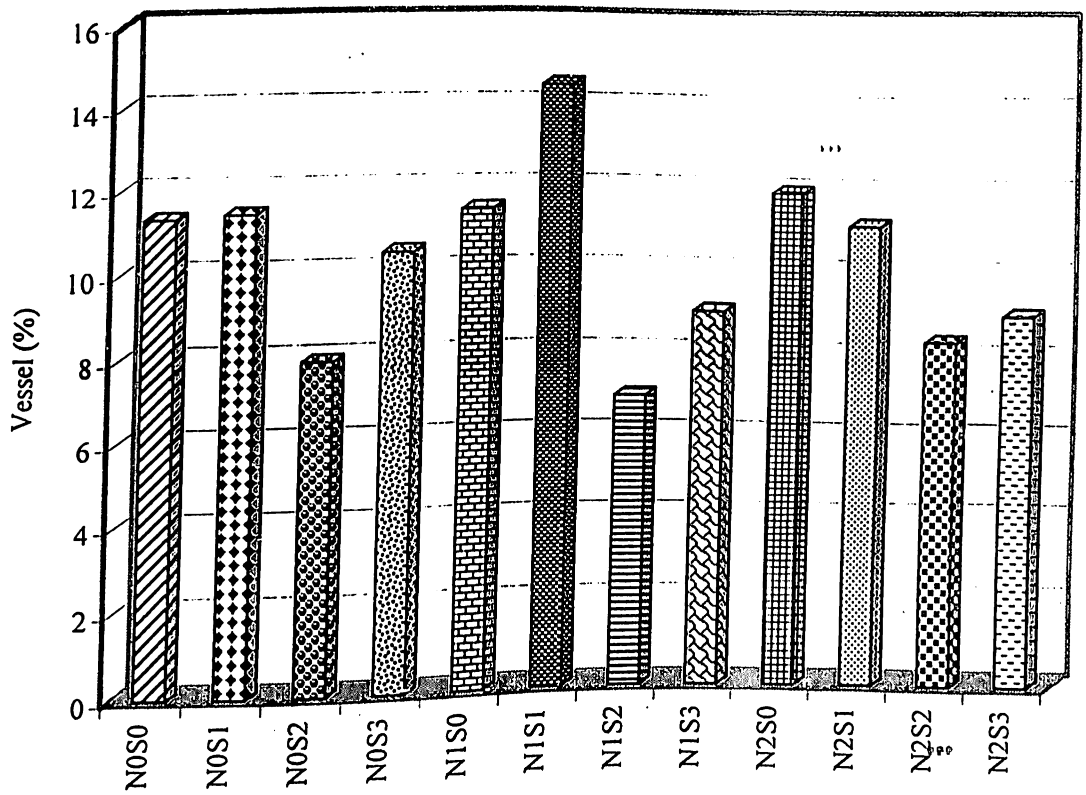

Fig. 9. Effect of nutrients and sowing methods on vessel percentage of teak seedlings at eighth month

Table 18. Effect of nutrients and sowing methods on vessel percentage of teak seedlings at monthly intervals

Treatment	Months							
	1	2	3	4	5	6	7	8
Nutrient								
1. No nutrient (control)	19.44^{b}	21.15	23.41^{a}	13.79	13.55	11.64	11.60^{ab}	10.27
2. Cowdung	32.07^{a}	22.07	16.83^{b}	14.63	13.58	9.44	13.29^{a}	10.50
3. Cowdung + Neem cake	29.33^{a}	22.85	17.02^{b}	12.33	14.10	11.85	10.07^{b}	10.13
F test	50.01*	0.42^{NS}	7.52*	1.06^{NS}	0.08^{NS}	3.25^{NS}	4.46*	0.14^{NS}
Sowing methods								
1.Broadcasting (control)	17.91^{d}	21.62^{b}	22.10^{a}	13.77	13.54	11.37	14.83^{a}	11.57^{a}
2. Spacing 4 cm x 4 cm	42.70^{a}	33.87^{a}	21.96^{a}	13.09	15.12	11.94	10.50^{b}	12.37^{a}
3. Spacing 8 cm x 8 cm	22.07^{c}	18.20^{c}	17.67^{b}	14.12	12.55	10.38	9.96^{b}	7.74^{c}
4. Spacing 12 cm x 12 cm	25.11^{b}	14.40^{d}	14.61^{b}	13.35	13.77	10.24	11.33^{b}	9.51^{b}
F test	101.18*	30.69*	5.27*	0.12^{NS}	0.73^{NS}	0.91^{NS}	6.20*	13.30*
Nutrient vs spacing								
F test	19.94*	8.84*	10.98*	2.58*	3.41*	1.60^{NS}	2.23^{NS}	1.61^{NS}
SEM	0.77	1.08	1.12	0.92	0.87	0.60	0.62	0.40

* Significant at 0.05; ** Significant at 0.01; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at P = 0.05

levels were non significant during fourth, fifth and sixth month of observation. In the first month of study, the spacingof 4 cm x 4 cm between seeds recorded the maximum vessel percentage of 42.70 per cent. The minimum vessel percentage was recorded by the broadcast sowing method with vessel percentage of 17.90 per cent in the first month of observation. The maximum vessel percentage (12.37%) was recorded by the sowing method with a spacing of 4 cm x 4 cm between seeds which was at par with the broadcast sowing method.

While considering the different sowing levels, highest vessel percentage was found in the 4 cm x 4 cm spacing treatment which is a densely populated treatment with a value of 42.70 per cent in the first month and in the last month 12.37 per cent.

4.3.1.2 *Parenchyma percentage*

Table 19 shows the effect of nutrients and sowing methods on parenchyma percentage of teak seedlings and Figure 10 graphically illustrates the data. Levels of nutrients and sowing methods were found to vary significantly except for the fifth month. As shown in the Table 19 maximum parenchyma percentage (34.82%) was observed for the treatment N_0S_1 (no nutrients and a spacing of 4 cm x 4 cm between seeds) in the first month and lowest (13.97%) was found in the treatment combination N_0S_0 (no nutrients and broadcast sowing method. But in the eighth month maximum parenchyma percentage (16.85%) was found in the treatment N_1S_1 (cowdung 0.4 kg m^{-2} and a spacing of 4 cm x 4 cm between seeds) in the first month of study and during the last month of study lowest parenchyma percentage was recorded by the treatment N_0S_0 (no nutrients and broadcast sowing method) with a parenchyma percentage of 5.62 per cent.

Table 20 showed the effect of nutrients and sowing methods on parenchyma percentage of seedlings. Levels of nutrients were found to vary significantly during the first, third and fourth month of study. The levels of nutrients were non significant after fourth month of study. Considering the effect of nutrients, parenchyma percentage of teak seedlings differed significantly in the first month and

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Table 19. Effect of combination of nutrients and sowing methods on parenchyma percentage of teak seedlings at monthly intervals

Treat-ment	Treatment details	Months							
		1	2	3	4	5	6	7	8
N_0S_0	No nutrients + broadcasting (control)	13.97[d]	14.03[bc]	10.47[a]	6.92[d]	7.77	5.83[e]	6.43[c]	5.63[f]
N_0S_1	No nutrients + spacing 4 x 4 cm	34.80[a]	32.44[cd]	24.97[b]	12.59[c]	14.48	8.06[cde]	13.76[abcd]	14.73[ab]
N_0S_2	No nutrients + spacing 8 x 8 cm	18.23[cd]	15.34[def]	16.65[de]	12.18[c]	10.00	12.79[ab]	10.72[cde]	11.91[bcd]
N_0S_3	No nutrients + spacing 12 x 12cm	15.11[d]	19.02[f]	16.26[cde]	11.96[c]	12.82	16.74[a]	16.37[a]	10.63[cd]
N_1S_0	Cowdung + broadcasting	19.07[cd]	17.97[def]	10.526[e]	11.36[c]	14.07	11.39[bc]	15.66[ab]	11.39[cd]
N_1S_1	Cowdung + spacing 4 x 4 cm	20.08[cd]	24.14[a]	26.03[bcde]	13.56[bc]	12.94	13.79[ab]	11.78[bcd]	16.85[a]
N_1S_2	Cowdung + spacing 8 x 8 cm	31.70[a]	18.05[ef]	24.77[bcd]	21.41[a]	14.19	12.54[ab]	11.11[bcd]	10.33[cd]
N_1S_3	Cowdung + spacing 12 x12 cm	28.80[ab]	14.77[f]	16.25[bcde]	16.90[b]	13.61	6.39[de]	13.76[abcd]	5.70[f]
N_2S_0	Cowdung + neem cake + broadcasting	17.58[cd]	16.05[ef]	17.13[cde]	10.69[cd]	9.25	14.14[ab]	11.47[bcd]	12.54[bc]
N_2S_1	Cowdung + neem cake + spacing 4 x 4 cm	24.15[bc]	22.57[ab]	15.67[bc]	13.05[bc]	18.65	10.91[bc]	14.27[abc]	12.70[bc]
N_2S_2	Cowdung + neem cake + spacing 8 x 8 cm	23.23[bc]	21.99[de]	17.09[bcde]	11.62[c]	14.15	12.87[ab]	9.42[de]	7.44[ef]
N_2S_3	Cowdung + neem cake + spacing 12 x 12 cm	19.11[cd]	16.13[def]	11.07[e]	11.97[c]	11.84	10.10[bcd]	9.49[de]	9.41[de]
F		10.75*	3.81*	12.50*	3.23*	1.87[NS]	9.83*	5.45*	11.63*
SEM		0.84	0.82	0.52	0.54	0.75	0.54	0.57	0.38
CD(0.05)		3.22	3.11	1.96	2.06	2.86	2.07	2.18	1.43

* Significant at 0.05; ** Significant at 0.01; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at $P = 0.05$

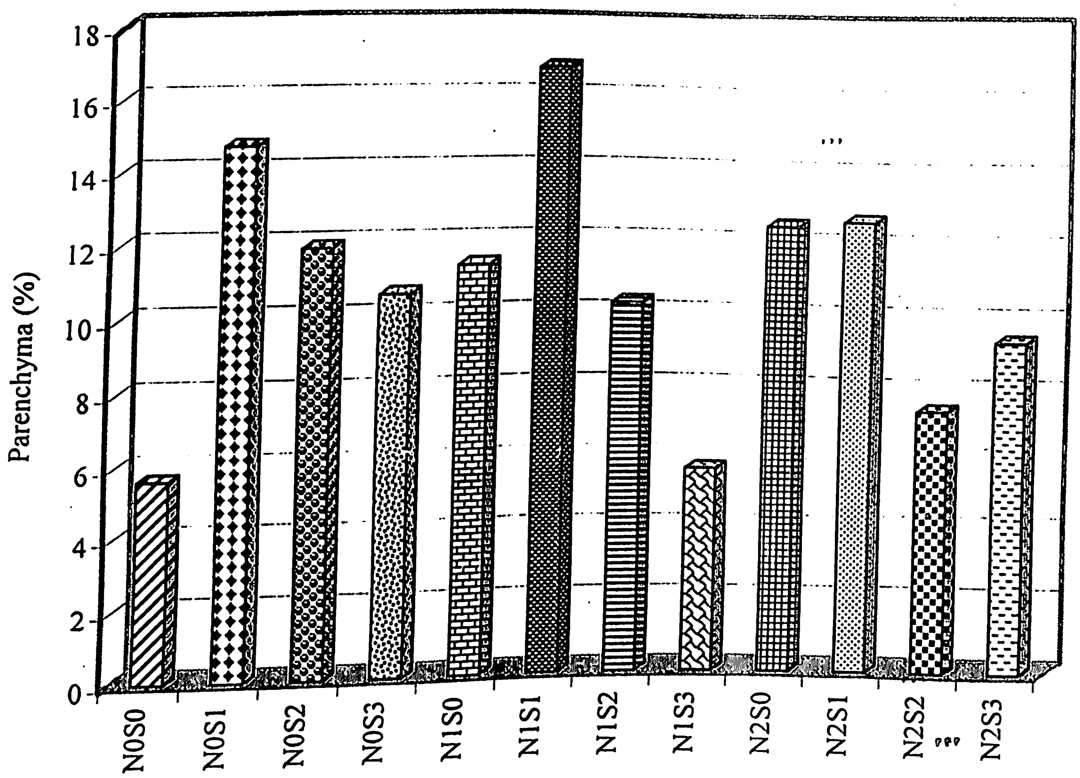

Fig. 10. Effect of nutrients and sowing methods on parenchyma percentage of teak seedlings at eighth month

Table 20. Effect of nutrients and sowing methods on parenchyma percentage of teak seedlings at monthly intervals

Treatment	Months							
	1	2	3	4	5	6	7	8
Nutrient								
1. No nutrient (control)	20.53[b]	20.21	17.09[b]	10.91[b]	11.27	10.85	11.82	10.72
2. Cowdung	24.91[a]	18.73	19.39[a]	15.81[a]	13.70	11.03	13.08	11.07
3. Cowdung + Neem cake	21.02[b]	19.18	15.24[b]	11.83[b]	13.47	12.00	11.16	10.52
F test	5.40*	0.57[NS]	10.88*	15.23*	2.15[NS]	0.87[NS]	1.93[NS]	0.36[NS]
Sowing methods								
1.Broadcasting (control)	16.88[c]	16.02[b]	12.71[d]	9.66[c]	10.36[c]	10.45	11.19[b]	9.85[b]
2. Spacing 4 cm x 4 cm	26.35[a]	26.38[a]	22.22[a]	13.07[b]	15.36[a]	10.92	13.27[a]	14.76[a]
3. Spacing 8 cm x 8 cm	24.39[a]	18.46[b]	19.50[b]	15.07[a]	12.78[b]	12.73	10.42[b]	9.90[b]
4. Spacing 12 cm x 12 cm	21.01[b]	16.64[b]	14.53[c]	13.61[ab]	12.76[b]	11.08	13.20[a]	8.58[c]
F test	12.13*	17.22*	36.38*	8.86*	3.71*	1.68[NS]	3.16*	26.42*
Nutrient vs spacing								
F test	10.75*	3.81*	12.50*	3.23*	1.87[NS]	9.83*	5.45*	11.63*
SEM	0.84	0.82	0.52	0.54	0.75	0.54	0.57	0.38

* Significant at 0.05; ** Significant at 0.01; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at P = 0.05

highest (24.91%) parenchyma percentage was for cowdung treatment (24.91%) which is followed by the treatment cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} (21.02%). But when the plants grew up, parenchyma percentage reduced and in the last four months differences were not significant at all.

The effect of sowing methods produced significant difference between treatments except at the sixth month of observation (Table 20). The highest (26.35%) parenchyma percentage was shown by the sowing method with the lowest spacing of 4 cm x 4 cm between seeds. This trend continued upto the last month. The lowest parenchyma percentage of 8.58 per cent was found in the widest spaced treatment with sowing method of spacing 12 cm x 12 cm between seeds in the last month of observation.

4.3.1.3 Fibre percentage

Table 21 and Figure 11 show the effect of nutrients and sowing methods on fibre percentage of teak seedlings. Effect of the various combinations of the nutrients and sowing methods were found to vary significantly between treatments except for the fourth month of observation. The highest (57%) fibre percentage was shown by N_0S_2 (no nutrients and a spacing of 8 cm x 8 cm between seeds) which was followed by N_0S_0 (no nutrients and broadcast sowing method) in the first month. The highest fibre percentage (75.12%) was shown by N_0S_0 (no nutrients and broadcast sowing method) followed by N_1S_2 (cowdung 0.4 kg m^{-2} and a spacing of 8 cm x 8 cm between seeds) (72.68%) in the last month. The treatments N_0S_0 (no nutrient with broadcast sowing method), N_0S_2 (no nutrients and a spacing of 8 cm x 8 cm between seeds), N_1S_2 (cowdung 0.4 kg m^{-2} and a spacing of 8 cm x 8 cm between seeds) were at par.

Table 22 illustrates the effect of nutrients on fibre percentage of teak seedlings. When considering the effect of nutrients on fibre percentage of teak seedlings, it was found non significant at second, fifth, sixth and eighth months and at all other months the treatments significantly differed. The maximum fibre percentage (47.85%) was shown by the no nutrient treatment in the first month but in the seventh

Table 21. Effect of combination of nutrients and sowing methods on fibre percentage of teak seedlings at monthly intervals

Treat-ment	Treatment details	Months							
		1	2	3	4	5	6	7	8
N_0S_0	No nutrients + broadcasting (control)	56.27^{a}	41.94^{cd}	39.99^{d}	61.97	56.05^{abc}	67.98^{abc}	63.03^{ab}	75.12^{a}
N_0S_1	No nutrients + spacing 4 x 4 cm	34.32^{de}	36.38^{de}	39.74^{d}	65.58	56.26^{abc}	66.48^{abcd}	66.16^{ab}	60.23^{c}
N_0S_2	No nutrients + spacing 8 x 8 cm	57.00^{a}	59.48^{ab}	56.88^{abc}	64.62	68.85^{a}	66.69^{abcd}	63.79^{ab}	72.23^{a}
N_0S_3	No nutrients + spacing 12 x 12cm	43.81^{bc}	52.27^{abc}	47.49^{cd}	64.26	52.15^{bc}	58.30^{de}	57.58^{bc}	63.06^{c}
N_1S_0	Cowdung + broadcasting	49.20^{ab}	48.58^{bcd}	57.52^{abc}	59.78	61.03^{ab}	68.54^{abc}	52.36^{c}	63.35^{c}
N_1S_1	Cowdung + spacing 4 x 4 cm	17.90^{f}	21.52^{f}	38.35^{d}	60.70	62.28^{ab}	56.43^{e}	62.28^{ab}	59.35^{c}
N_1S_2	Cowdung + spacing 8 x 8 cm	38.99^{cd}	49.71^{bcd}	36.69^{d}	46.70	52.34^{bc}	62.65^{bcde}	62.87^{ab}	72.68^{a}
N_1S_3	Cowdung + spacing 12 x12 cm	27.62^{e}	65.07^{a}	59.33^{ab}	56.34	50.17^{bc}	72.43^{a}	59.48^{bc}	64.45^{bc}
N_2S_0	Cowdung + neem cake + broadcasting	49.10^{ab}	52.76^{ab}	55.85^{abc}	67.31	58.90^{abc}	61.34^{cde}	65.53^{ab}	63.98^{bc}
N_2S_1	Cowdung + neem cake + spacing 4 x 4 cm	14.57^{f}	26.60^{ef}	48.04^{bcd}	57.96	48.13^{c}	60.80^{cde}	59.33^{bc}	61.72^{c}
N_2S_2	Cowdung + neem cake + spacing 8 x 8 cm	35.48^{de}	42.39^{cd}	54.54^{abc}	62.26	62.02^{ab}	63.25^{bcde}	70.63^{a}	71.56^{a}
N_2S_3	Cowdung + neem cake + spacing 12 x 12 cm	40.52^{cd}	47.54^{bcd}	61.83^{a}	59.99	61.12^{ab}	71.24^{ab}	70.12^{a}	69.67^{ab}
F		3.88*	3.81*	5.40*	2.19^{NS}	3.42*	4.79*	2.66*	4.29*
SEM		1.09	1.76	1.48	1.31	1.59	1.11	1.24	0.81
CD (0.05)		4.17	6.72	5.63	5.01	6.07	4.25	4.71	3.08

* Significant at 0.05; ** Significant at 0.01; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at $P = 0.05$

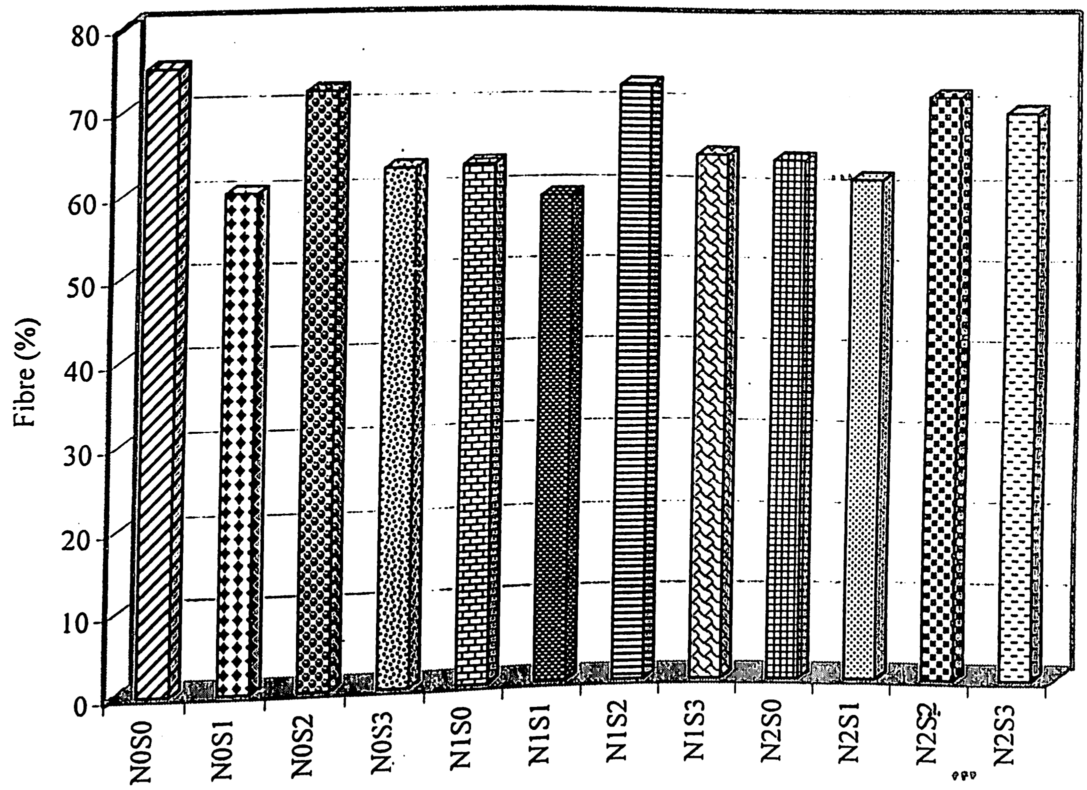

Fig. 11. Effect of nutrients and sowing methods on fibre percentage of teak seedlings at eighth month

Table 22. Effect of nutrients and sowing methods on fibre percentage of teak seedlings at monthly intervals

Treatment	Months							
	1	2	3	4	5	6	7	8
Nutrient								
1. No nutrient (control)	47.85^{a}	47.52	46.02^{b}	64.11^{a}	58.33	64.86	62.64^{ab}	67.66
2. Cowdung	33.43^{b}	46.22	47.97^{b}	55.88^{b}	56.46	89.01	59.25^{b}	64.96
3. Cowdung + Neem cake	34.92^{b}	42.32	55.07^{a}	61.88^{a}	57.54	64.16	66.40^{a}	66.73
F test	35.09*	1.57^{NS}	6.94*	7.00*	0.23^{NS}	1.03^{NS}	5.60*	1.93^{NS}
Sowing methods								
1.Broadcasting (control)	51.52^{a}	47.76^{b}	51.12^{b}	63.02	58.66	65.95	60.31	67.48^{b}
2. Spacing 4 cm x 4 cm	22.26^{d}	28.17^{c}	42.04^{c}	61.41	55.56	93.24	62.59	60.44^{c}
3. Spacing 8 cm x 8 cm	43.83^{b}	50.53^{ab}	49.37^{b}	57.86	61.07	64.20	65.76	72.15^{a}
4. Spacing 12 cm x 12 cm	37.32^{c}	54.96^{a}	56.22^{a}	60.20	54.48	67.32	62.40	65.73^{b}
F test	64.54*	22.53*	7.91*	1.37^{NS}	1.78^{NS}	0.73^{NS}	1.66^{NS}	18.00*
Nutrient vs spacing								
F test	3.88*	3.81*	5.40*	2.19	3.42*	4.79*	2.66*	4.29*
SEM	1.09	1.76	1.48	1.31	1.59	1.11	1.24	0.81

* Significant at 0.05; ** Significant at 0.01; NS - Non significant
Values sharing same alphabets do not differ significantly between themselves at P = 0.05

month, fibre percentage was higher (66.40%) in the cowdung 0.4 kg m^{-2} and neem cake 0.2 kg m^{-2} treatment.

Table 22 shows the effect of nutrients and sowing methods on fibre percentage of teak seedlings. Levels of sowing methods were found to vary significantly during the first, second, third and eighth month of observation. In the initial three months the best performing sowing method was broadcasting with a fibre percentage of 51.52 per cent at the first month and the least performing one was 4 cm x 4 cm with a fibre percentage of 22.26 per cent. In the last month, the best treatment was 8 cm x 8 cm spacing with a fibre percentage of 72.15 per cent and least performing one was with a spacing of 4 cm x 4 cm between seeds with a fibre percentage of 60.44 per cent.

4.3.1.4 Ray percentage

Table 23 and Figure 12 illustrates the effect of nutrients and sowing methods on fibre percentage of teak seedlings. Ray percentage of teak seedlings differed significantly except at the fourth, fifth and sixth months respectively. The maximum ray percentage was shown by N_0S_3 (no nutrients and a spacing of 12 cm x 12 cm between seeds) (25.85%) and minimum was recorded by N_1S_2 (cowdung 0.4 kg m^{-2} and a spacing of 8 cm x 8 cm between seeds) (6.07%) in the first month. In the eighth month the maximum ray percentage was shown by N_1S_3 (cowdung 0.4 kg m^{-2} and a spacing of 12 cm x 12 cm between seeds) (20.87%) and minimum was recorded by the treatment N_0S_0 (no nutrients and broadcast sowing method) (7.95%).

Table 24 illustrates the effect of nutrients and sowing methods on ray percentage of teak seedlings. The nutrient produced the same effect on ray percentage of teak seedling as that of the nutrient and sowing method combination. All the treatments were found significant except for the fifth, sixth and seventh months. The maximum (14.27%) ray percentage was found in the cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} treatment in the first month and the least ray percentage of 9.59 per cent was observed in the cowdung 0.4 kg m^{-2} alone treatment in that month. But in the last month the maximum ray percentage was showed by cowdung 0.4 kg m^{-2} treatment

Table 23. Effect of combination of nutrients and sowing methods on ray percentage of teak seedlings at monthly intervals

Treat-ment	Treatment details	Months							
		1	2	3	4	5	6	7	8
N_0S_0	No nutrients + broadcasting (control)	8.89^{d}	14.25^{abc}	8.66^{f}	11.70	18.35	12.00	15.47^{ab}	7.95^{e}
N_0S_1	No nutrients + spacing 4 x 4 cm	6.49^{d}	7.53^{c}	10.80^{ef}	9.14	13.77	15.14	9.39^{c}	13.63^{bc}
N_0S_2	No nutrients + spacing 8 x 8 cm	7.47^{d}	7.67^{c}	13.27^{cde}	12.06	11.96	10.28	16.72^{a}	7.96^{e}
N_0S_3	No nutrients + spacing 12 x 12cm	25.85^{a}	16.13^{a}	21.19^{a}	11.86	23.33	13.15	14.17^{abc}	15.84^{b}
N_1S_0	Cowdung + broadcasting	15.07^{b}	14.24^{abc}	21.22^{a}	17.65	14.99	12.50	13.40^{abc}	13.79^{bc}
N_1S_1	Cowdung + spacing 4 x 4 cm	9.78^{cd}	12.00^{abc}	19.34^{ab}	12.77	12.77	19.97	16.28^{a}	9.18^{de}
N_1S_2	Cowdung + spacing 8 x 8 cm	6.07^{d}	17.09^{a}	16.47^{bc}	12.99	19.15	14.78	14.89^{abc}	10.04^{de}
N_1S_3	Cowdung + spacing 12 x12 cm	7.45^{d}	8.57^{bc}	8.21^{f}	11.33	18.13	12.52	13.38^{abc}	20.82^{a}
N_2S_0	Cowdung + neem cake + broadcasting	17.28^{b}	16.41^{a}	12.34^{de}	11.78	18.95	12.19	12.57^{abc}	11.54^{cd}
N_2S_1	Cowdung + neem cake + spacing 4 x 4 cm	9.78^{d}	15.20^{ab}	13.18^{cde}	15.78	15.37	14.42	15.26^{abc}	14.43^{bc}
N_2S_2	Cowdung + neem cake + spacing 8 x 8 cm	13.62^{bc}	13.69^{abc}	10.64^{ef}	13.79	9.68	12.93	9.98^{bc}	12.62^{bcd}
N_2S_3	Cowdung + neem cake + spacing 12 x 12 cm	16.41^{b}	17.28^{a}	14.55^{cd}	15.32	15.53	8.42	11.65^{abc}	11.90^{cd}
F		19.19*	13.07*	23.99*	1.94^{NS}	2.98^{NS}	1.20^{NS}	2.58*	9.77*
SEM		0.54	0.88	0.48	0.72	0.89	0.72	0.73	0.46
CD (0.05)		2.07	3.37	1.81	2.73	3.39	2.75	2.80	1.76

* Significant at 0.05; ** Significant at 0.01; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at P = 0.05

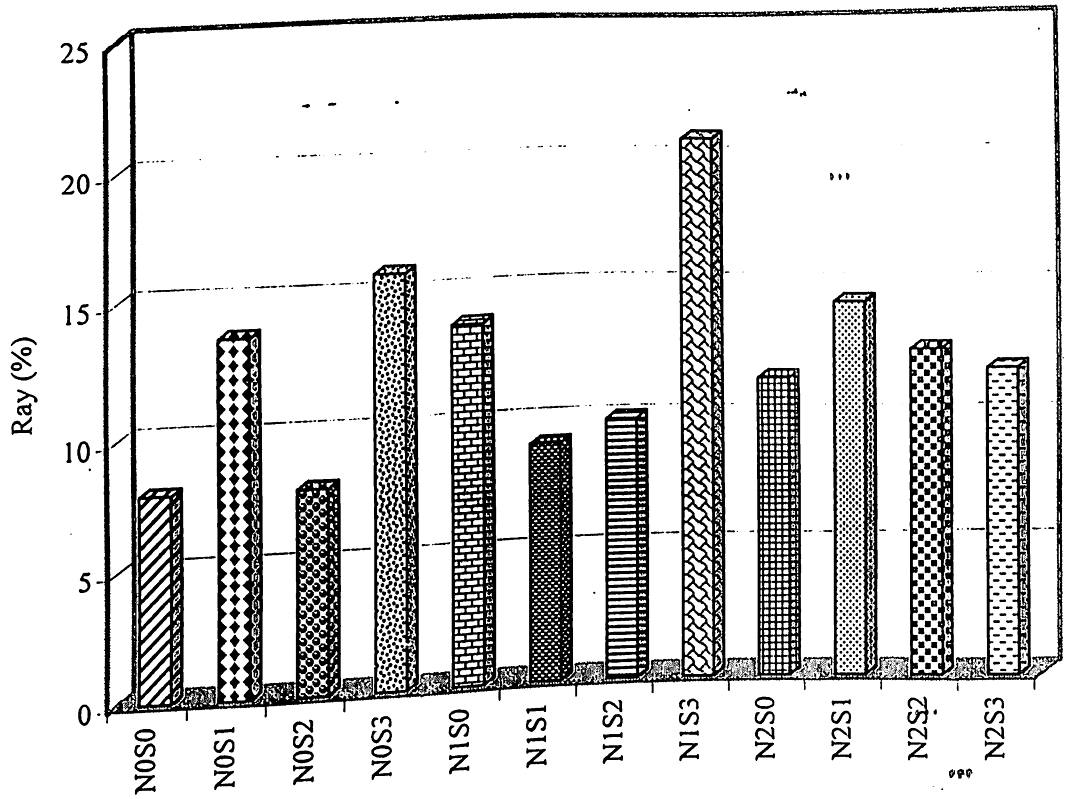

Fig. 12. Effect of nutrients and sowing methods on ray percentage of teak seedlings at eighth month

Table 24. Effect of nutrients and sowing methods on ray percentage of teak seedlings at monthly intervals

Treatment	Months							
	1	2	3	4	5	6	7	8
Nutrient								
1. No nutrient (control)	12.18[a]	11.40[b]	13.48[b]	11.19[a]	16.85	12.64	13.94	11.35[b]
2. Cowdung	9.59[b]	12.98[ab]	16.31[a]	13.68[a]	16.26	14.94	14.49	13.46[a]
3. Cowdung + Neem cake	14.27[a]	15.65[a]	12.68[b]	14.17[a]	14.88	11.99	12.37	12.62[ab]
F test	12.50*	3.95*	10.77*	3.32*	0.86[NS]	3.09[NS]	1.50[NS]	3.52*
Sowing methods								
1.Broadcasting (control)	13.75[b]	14.97	14.07	13.71	17.43[a]	12.23[b]	13.81	11.09[bc]
2. Spacing 4 cm x 4 cm	8.68[c]	11.58	14.44	12.56	13.97[b]	16.51[a]	13.65	12.41[b]
3. Spacing 8 cm x 8 cm	9.05[c]	12.82	13.46	12.95	13.60[b]	12.66[b]	13.87	10.21[c]
4. Spacing 12 cm x 12 cm	16.57[a]	14.00	14.65	12.84	19.00[a]	11.37[b]	13.07	16.19[a]
F test	24.78*	1.38[NS]	0.60[NS]	0.24[NS]	4.42*	4.98*	0.12[NS]	16.24*
Nutrient vs spacing								
F test	19.19*	13.07*	23.99*	1.94[NS]	2.98[NS]	1.20[NS]	2.58*	9.77*
SEM	0.54	0.88	0.48	0.72	0.89	0.72	0.73	0.46

* Significant at 0.05; ** Significant at 0.01; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at P = 0.05

i.e., 13.46 per cent and minimum was shown by the no nutrient treatment of 11.35 per cent.

While considering the effect of sowing methods on ray percentage of teak seedlings the treatments did not show significant difference except at the first, fifth and eighth months (Table 24). The maximum ray percentage of 16.57 per cent was observed for the sowing treatment of 12 cm x 12 cm between seeds and minimum ray percentage of 8.68 per cent was observed in the treatment with a spacing of 4 cm x 4 cm between seeds in the first month. In the eight month maximum ray percentage of 16.19 per cent was observed in the treatment 12 cm x 12 cm spacing between seeds and minimum ray percentage of 10.21 per cent was shown by the treatment with a spacing of 8 cm x 8 cm between seeds.

4.3.2 Vessel diameter

Table 25 shows the data pertaining to the effect of nutrient and sowing method combinations on vessel diameter of teak seedlings. Figure 13 graphically illustrates the effect of nutrients and sowing methods on vessel diameter of teak seedlings. Significant variation in vessel diameter was observed due to the combined effect of nutrient and sowing methods except in the fourth month. Vessel diameter was found to be maximum (44.57 µm) in the treatment N_0S_0 (no nutrients and broadcast sowing method) and minimum (27.19 µm) in the treatment N_2S_3 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} with a spacing of 12 cm x 12 cm between seeds) in the first month. But in the eighth month the vessel diameter was maximum (52.79 µm) for the treatment N_2S_3 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and a spacing of 12 cm x 12 cm between seeds) and minimum (36.01 µm) for the treatment N_1S_2 (cowdung 0.4 kg m^{-2} and a spacing of 8 cm x 8 cm between seeds).

Table 26 illustrates the effect of nutrients and sowing methods on vessel diameter of teak seedlings. Levels of nutrients were found to vary significantly except for the fourth month. When analyzing the effect of nutrients on vessel diameter of teak seedling the same trend as observed in the combined effect was obtained. Maximum vessel diameter (37.29 µm) was due to the treatment, no nutrients and minimum was

Table 25. Effect of combination of nutrients and sowing methods on vessel diameter (μm) of teak seedlings at monthly intervals

Treat-ment	Treatment details	Months 1	2	3	4	5	6	7	8
N_0S_0	No nutrients + broadcasting (control)	44.57^{a}	45.31^{a}	46.20^{ab}	41.61	44.34^{bc}	42.40^{bcd}	48.71^{ab}	50.30^{ab}
N_0S_1	No nutrients + spacing 4 x 4 cm	33.70^{c}	42.07^{ab}	43.91^{abc}	40.01	43.62^{bc}	45.87^{abcd}	43.03^{c}	48.46^{abc}
N_0S_2	No nutrients + spacing 8 x 8 cm	39.18^{b}	36.19^{bcd}	46.69^{ab}	41.59	41.08^{cd}	39.84^{cd}	41.83^{cd}	42.08^{d}
N_0S_3	No nutrients + spacing 12 x 12cm	31.71^{cd}	40.50^{abc}	41.17^{bcd}	38.51	36.74^{d}	38.40^{d}	39.84^{cd}	40.84^{d}
N_1S_0	Cowdung + broadcasting	30.38^{cd}	33.50^{de}	38.51^{cd}	39.94	42.54^{bcd}	47.89^{ab}	36.27^{de}	43.74^{cd}
N_1S_1	Cowdung + spacing 4 x 4 cm	26.56^{d}	32.54^{de}	39.01^{cd}	41.09	48.22^{b}	42.51^{bcd}	40.77^{cd}	41.50^{d}
N_1S_2	Cowdung + spacing 8 x 8 cm	30.96^{cd}	37.68^{bcd}	48.64^{a}	47.39	48.80^{b}	48.80^{ab}	32.95^{e}	36.01^{e}
N_1S_3	Cowdung + spacing 12 x12 cm	32.81^{c}	40.95^{abc}	40.34^{bcd}	46.37	45.59^{bc}	47.48^{abc}	44.82^{bc}	47.70^{abc}
N_2S_0	Cowdung + neem cake + broadcasting	29.18^{cd}	32.87^{de}	34.9^{d}	38.18	46.15^{bc}	30.40^{e}	42.33^{c}	48.14^{abc}
N_2S_1	Cowdung + neem cake + spacing 4 x 4 cm	33.31^{c}	36.35^{bcd}	46.65^{ab}	43.27	55.28^{a}	52.95^{a}	45.65^{bc}	48.56^{abc}
N_2S_2	Cowdung + neem cake + spacing 8 x 8 cm	29.62^{cd}	29.75^{e}	41.50^{bcd}	47.31	39.34^{cd}	38.18^{d}	41.00^{cd}	45.24^{bcd}
N_2S_3	Cowdung + neem cake + spacing 12 x 12 cm	27.19^{d}	35.61^{cd}	28.97^{e}	46.65	45.40^{bc}	48.97^{ab}	53.78^{a}	52.79^{a}
F		6.49*	4.20*	5.09*	1.30^{NS}	4.11*	8.11*	6.95*	5.25*
CD (0.05)		2.60	2.86	3.24	3.79	3.31	3.81	2.81	2.60

* Significant at 0.05; ** Significant at 0.01; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at $P = 0.05$

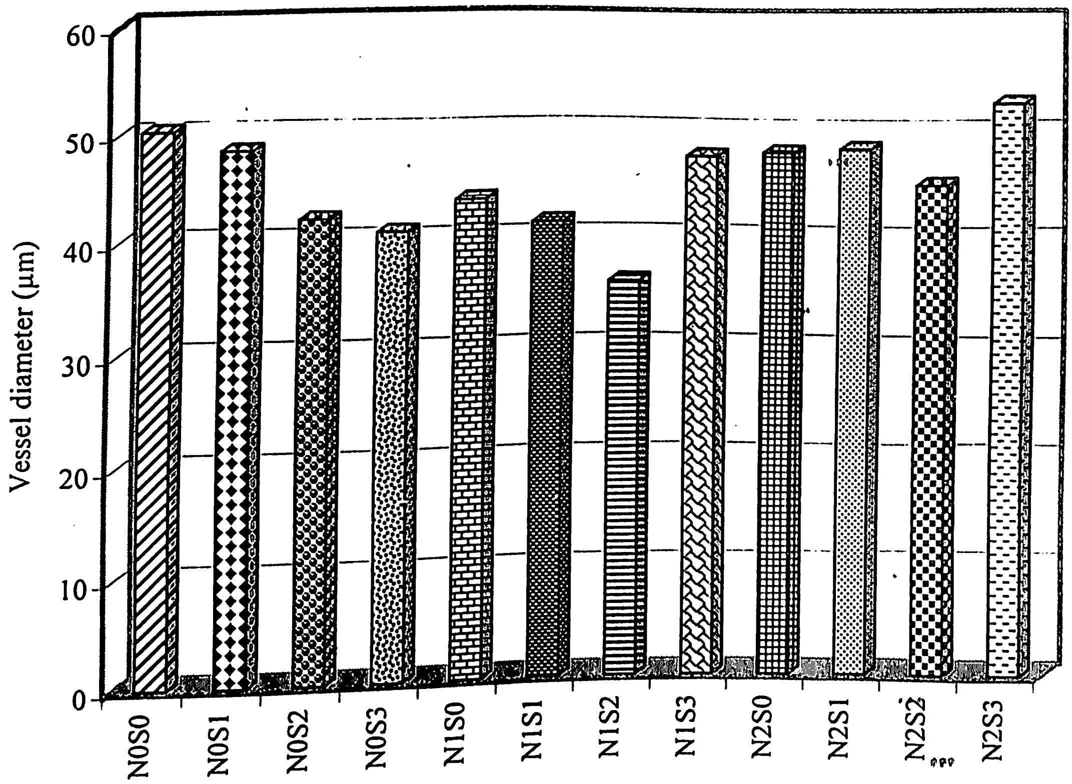

Fig. 13. Effect of nutrients and sowing methods on vessel diameter (μm) of teak seedlings at eighth month

Table 26. Effect of nutrients and sowing methods on vessel diameter (μm) of teak seedlings at monthly intervals

Treatment	Months							
	1	2	3	4	5	6	7	8
Nutrient								
1. No nutrient (control)	37.29^{a}	41.02^{a}	44.49^{a}	40.43	41.45^{b}	41.63^{b}	43.35^{a}	45.42^{b}
2. Cowdung	30.18^{b}	36.17^{b}	41.63^{ab}	43.70	46.29^{a}	46.67^{a}	38.70^{b}	42.24^{c}
3. Cowdung + Neem cake	29.83^{b}	33.65^{b}	38.00^{b}	43.85	46.54^{a}	42.63^{ab}	45.69^{a}	48.68^{a}
F test	25.508*	16.64*	9.77*	2.52^{NS}	7.31*	4.77*	15.52*	14.86*
Sowing methods								
1.Broadcasting (control)	34.71^{a}	37.23^{a}	39.87^{b}	39.91^{c}	44.35^{b}	40.23^{c}	42.44^{b}	47.39^{a}
2. Spacing 4 cm x 4 cm	31.19^{bc}	36.99^{a}	43.19^{a}	41.45^{bc}	49.04^{a}	47.11^{a}	43.15^{b}	46.17^{a}
3. Spacing 8 cm x 8 cm	33.25^{ab}	34.54^{b}	45.61^{a}	45.43^{a}	43.08^{b}	42.28^{bc}	38.60^{c}	41.11^{b}
4. Spacing 12 cm x 12 cm	30.57^{c}	39.02^{a}	36.83^{c}	43.84^{ab}	42.58^{b}	44.95^{ab}	46.15^{a}	47.11^{a}
F test	3.91*	3.01*	10.21*	3.05*	5.78*	4.56*	8.88*	9.27*
Nutrient vs spacing								
F test	6.49*	4.20*	5.09*	1.30^{NS}	4.11*	8.11*	6.95*	5.25*
SEM	0.68	0.75	0.85	0.99	0.87	1.00	0.74	

* Significant at 0.05; ** Significant at 0.01; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at P = 0.05

for cowdung 0.4 kg m^{-2} and neem cake 0.2 kg m^{-2} treatment with a vessel diameter of 29.83 µm during the first month. But in the eighth month the maximum vessel diameter was shown by the treatment cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} with a vessel diameter of 48.68 µm and minimum vessel diameter was observed for the treatment cowdung 0.4 kg m^{-2} with a size of 42.24 µm.

Considering the sowing method alone, significant difference was shown by all the treatments. Here also in the initial month the maximum vessel diameter of 34.71 µm was shown by the broadcast treatment which was followed by the treatment of spacing at 8 cm x 8 cm between seeds with a vessel diameter of 33.25 µm. Minimum vessel size (30.57 µm) was found in the spacing of 12 cm x 12 cm between seeds which was followed by the spacing of 4 cm x 4 cm between seeds with a vessel diameter of 31.19 µm. In the eighth month, maximum vessel diameter of 47.39 µm was shown by the broadcast sowing treatment which is followed by the spacing 12 cm x 12 cm between seeds with a vessel size of 47.11 µm. The smallest vessel diameter of 41.11 µm was shown by the 8 cm x 8 cm spacing treatment which was followed by the 4 cm x 4 cm spacing treatment with a vessel diameter of 46.17 µm.

4.3.3 Vessel frequency

Table 27 gives the data pertaining to vessel frequency (no. mm^{-2}) of the seedlings. Graphical representation of the same is shown in Figure 14. Significant difference between the treatments was noticed in the case of vessel frequency of teak seedlings. Maximum vessel frequency (171.76 mm^{-2}) was found in the treatment N_1S_2 (cowdung 0.4 kg m^{-2} and a spacing of 8 cm x 8 cm between seeds), followed by N_1S_0 (cowdung 0.4 kg m^{-2} and broadcast sowing method) with a vessel frequency of 162.85 mm^{-2} in the first month of observation. Lowest vessel frequency was found in the treatment N_2S_1 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and a spacing of 4 cm x 4 cm between seeds) with a value of 68.07 mm^{-2} which is followed by N_0S_1 (no nutrients and a spacing of 4 cm x 4 cm between seeds) with a frequency of 79.13 mm^{-2} in the first month of observation. The frequency of the vessels was found to reduce as the seedlings grew up. In the eight month of observation, maximum vessel frequency was shown by the treatment N_0S_0 (no nutrients and broadcast sowing method) with a

Table 27. Effect of combination of nutrients and sowing methods on vessel frequency (no./mm^2) of teak seedlings at monthly intervals

Treat-ment	Treatment details	Months							
		1	2	3	4	5	6	7	8
N_0S_0	No nutrients + broadcasting (control)	123.41^{bc}	140.20^{cde}	133.46^{d}	135.75^{abc}	144.71^{ab}	157.50^{a}	175.57^{a}	160.05^{a}
N_0S_1	No nutrients + spacing 4 x 4 cm	79.13^{de}	103.81^{f}	95.93^{e}	86.00^{g}	88.17^{d}	93.99^{cd}	108.65^{cd}	119.34^{c}
N_0S_2	No nutrients + spacing 8 x 8 cm	149.48^{ab}	137.15^{cde}	143.64^{cd}	147.32^{a}	120.22^{bc}	79.13^{d}	84.48^{e}	87.15^{d}
N_0S_3	No nutrients + spacing 12 x 12cm	147.58^{ab}	142.49^{cd}	136.13^{cd}	122.14^{cde}	101.78^{cd}	72.52^{d}	54.71^{f}	54.71^{e}
N_1S_0	Cowdung + broadcasting	162.85^{a}	153.94^{c}	151.08^{cd}	139.95^{abc}	133.59^{ab}	132.32^{ab}	65.40^{f}	97.71^{d}
N_1S_1	Cowdung + spacing 4 x 4 cm	80.66^{de}	115.80^{ef}	123.41^{d}	147.83^{a}	152.67^{a}	147.58^{a}	143.77^{b}	145.04^{ab}
N_1S_2	Cowdung + spacing 8 x 8 cm	171.76^{a}	226.46^{a}	230.02^{a}	145.04^{ab}	120.87^{bc}	94.15^{cd}	97.96^{de}	91.09^{d}
N_1S_3	Cowdung + spacing 12 x12 cm	106.36^{cd}	193.85^{b}	199.49^{b}	99.24^{fg}	101.53^{cd}	101.52^{cd}	110.94^{cd}	97.07^{d}
N_2S_0	Cowdung + neem cake + broadcasting	101.02^{cd}	143.64^{cd}	163.36^{c}	122.39^{cde}	81.17^{d}	111.45^{bc}	144.40^{b}	99.75^{d}
N_2S_1	Cowdung + neem cake + spacing 4 x 4 cm	68.07^{e}	134.86^{cde}	142.49^{cd}	125.70^{bcd}	149.87^{a}	111.32^{bc}	126.25^{c}	130.28^{bc}
N_2S_2	Cowdung + neem cake + spacing 8 x 8 cm	89.06^{de}	127.23^{def}	142.49^{cd}	102.54^{efg}	101.78^{cd}	110.73^{bc}	106.87^{d}	91.35^{d}
N_2S_3	Cowdung + neem cake + spacing 12 x 12 cm	100.76^{cd}	119.59^{def}	108.14^{f}	108.65^{def}	146.31^{ab}	90.33^{cd}	97.25^{de}	89.53^{d}
F		5.21*	13.83*	11.58*	10.75*	12.54*	5.32*	39.66*	13.90*
CD (0.05)		15.57	11.95	14.23	10.62	14.09	14.56	9.33	10.56

* Significant at 0.05; ** Significant at 0.01; NS - Non significant
Values sharing same alphabets do not differ significantly between themselves at $P = 0.05$

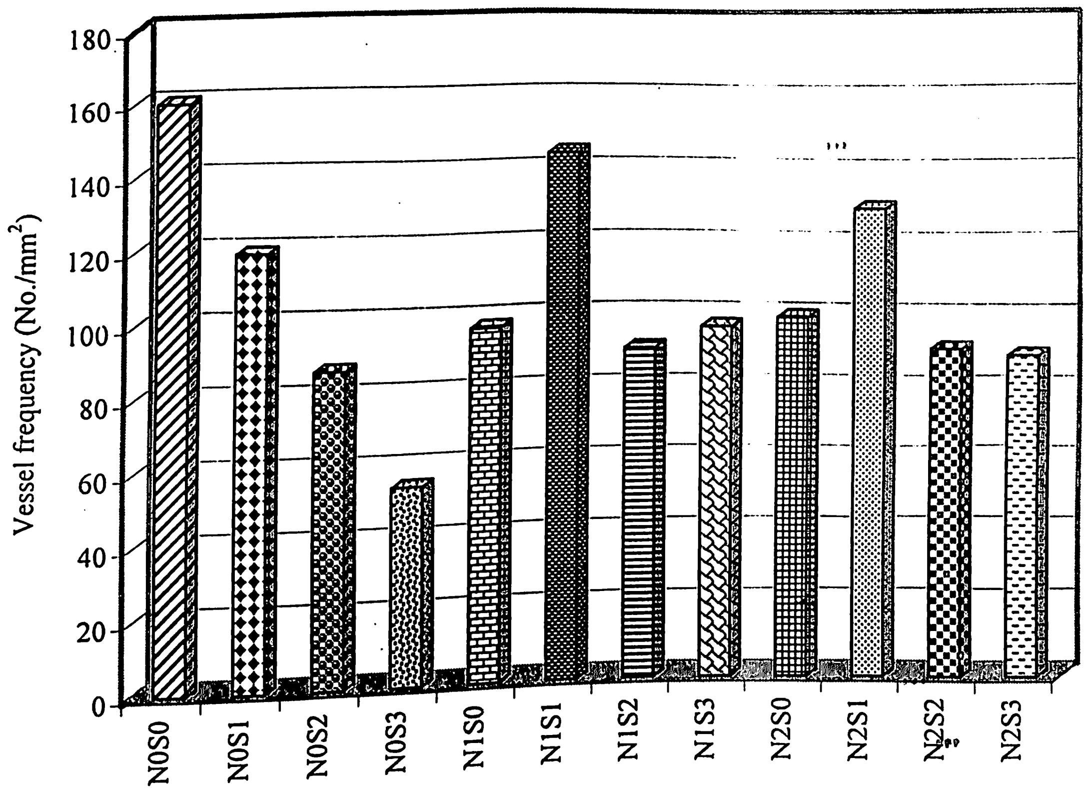

Fig. 14. Effect of nutrients and sowing methods on vessel frequency (No./mm^2) of teak seedlings at eighth month

value of 160.05 mm^{-2} which is followed by N_1S_0 (cowdung 0.4 kg m^{-2} and broadcast sowing method) with a frequency of 145.04 mm^{-2}. The least vessel frequency was found in the treatment N_0S_3 (no nutrients and a spacing of 12 cm x 12 cm between seeds) with a frequency of 54.71 mm^{-2} which is followed by N_0S_2 (no nutrients and a spacing of 8 cm x 8 cm between seeds) with a frequency of 87.15 mm^{-2}.

Table 28 illustrates the effect of nutrients and sowing methods on vessel frequency of teak seedlings. Levels of nutrients differed significantly except for the fifth and eighth month with respect to vessel frequency. The maximum vessel frequency of 130.41 mm^{-2} was showed by the cowdung alone that in the first and the minimum vessel frequency of 89.73 mm^{-2} was showed by the treatment cowdung + neem cake in the first month of observation. In the seventh month of observation the maximum vessel frequency was recorded by treatment cowdung 0.4 kg m^{-2} and neem cake 0.4 kg m^{-2} with a frequency of 118.69 mm^{-2}. However, the other two nutrient levels, no nutrients and cowdung 0.4 kg m^{-2} were at par with the vessel frequency value of 105.85 mm^{-2} and 104.52 mm^{-2} respectively. In the eighth month there was no significant difference between the treatment.

Levels of sowing methods were found to vary significantly except for the fifth month of observation. The highest vessel frequency (136.77 mm^{-2}) was observed for the spacing of 8 cm x 8 cm between seeds while the lowest (75.95 mm^{-2}) was for the sowing method of 4 cm x 4 cm spacing between seeds in the first month of observation. In the eighth and final month of observation the minimum vessel frequency of 80.44 mm^{-2} was found for the spacing of 12 cm x 12 cm between seeds and the maximum vessel frequency was recorded by the spacing 4 cm x 4 cm between seeds with a value of 131.55 mm^{-2}.

4.3.4 Ring width

The data furnished in the Table 29 illustrates the effect of nutrients and sowing methods on ring width of teak seedlings. Graphical representation of the same is found in Figure 15. Plate 4 to 12 shows the ring width of the seedlings as influenced by various nursery techniques at different stages of growth. Significant difference was observed between treatments with respect to ring width (μm) in all the eight months of

Table 28. Effect of nutrients and sowing methods on vessel frequency (no/mm^2) of teak seedlings at monthly intervals

Treatment	Months							
	1	2	3	4	5	6	7	8
Nutrient								
1. No nutrient (control)	124.90^{a}	130.91^{b}	127.29^{b}	122.80^{ab}	113.72	100.79^{b}	105.85^{b}	105.31
2. Cowdung	130.41^{a}	172.51^{a}	176.00^{a}	133.02^{a}	127.16	118.89^{a}	104.52^{b}	107.73
3. Cowdung + Neem cake	89.73^{b}	131.33^{b}	139.12^{b}	114.82^{b}	119.79	105.96^{ab}	118.69^{a}	102.73
F test	19.48*	38.75*	30.89*	7.15*	2.21^{NS}	3.98*	6.82*	0.55^{NS}
Sowing methods								
1. Broadcasting (control)	129.09^{ab}	145.93^{b}	149.30^{b}	132.70^{a}	119.82	133.76^{a}	128.46^{a}	119.17^{b}
2. Spacing 4 cm x 4 cm	75.95^{c}	118.16^{c}	120.61^{c}	119.85^{b}	130.24	117.63^{b}	126.22^{a}	131.55^{a}
3. Spacing 8 cm x 8 cm	136.77^{a}	163.61^{a}	172.05^{a}	131.64^{a}	114.29	94.67^{c}	96.44^{b}	89.86^{c}
4. Spacing 12 cm x 12 cm	118.24^{b}	151.98^{b}	147.92^{b}	110.01^{c}	116.54	88.13^{c}	87.63^{c}	80.44^{d}
F test	22.07*	18.94*	15.91*	7.44*	1.82^{NS}	15.19*	35.83*	37.89*
Nutrient vs spacing								
F test	5.21*	13.83*	11.58*	10.75*	12.54*	5.32*	39.66*	13.90*
SEM	4.08	3.13	3.73	2.79	3.70	3.82	2.45	2.77

* Significant at 0.05; ** Significant at 0.01; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at P = 0.05

Table 29. Effect of combination of nutrients and sowing methods on ring width (μm) of teak seedlings at monthly intervals

Treat-ment	Treatment details	Months							
		1	2	3	4	5	6	7	8
N_0S_0	No nutrients + broadcasting (control)	43.99^{e}	102.09^{e}	158.12^{f}	341.96^{g}	485.55^{e}	538.67^{g}	649.46^{g}	774.39^{g}
N_0S_1	No nutrients + spacing 4 x 4 cm	91.30^{d}	177.62^{d}	308.35^{e}	493.85^{e}	634.12^{c}	742.02^{e}	883.02^{ef}	1129.10^{e}
N_0S_2	No nutrients + spacing 8 x 8 cm	127.82^{c}	282.20^{c}	444.05^{cd}	539.50^{cd}	674.79^{c}	824.19^{cd}	1086.35^{bc}	1453.10^{b}
N_0S_3	No nutrients + spacing 12 x 12cm	124.50^{c}	325.36^{bc}	411.68^{d}	576.85^{c}	768.58^{b}	882.08^{c}	1075.32^{bc}	1325.90^{c}
N_1S_0	Cowdung + broadcasting	81.34^{d}	169.09^{d}	324.53^{e}	445.77^{f}	531.20^{d}	654.04^{f}	851.51^{f}	948.69^{f}
N_1S_1	Cowdung + spacing 4 x 4 cm	66.40^{de}	169.09^{d}	346.55^{e}	462.31^{ef}	550.29^{d}	664.83^{f}	951.12^{de}	1251.62^{d}
N_1S_2	Cowdung + spacing 8 x 8 cm	159.36^{bc}	355.24^{b}	443.22^{cd}	618.35^{b}	786.01^{b}	993.50^{b}	1324.97^{a}	1498.60^{ab}
N_1S_3	Cowdung + spacing 12 x12 cm	175.96^{b}	350.26^{b}	443.22^{cd}	540.41^{cd}	678.94^{c}	897.23^{c}	1082.63^{bc}	1368.50^{c}
N_2S_0	Cowdung + neem cake + broadcasting	134.46^{c}	297.13^{c}	478.91^{c}	648.23^{b}	775.22^{b}	866.52^{c}	1004.64^{cd}	1119.77^{e}
N_2S_1	Cowdung + neem cake + spacing 4 x 4 cm	83.00^{d}	301.29^{c}	460.65^{c}	535.35^{d}	674.39^{c}	761.11^{de}	856.56^{f}	969.36^{f}
N_2S_2	Cowdung + neem cake + spacing 8 x 8 cm	159.36^{bc}	309.59^{bc}	525.40^{b}	622.26^{b}	746.07^{b}	848.48^{c}	1138.34^{b}	1366.75^{c}
N_2S_3	Cowdung + neem cake + spacing 12 x 12 cm	292.99^{a}	523.90^{a}	681.43^{a}	844.11^{a}	971.15^{a}	1207.05^{a}	1390.90^{a}	1537.60^{a}
F		13.27*	12.58*	16.43*	40.03*	30.30*	41.24*	22.98*	32.25*
SEM		4.51	6.20	6.08	5.31	6.44	9.86	10.96	9.86
CD (0.05)		17.21	23.64	23.19	20.23	24.56	37.61	41.79	37.61

* Significant at 0.05; ** Significant at 0.01; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at P = 0.05

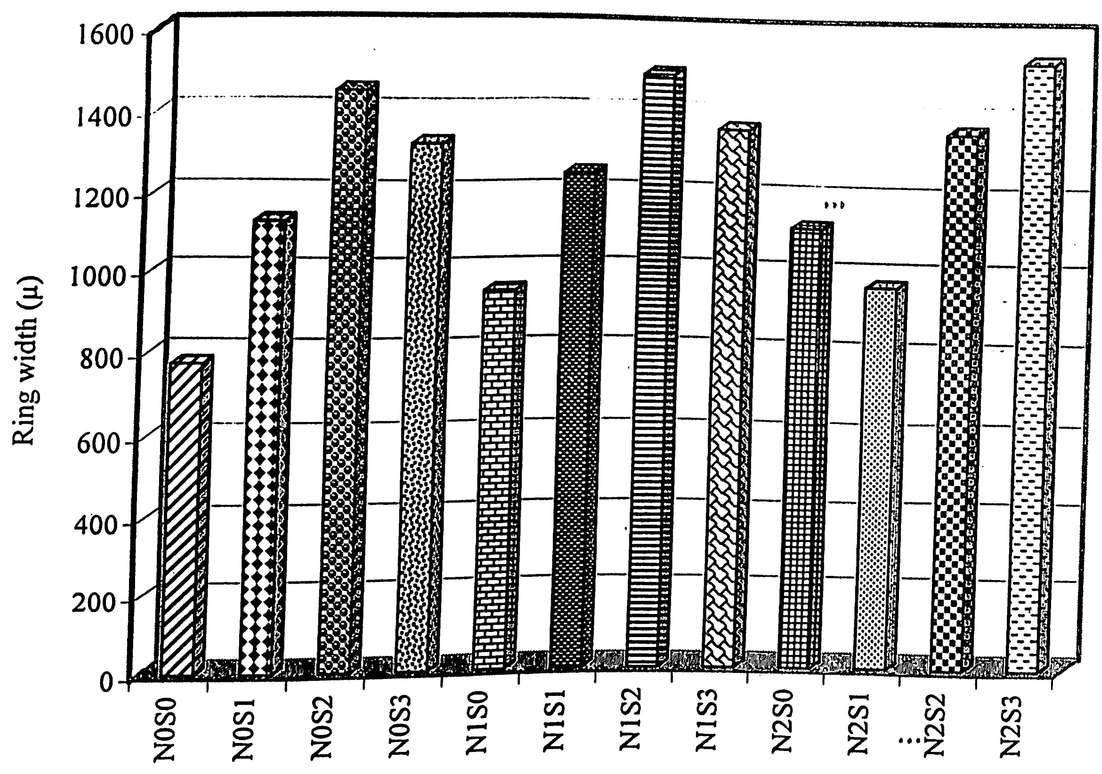

Fig. 15. Effect of nutrients and sowing methods on ring width (µm) of teak seedlings at eighth month

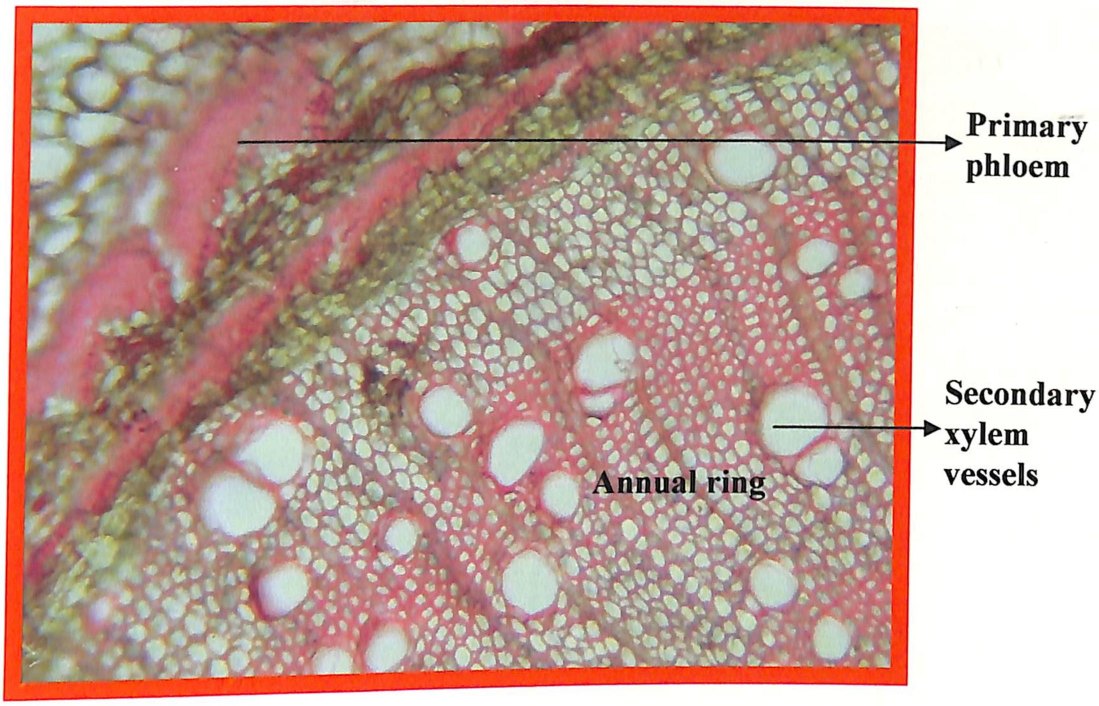

Plate 4. Cross sectional view of the treatment N_0S_0 (no nutrient + broadcast sowing method at the eighth month of observation (T.S. 40x)

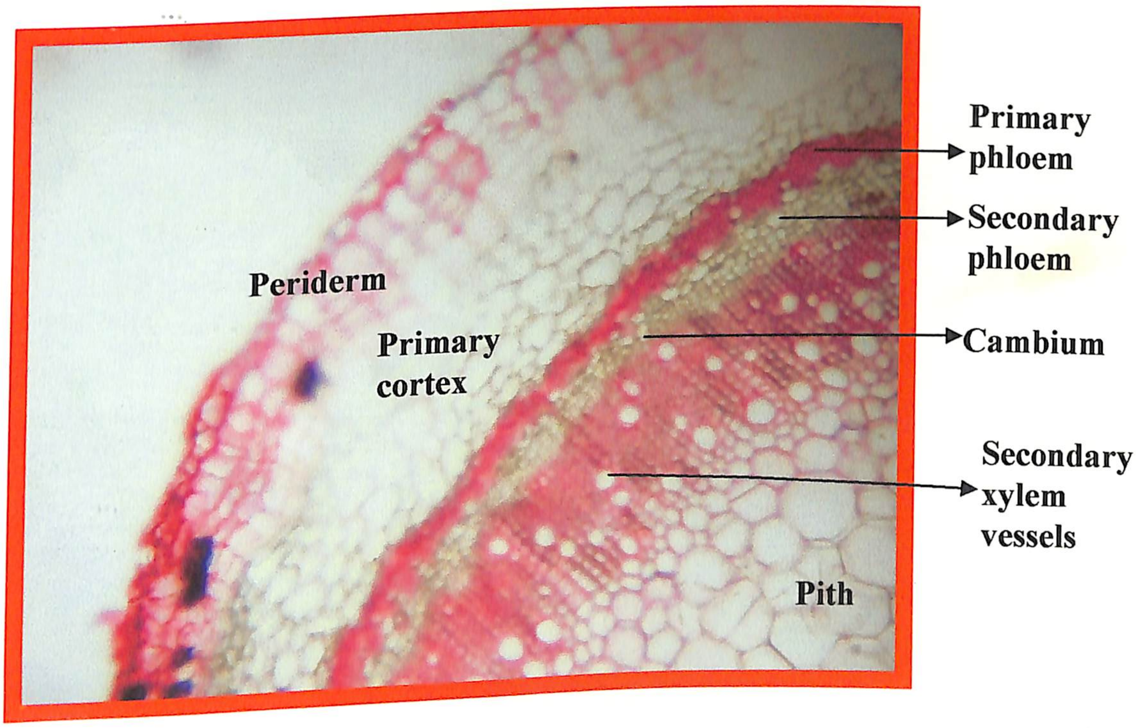

Plate 5. Cross sectional view of the treatment N_0S_1 (no nutrient and spacing 4 cm x 4 cm between seeds at the third month of observation (T.S. 10x)

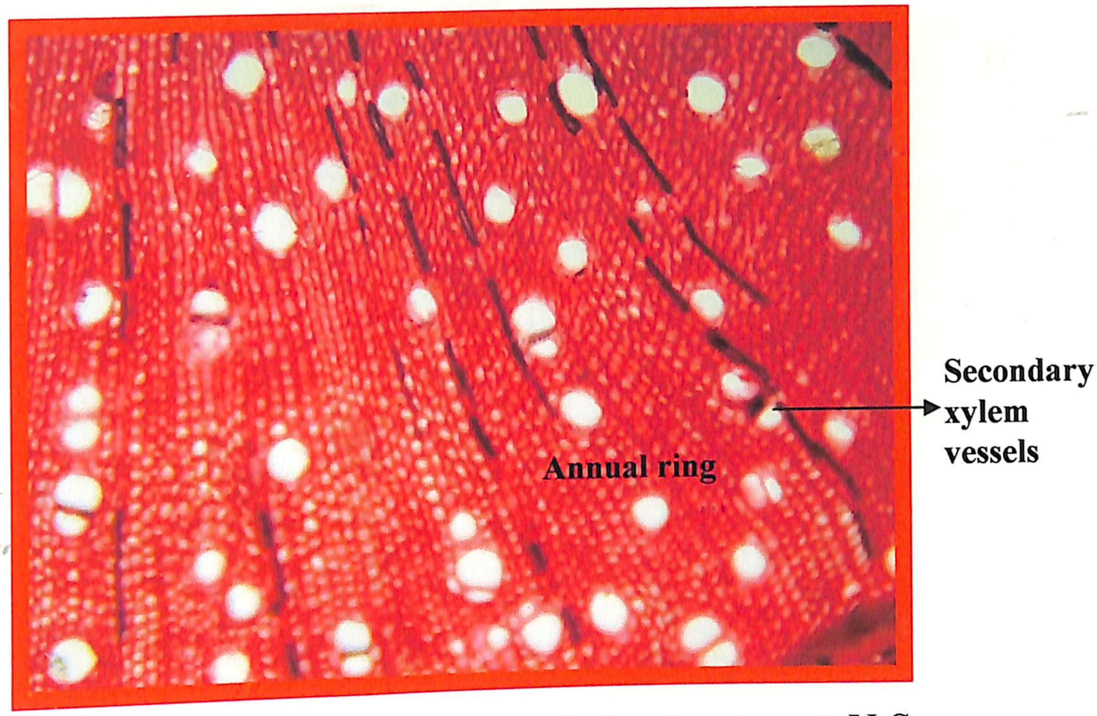

Plate 6. Cross sectional view of the treatment N_0S_2 (no nutrient and spacing 8 cm x 8 cm between seeds at the eighth month of observation (T.S. 10x)

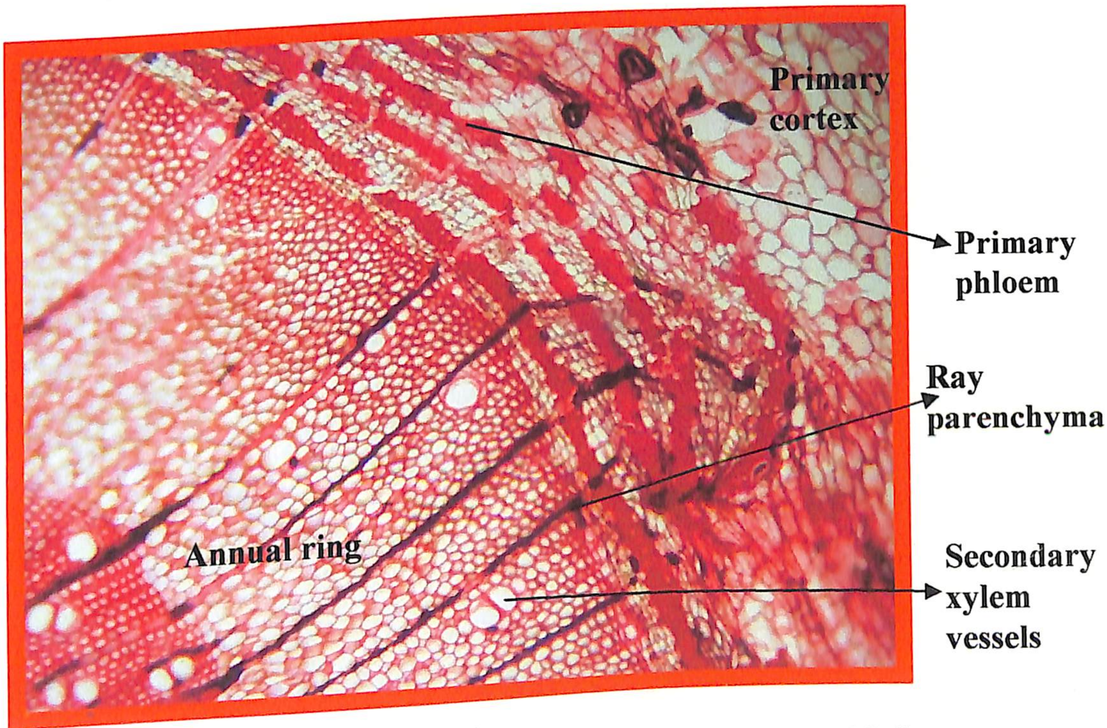

Plate 7. Cross sectional view of the treatment N_1S_1 (cowdung 0.4 kg m^{-2} and spacing 4 cm x 4 cm between seeds) at the eighth month of observation (T.S. 4x)

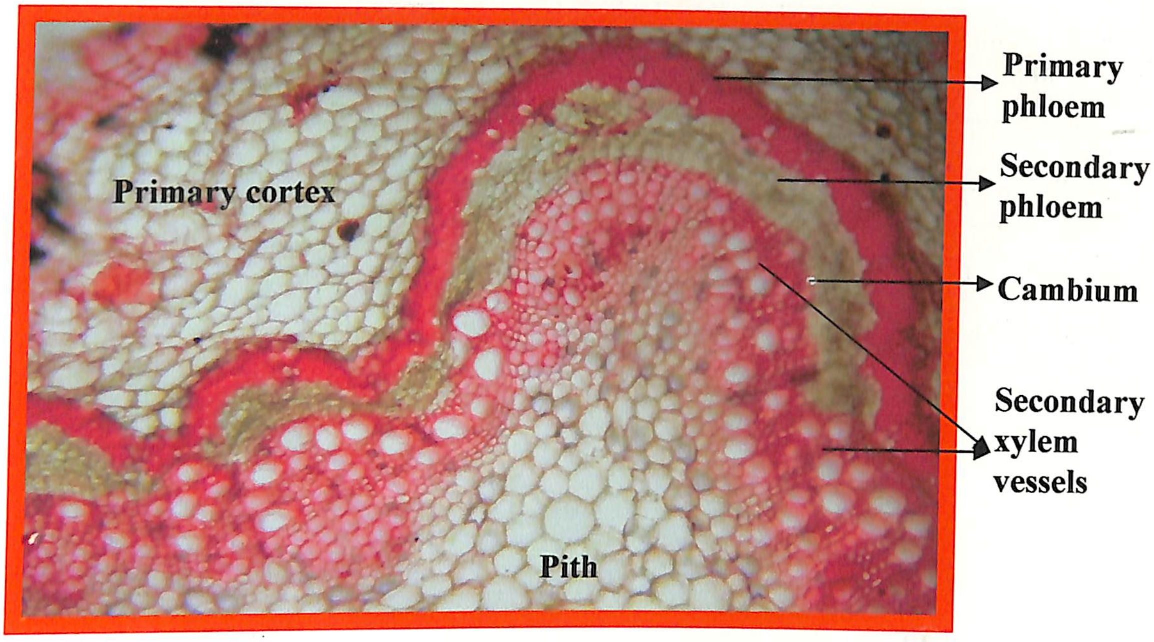

Plate 8. Cross sectional view of the treatment N_1S_2 (cowdung 0.4 kg m^{-2} and spacing 8 cm x 8 cm between seeds) at the second month of observation (T.S. 4x)

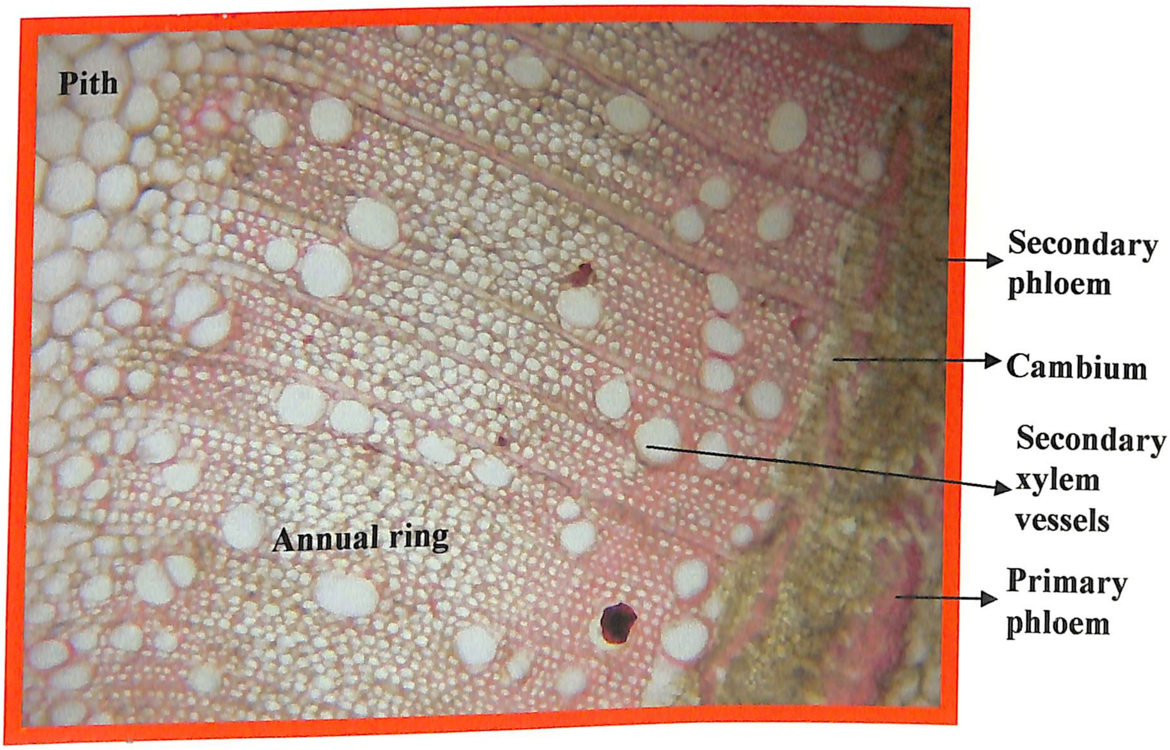

Plate 9. Cross sectional view of the treatment N_2S_0 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and broadcast sowing method) at the eighth month of observation (T.S. 4x)

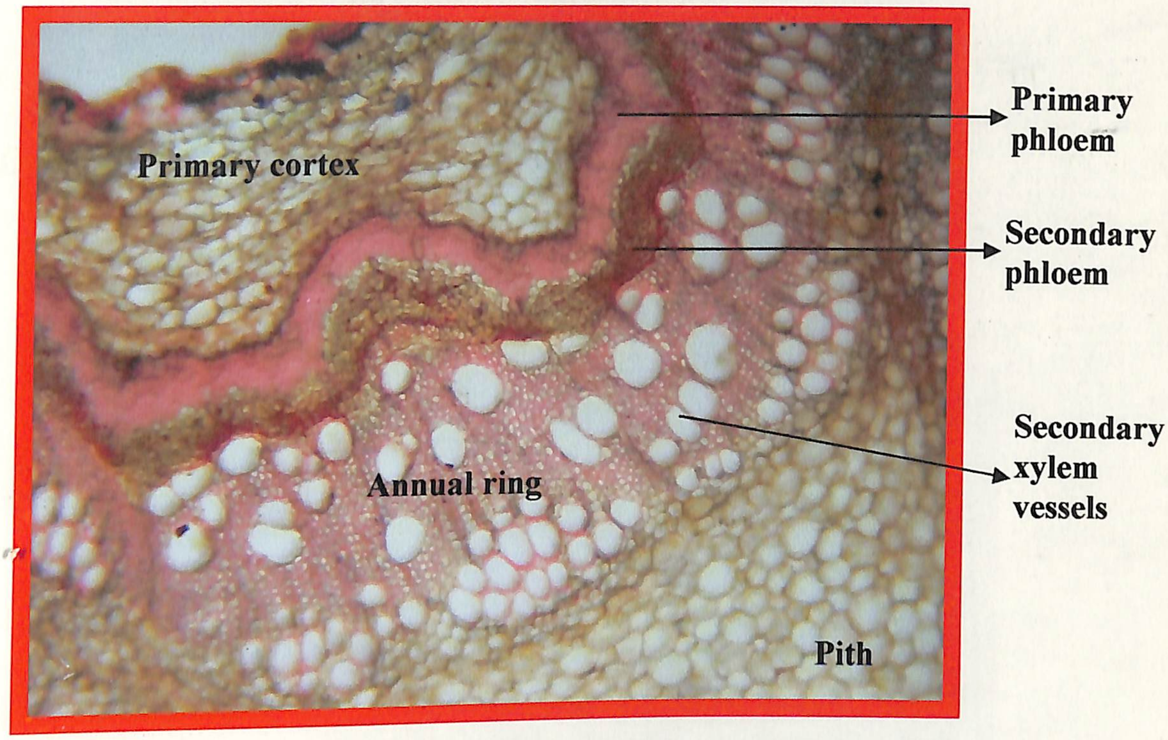

Plate 10. Cross sectional view of the treatment N_2S_1 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and spacing 4 cm x 4 cm between seeds) at the fourth month of observation (T.S. 10x)

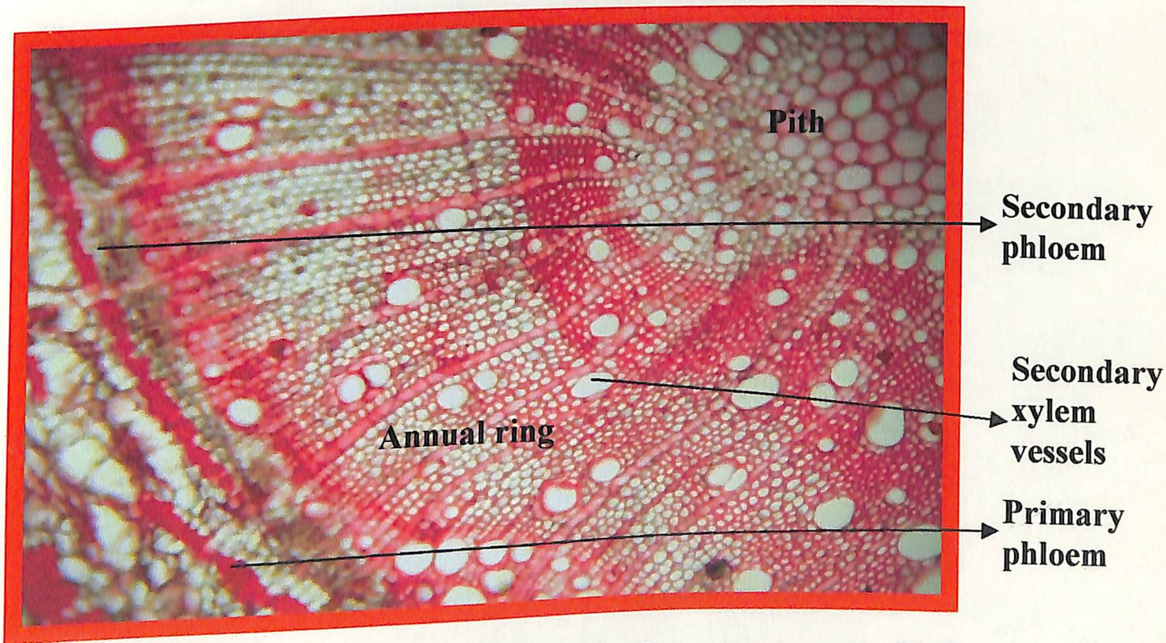

Plate 11. Cross sectional view of the treatment N_2S_3 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and spacing 12 cm x 12 cm between seeds) at the sixth month of observation (T.S. 10x)

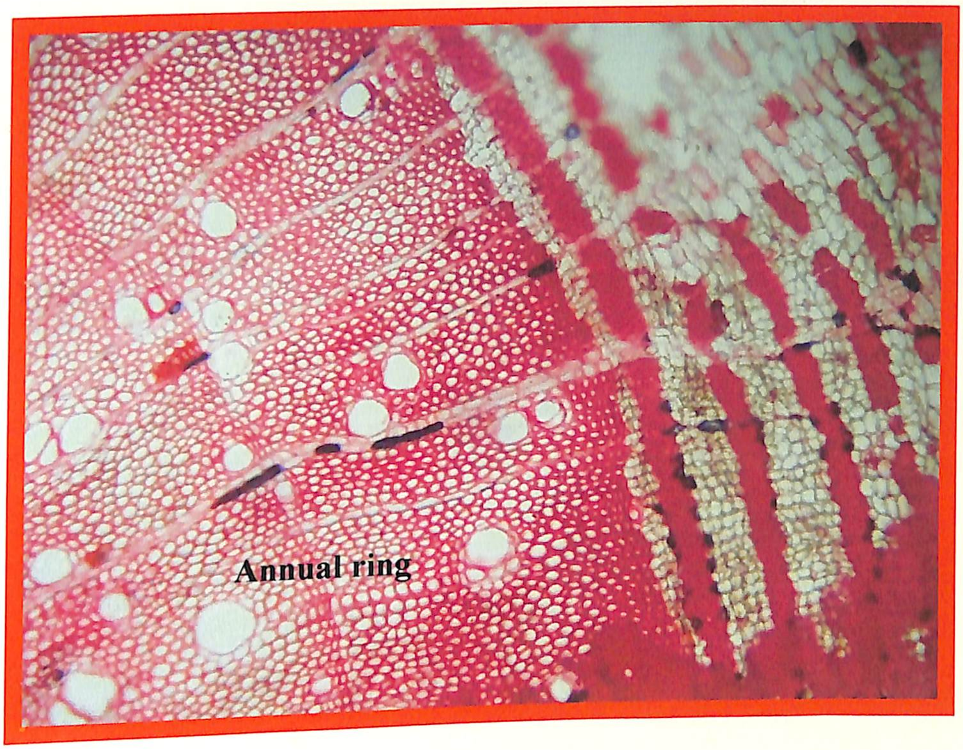

Plate 12. Cross sectional view of the treatment N_2S_3 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and spacing 12 cm x 12 cm between seeds) at the eighth month of observation (T.S. 10x)

observations. In the first month of observation maximum ring width of 292.99 µm was found in the treatment N_2S_3 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and a spacing of 12 cm x 12 cm between seeds) which is followed by N_1S_3 (cowdung 0.4 kg m^{-2} and a spacing of 12 cm x 12 cm between seeds) with a ring width of 175.96 µm. Lowest ring width was showed by the treatment N_0S_0 (no nutrients and broadcast sowing method) with a value of 43.99 µm which is followed by N_1S_1 (cowdung 0.4 kg m^{-2} and a spacing of 4 cm x 4 cm between seeds) with a ring width of 66.4 µm. It can be seen that differing cambial activity at different stages of growth resulted in varying ring width in the different treatments applied.

Table 30 shows the effect of nutrients and sowing methods on ring width of teak seedlings. Levels of nutrients were found to vary significantly with respect to the anatomical property ring width. While considering the effect of the nutrient alone on ring width of teak seedlings the maximum ring width of 167.45 µm was shown by the treatment cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} which was followed by the treatment cowdung 0.4 kg m^{-2} with a ring width of 120.77 µm. Lowest ring width of 96.9 µm was shown by the treatment no nutrients (control) in the initial month of observation. The same trend continued upto the seventh month of observation. But in the eighth month, maximum ring width of 1266.85 µm was shown by the treatment cowdung 0.4 kg m^{-2} which was followed by the treatment cowdung 0.4 kg m^{-2} and neem cake 0.2 kg m^{-2} with a ring width of 1248.37 µm. In the eighth month of observation, the nutrient levels cowdung alone 0.4 kg m^{-2} and cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} were on par.

Significant variation between the levels of sowing methods were found. Maximum ring width of 197.82 µm was found for the treatment 12 cm x 12 cm spacing between seeds which was followed by the treatment with 8 cm x 8 cm spacing between seeds with a ring width of 148.85 µm. A ring width value of 80.23 µm was observed for the treatment, 4 cm x 4 cm spacing between seeds which was followed by the broadcast sowing method in the initial month of observation. Similar trend was shown by the treatments upto the sixth month of observation. From the sixth month onwards slight increase in ring width was shown by the 8 cm x 8 cm spacing treatment. In the last month of observation maximum ring width of 1439.49 µm was

Table 30. Effect of nutrients and sowing methods on ring width of teak seedlings at monthly intervals

Treatment	Months							
	1	2	3	4	5	6	7	8
Nutrient								
1. No nutrient (control)	96.90^{c}	221.82^{c}	330.52^{c}	488.04^{c}	640.76^{b}	746.74^{c}	923.54^{b}	1170.62^{b}
2. Cowdung	120.77^{b}	260.92^{b}	389.38^{b}	516.71^{b}	636.61^{b}	802.40^{b}	1052.56^{a}	1266.85^{a}
3. Cowdung + Neem cake	167.45^{a}	357.98^{a}	536.60^{a}	662.49^{a}	791.71^{a}	920.79^{a}	1097.61^{a}	1248.37^{a}
F test	42.14*	85.31*	203.10*	207.31*	125.59*	96.15*	45.33*	17.88*
Sowing methods								
1.Broadcasting (control)	86.60^{c}	189.44^{d}	320.52^{d}	478.65^{d}	597.32^{d}	686.41^{d}	835.20^{c}	947.62^{c}
2. Spacing 4 cm x 4 cm	80.23^{c}	216.00^{c}	371.85^{c}	497.17^{c}	619.60^{c}	722.65^{c}	896.90^{b}	1116.69^{b}
3. Spacing 8 cm x 8 cm	148.85^{b}	315.68^{b}	470.89^{b}	593.37^{b}	735.62^{b}	888.72^{b}	1183.22^{a}	1439.49^{a}
4. Spacing 12 cm x 12 cm	197.82^{a}	399.84^{a}	512.11^{a}	653.79^{a}	806.22^{a}	995.45^{a}	1182.95^{a}	1410.67^{a}
F test	76.13*	121.21*	104.95*	120.84*	117.13*	191.00*	142.19*	289.85*
Nutrient vs spacing								
F test	13.27*	12.58*	16.43*	40.03*	30.30*	41.24*	22.98*	32.25*
SEM	4.51	6.20	6.08	5.31	6.449		10.96	9.86

* Significant at 0.05; ** Significant at 0.01; NS - Non significant

Values sharing same alphabets do not differ significantly between themselves at P = 0.05

found fot the treatment 8 cm x 8 cm spacing between seeds which was followed by the 12 cm x 12 cm spacing treatment with a ring width of 1410.67 μm. The lowest value of ring width (947.62 μm) was found in the broadcast treatment.

4.4 RELATIONSHIP BETWEEN ANATOMICAL PROPERTIES AND BIOMETRIC CHARACTERS

Relationship between selected pairs of anatomical properties such as vessel diameter, vessel frequency and ring width and biometric characters such as shoot length, collar girth, leaf number and root length was studied using regression analysis. From Figure 16 it can be seen that the relationship between shoot length and vessel diameter was positive with an R^2 value of 0.0482. Figure 17 indicates that the relationship between shoot length and vessel frequency was positive and weak. Figure 18 reveals the relationship between shoot length and ring width which was negative and weak.

Collar girth shows a positive relationship with anatomical properties such as ring width and vessel frequency and a negative relationship with vessel diameter. From Figure 19 it can be seen that the relationship between collar girth and vessel diameter was very weak (R^2 value of 0.0295). Figure 20 illustrates the relationship between collar girth and vessel frequency (R^2 value of 0.1058). Figure 21 reveals the relationship between the collar girth and ring width which is positive with an R^2 value of 0.199.

It was found that the number of leaves produced had a negative relationship with vessel diameter with an R^2 value of 0.0174 (Fig. 22). From Figure 23 it was found that the number of leaves produced had weak positive relationship with vessel frequency, with an R^2 value of 0.1141. The relationship between leaf number and ring width is presented in Figure 24. Leaf number shows a weak positive relationship with ring width with an R^2 value of 0.1564.

From Figure 25 it can be seen that the relationship between the biometric character root length and vessel diameter was very weak with an R^2 value of 0.0069. From Figure 26 it can also be seen that root length and vessel frequency had a very poor relationship with an R^2 value of 0.0013. From Figure 27 it is also noted that there is a very poor relation between root length and ring width with an R^2 value of 0.0009.

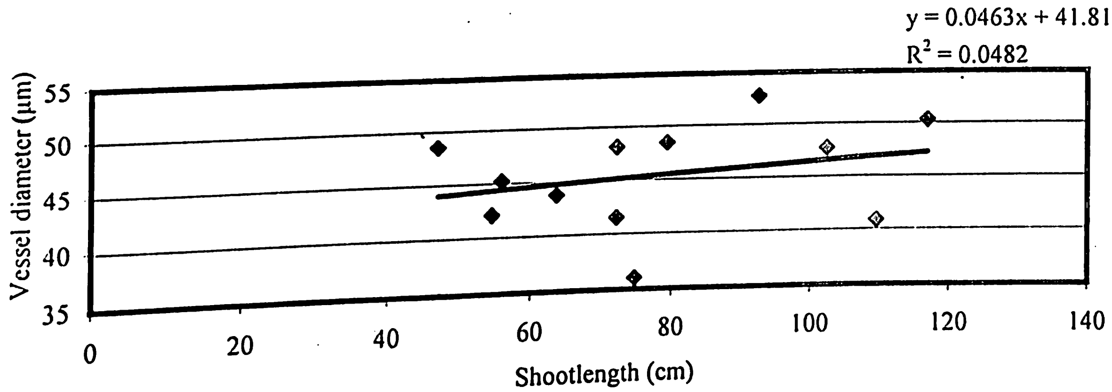

Fig. 16. Relationship between shootlength and vessel diameter

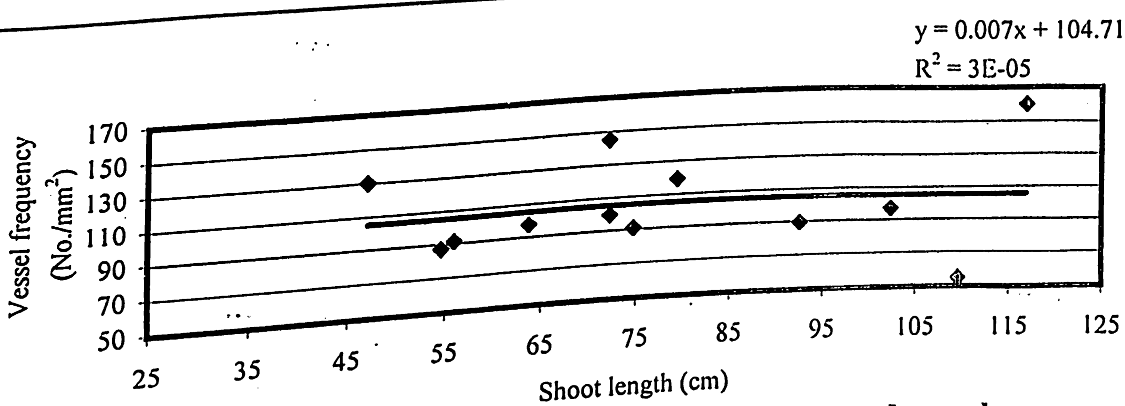

Fig. 17. Relationship between shoot length and vessel frequency

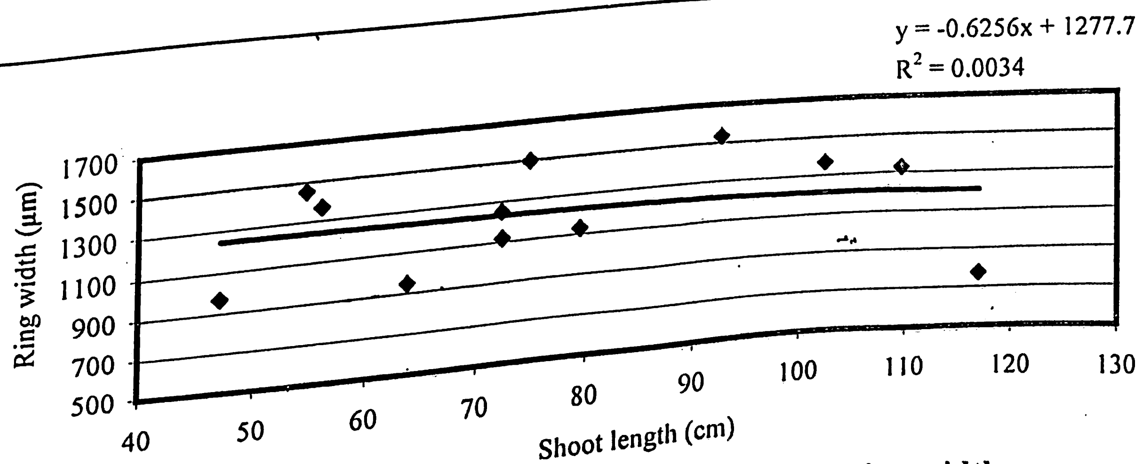

Fig. 18. Relationship between shootlength and ring width

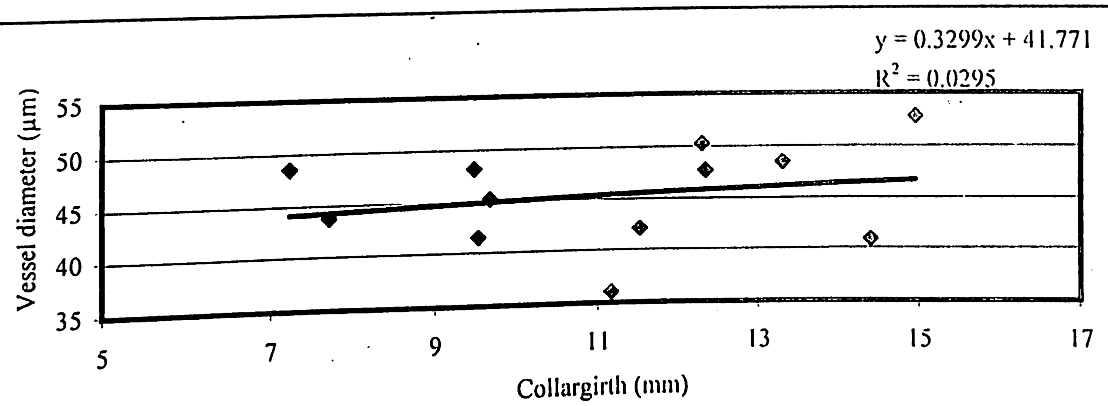

Fig. 19. Relationship between collargirth and vessel diameter

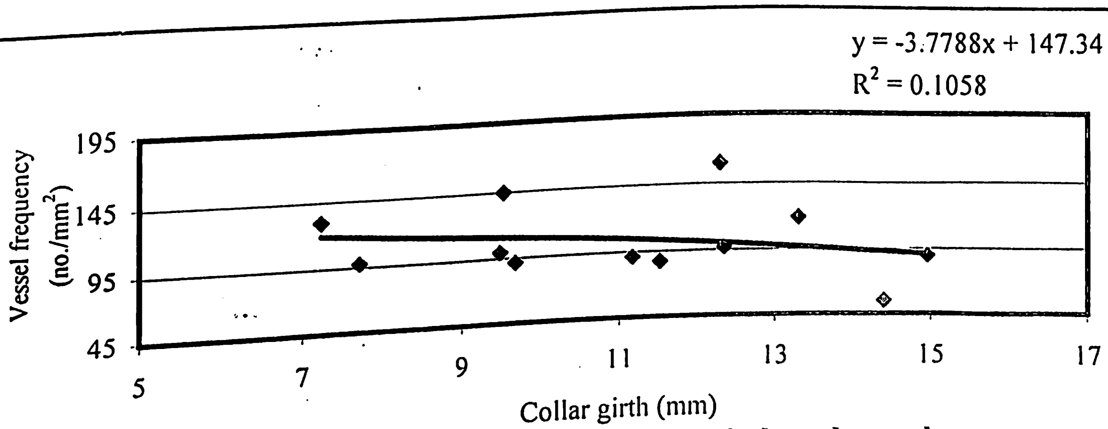

Fig. 20. Relationship between collargirth and vessel frequency

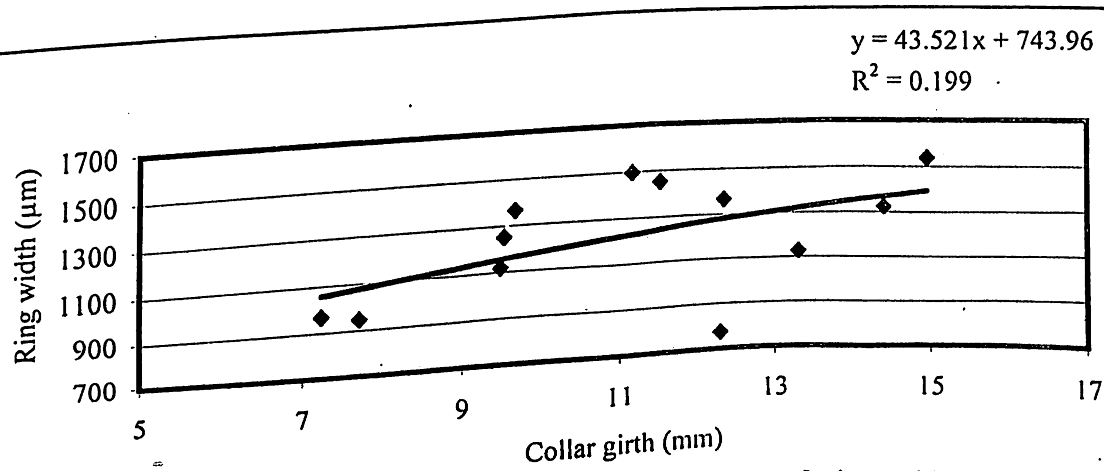

Fig. 21. Relationship between collargirth and ring width

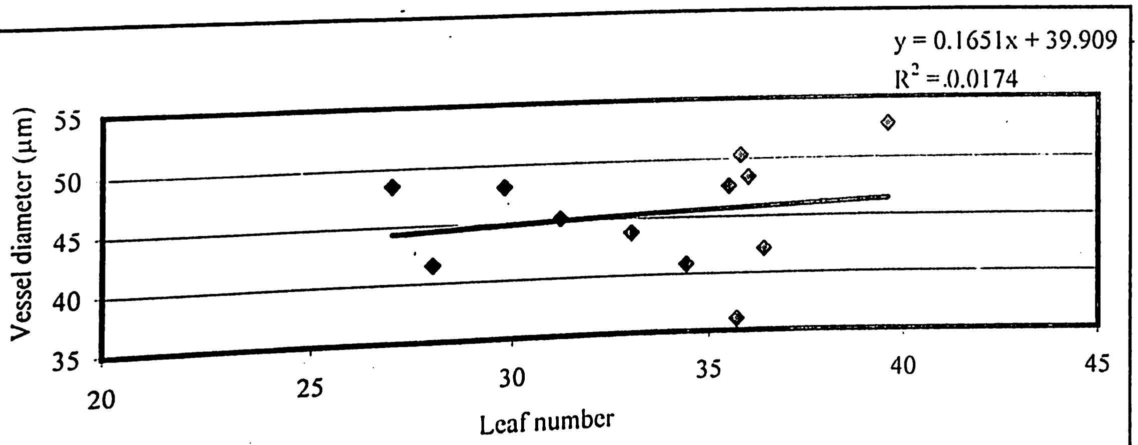

Fig. 22. Relationship between leaf number and vessel diameter

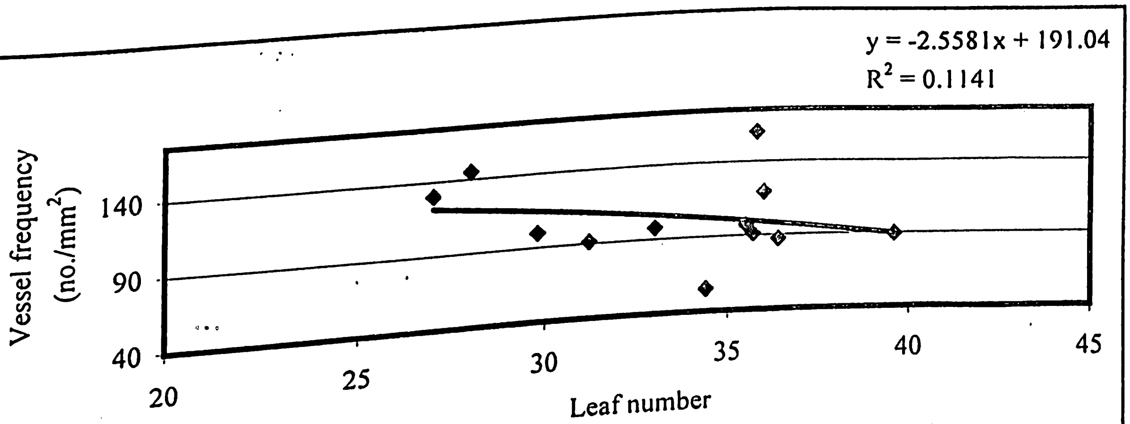

Fig. 23. Relationship between leaf number and vessel frequency

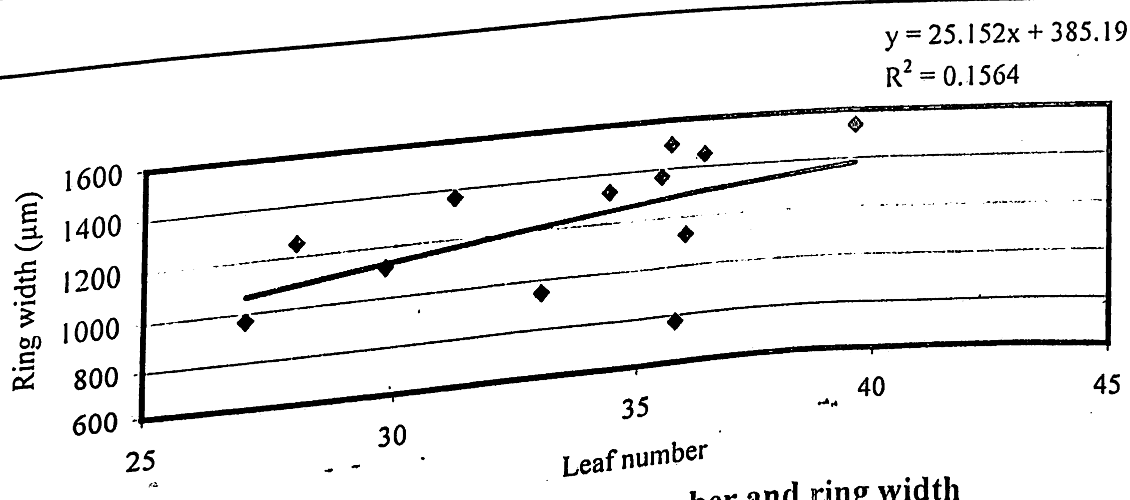

Fig. 24. Relationship between leaf number and ring width

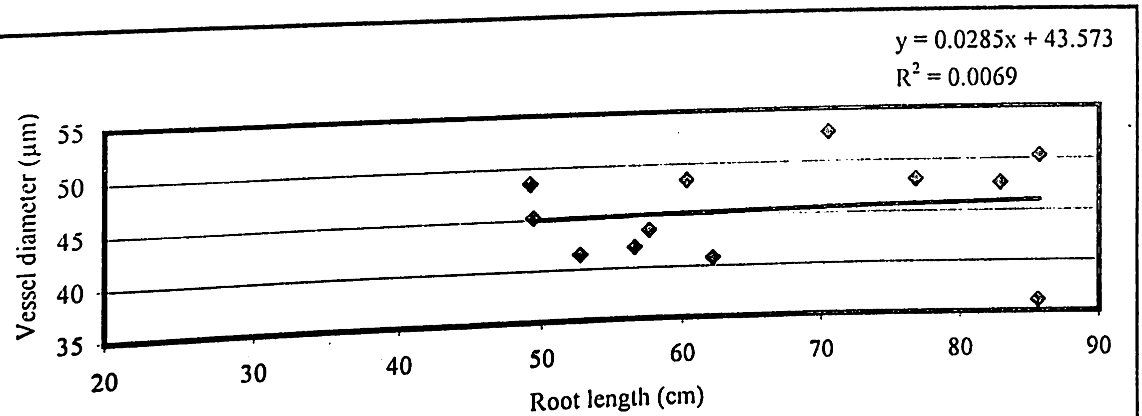

Fig. 25. Relationship between root length and vessel diameter

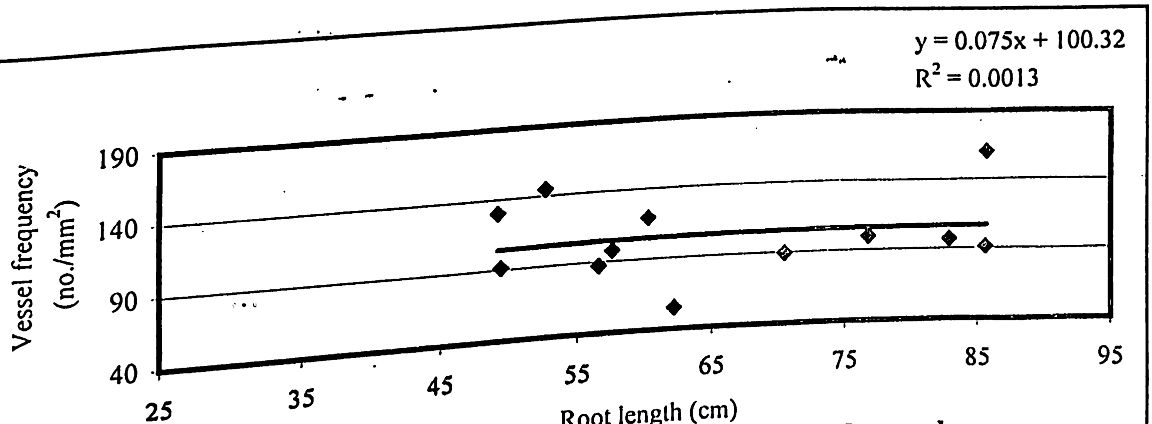

Fig. 26. Relationship between root length and vessel frequency

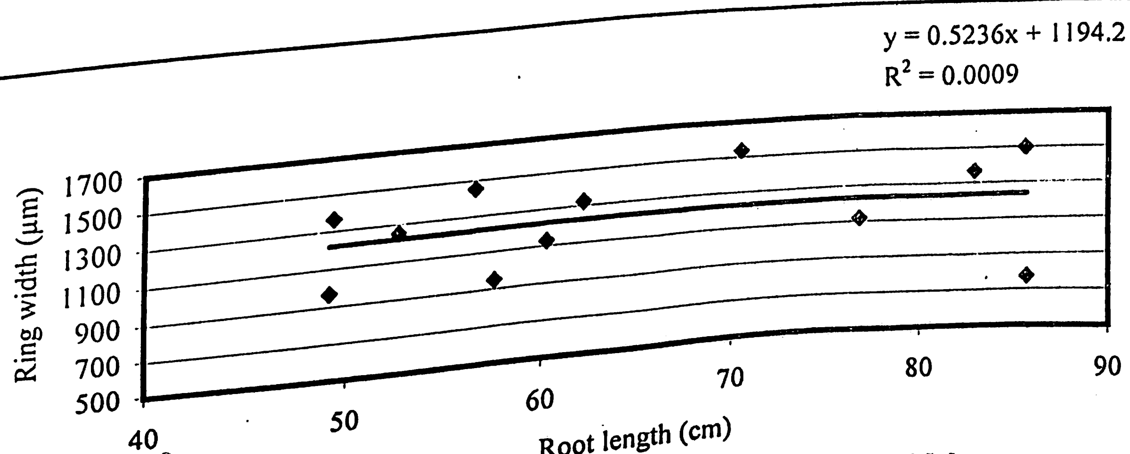

Fig. 27. Relationship between rootlength and ring width

Discussion

DISCUSSION

Traditionally, teak plantations of Kerala are raised from stumps produced from one year old seedlings. Optimum nutrition and sowing practices in the nursery are found to yield better seedlings suited for making stumps. Hence, in this study, nutrient and sowing treatments were imposed in a factorial combination to study the differences in biometric characters, biomass characteristics and anatomical properties of nursery seedlings. In most of the characters studied significant differences among treatments were observed. Thus it can be seen that nutrients and sowing methods have considerable importance in the production of good quality teak stumps. The salient findings of the studies are discussed here under.

5.1 EFFECT OF NUTRIENTS AND SOWING METHODS ON BIMETRIC CHARACTERS

Biometric characters such as shoot length, collar girth, number of leaves produced and root length differed significantly as was evident from the statistical analysis of the data. It was found that N_2S_3 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and seeds dibbled at a spacing of 12 cm x 12 cm) was the best treatment combination in terms of shoot length, collar girth, number of leaves produced and root length.. When the effects of nutrient and sowing methods were considered separately also it was found that cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} was the best nutrient combination and dibbling in lines of 12 cm x 12 cm was the best sowing method for getting good results with respect to these characters.

Height, diameter and leaf area could be considered as important criteria for measuring vigour of seedlings. Similar results were also obtained in *Anogeissus pendula* seedlings by Tripathi and Bajpai (1984). In the present study, the seedlings of teak recorded a maximum shoot length of 116.5 cm in the nutrient combination of cowdung 0.4 kg m^{-2} and neem cake 0.2 kg m^{-2} and the sowing method, dibbling in lines of 12 cm x 12 cm at the end of sixteenth fortnight. Ani (1992) also observed a positive trend in height growth in teak when a mixture of soil, vermiculite and cowdung was used as potting media. The height growth of *Eucalyptus urophylla* seedlings was found to be maximum in pure latosol and that of *Maesopsis aminii* was greater in a medium with soil and sand in the ratio 3:1 (Daryono, 1982). The maximum height growth seen in the medium containing cowdung may be due to the higher nutrient status of the cowdung media as reported by many researchers and this may be the reason for the better performance of teak seedlings. Sowing method with dibbling in lines of 12 cm x 12 cm recorded maximum shoot length which was also at par with the broadcasting treatment. Bahuguna *et al.* (1990) also reported that height, collar diameter and number of branches in 150 day old seedlings of *Priotropis cytisoides* were best in dibbling treatments at the same spacing used in this study. Similar observations were also reported by Bahuguna *et al.* (1989); Bahuguna *et al.* (1992); Maithani *et al.* (1992); and Lal *et al.* (1999) in tropical tree seedlings in the nursery while Islam and Siddiqi (1987) reported that seeds sown by broadcasting gave significantly better performance than dibbling in *Sonneratia apetale* nursery.

With regard to collar girth, the seedlings of teak showed a trend almost similar to that of height growth. At the end of the study the maximum collar girth of 14.96 mm was recorded by the treatment N_2S_3 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and seeds dibbled at a spacing of 12 cm x 12 cm). The treatment N_2S_1 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and seeds dibbled at a spacing of 4 cm x 4 cm) had the minimum collar girth of 7.234 mm at the end of sixteenth fortnight. Birdar *et al.* (1998) observed better collar girth and shoot growth in the case of *Azadirachta indica* seedlings as a result of addition of vermicompost to soil. He also evaluated the effect of potting media on vigour index of *Acacia nilotica* and found that an equal proportion of composted tank silt, farmyard manure and sand in 1:3:1 ratio promoted diameter growth. Addition of cowdung can improve soil physical properties and also nutrient availability and this may be responsible for better growth in media with cowdung. Neem cake has an insecticidal property, hence the soil insects which attacks the teak in the nursery stages such as white grubs, termites and cut worms will be less. So the growth and vigour of the seedlings will improve. Neem cake is also a source of nutrients which will increase growth performance of teak seedlings.

Wider spacing also increased growth performance of individual seedlings which is expected. In similar studies Tewari (1992) reported that dibbling seeds at the espacement of 10 cm x 10 cm gave higher germination and survival percentage than broadcast sowing. Further, because of higher frequency of small diameter plants in broadcast sowing plots a greater percentage of useable plants will be obtained in dibbling at 8 cm x 8 cm espacement plots. Line sowing also has the advantage of obtaining uniform sized stumps and more planting stocks.

Number of leaves produced by the teak seedlings at the end of sixteenth fortnight had a maximum value for the treatment N_2S_3 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and seeds dibbled at a spacing of 12 cm x 12 cm). N_2S_1 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and seeds dibbled at a spacing of 4 cm x 4 cm) is the treatment with least number of leaves. It was found that with respect to this parameter treatments differed significantly upto thirteenth fortnight. The reason might be due to the fact that plants with higher rate of leaf growth probably had a higher photo synthetic efficiency and growth potential (Wierland, 1985).

Root length of teak seedlings also varied significantly as a result of nutrient and sowing methods. The best treatment combination was N_2S_3 (cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and seeds dibbled at a spacing of 12 cm x 12 cm) and the best nutrient was cowdung 0.4 kg m^{-2} + neem cake 0.2 kg m^{-2} and the best sowing method is dibbling in lines of 12 cm x 12 cm with respect to this character. Similar results were also reported by Adersh (2001).

5.2 EFFECT OF NUTRIENTS AND SOWING METHODS ON BIOMASS CHARACTERS

The results of the study revealed significant differences between treatments with regard to shoot fresh and dry weights. A close perusal of the data reveal that teak seedling recorded significant differences in both combination effects and main effects. The best performing treatment was N_2S_3 (cowdung 0.4 kg/m^2 + neem cake 0.2 kg/m^2 with spacing of 12 cm x 12 cm between seeds) while considering the combined effect of nutrient and sowing methods at the end of the study period. Considering main effects separately, the best nutrient combination was cowdung 0.4 kg/m^2 and neem cake 0.2 kg/m^2 and the best sowing method was broadcasting followed by dibbling in lines of 12 cm x 12 cm. In the case of shoot dry weight also significant difference between treatments was found. N_2S_3 (cowdung 0.4 kg/m^2 + neem cake 0.2 kg/m^2 with spacing of 12 cm x 12 cm between seeds) was the best performing treatment. Similar trend was found in the case of root fresh and dry weight of teak seedlings.

Biomass production is a function of photosynthetically active radiation (PAR) (Hazara and Tripathi, 1986). It is presumed that effective utilization of available solar energy and also the availability of ample supply of nutrients may be the reason for the better performance of seedlings. There was a positive relationship between stored carbohydrates or photosynthates present in the stem and development of healthy root system. This aspect is well defined in the present study also. The treatments that proved superior in teak seedlings with respect to root weight were having high shoot weight also. The difference in root biomass between treatments may be due to the variability in the level of photosynthesis and the translocation of photosynthates from the shoots to the roots.

5.3 EFFECT OF NUTRIENTS AND SOWING METHODS ON ANATOMICAL PROPERTIES

The study focussed on the anatomical changes that took place in the first year of the growth of teak seedlings. The salient findings related to anatomical characters are discussed here under.

5.3.1 Tissue proportion

The proportion of various tissues like vessels, parenchyma, fibre, and ray differed significantly due to interaction effects of nutrients and sowing methods as well as due to the effect of nutrients and sowing methods separately.

5.3.1.1 Vessel percentage

In the initial study period, the proportion of vessels varied from 15-52 per cent. But in the later stages the proportion of vessels reduced gradually and at the end of eighth month of study the vessel percentage varied from 6-15 per cent. This may be due to the reduction in number of vessels and the other cells such as fibres, parenchyma and ray parenchyma cells occupying its space. Bhat (1998) reported that juvenile teak wood has low percentage of vessels and a high percentage of cell wall with short fibres, in comparison with mature wood.

5.3.1.2 *Parenchyma Percentage*

The proportion of parenchyma cells varied from 13-35 per cent in the initial study period and as the tissue matured from juvenile stage the proportion of parenchyma cells reduced from 5-16 per cent by the end of the study period. As the juvenile tissues matures the proportional wood parenchyma cells reduces and wood fibres will be produced. This may be the reason for the reduction of parenchyma percentage as the study progressed.

5.3.1.3 *Fibre percentage*

The fibre percentage of teak seedlings varied from 14-56 per cent in the first month of study and it gradually increased to 59-75 per cent at the end of the study period. There also exists significant difference between the treatments. The increase in the fibre percentage may be due to fact that as juvenile cells mature, the schelerenchyma cells are distributed and lignifies to form fibres. Priya and Bhat (1997) have also reported similar results supporting this fact.

5.3.1.4 *Ray percentage*

Rays are rectangular shaped cells which does the function of radial conduction of food materials to the peripheral tissues. Ray parenchyma cells varied significantly and in the first month of study it varied from 6-25 per cent and at the end of the study it varied 7-20 per cent.

5.3.2 **Vessel diameter**

Vessels are vertical series of cells with open ends placed one above the other, forming a continuous tube, like the section of a drain pipe, running in the direction of the long axis of the tree. Their function is to conduct sap (water and nutrients) from the soil and roots to the crown for which they are structurally well adapted. In teak seedlings, vessel diameter significantly differed between the treatments. It was also found that vessel diameter first increased upto third month and later on it showed a reduction in diameter in the late wood vessels and then it increased slightly. This may be due to the good availability of water and nutrients.

It is a well known fact that wide vessels conduct large volume of water per unit time (Carlquist, 1985). The maximum vessel diameter of 52.79 µm was recorded by the teak seedlings at the end of the study period in the present investigation. Tewari (1992) reported that in teak, early wood vessel diameter ranges from 200-320 µm. Akachukwu (1987) found that narrow vessels are of smaller lengths than wider vessels; the vessel dimensions increase with age. Similar results as seen in this study were reported by Gupta *et al.* (1999) also.

5.3.3 Vessel frequency

Vessel frequency also significantly differed due to the combined effect of nutrient and sowing methods. In the first three months of growth the vessel frequency varied between 70 mm^{-2} to 230 mm^{-2}. But subsequently vessel frequency reduced to about 50 mm^{-2} to 160 mm^{-2} by the end of the study period. Similar results were reported by Chauhan *et al.* (2000). The reason for the reduction may be due to the growth of the cells in the xylem region. As xylem parenchyma, xylem fibres and ray parenchyma expands in size the vessel frequency distributes in a wide area and there by the frequency reduces. A similar decline in the frequency of vascular bundles and fibrous percentage with increasing in age was also noticed in bamboos.

5.3.4 Ring width

The primary structure of teak seedlings contains the epidermis, pericycle, vascular bundles and pith. The vascular bundle lies towards the centre and is composed of vessels, wood fibres and wood parenchyma. As the teak seedlings grows the primary vascular bundles disappears and secondary thickening happens in the seedlings. As a result the collar diameter of the seedlings increases. When secondary thickening starts the secondary xylem is produced towards the pith region and secondary phloem is pushed back towards periphery. Teak being a ring porous tree the secondary xylem production can be demarcated by measuring the ring width. The xylem or wood parenchyma of secondary wood usually becomes thick walled and lignified. The xylem elements i.e., vessels and trachieds, aid in the conduction of water and mineral salts from the roots to the leaves, whereas wood or xylem parenchyma are living tissues aid in the storage. The wood fibres give mechanical support to the plant body (Pandey, 2001).

Ringwidth also differed significantly due to the combined effect of nutrients and sowing methods as well as due to the effect of main factors individually. Maximum ring width was recorded by the treatment N_2S_3 (cowdung 0.4 kg/m^2 + neem cake 0.2 kg/m^2 with spacing of 12 cm x 12 cm between seeds). It was observed that secondary xylem production in seedlings was initiated in the first month of observation itself and by the eighth month of observation significant amount of wood had formed. In the initial stages the primary vascular bundles were present and they gradually secondary thickening started. As the cambium divides fast in the rainy season the ring width increased and collar girth also increased. This may be the reason for achieving stumpable sized seedlings earlier. Similar results were reported by Rao and Dave (1981). Young teak seedlings show prolonged period of cambial activity when compared to mature trees.

5.4 RELATIONSHIP BETWEEN ANATOMICAL PROPERTIES AND BIOMETRIC CHARACTERS

The relationship between anatomical characters such as ring width, vessel size and vessel frequency and biometric characters such as shoot length, collar girth, leaf number and root length was studied. Results showed that shoot length had very weak positive relationship with anatomical properties. Collar girth showed weak positive relationship with ring width and vessel frequency had weak negative relationship with vessel size. Number of leaves produced showed a positive relationship with vessel frequency and a very weak positive relationship with ring width relationship with vessel diameter. Root length showed a very weak negative relationship with all the three anatomical properties viz., ring width, vessel diameter and vessel frequency.

It can be thus seen that anatomical properties ring width and vessel frequency is positively related with the biometric characters such as collar girth and leaf number. This may be due to the fact that ring width directly influences increase in collar girth in plants and the large number of leaves produced accumulate photosynthates for translocation through the vessels.

Summary

SUMMARY

An experiment was carried out at the College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur to evaluate growth characteristics and wood formation of teak seedlings as affected by nutrient status of nursery beds and sowing methods. Seedlings were raised in nursery beds of standard diamensions in a Completely Randomized Design and the various biometric, biomass and anatomical observations were taken and statistical analysis of the data was done. The characters studied included, biometric, biomass and anatomical properties. The salient results are summarised here under.

1. The treatment N_2S_3 (cowdung 0.4 kg/m^2 + neem cake 0.2 kg/m^2 with a spacing of 12 cm x 12 cm between seeds) is the best treatment combination in terms of biometric characters such as shoot length, collar girth, number of leaves produced and root length.
2. Biomass characteristics were superior in the treatment combination N_2S_3 (cowdung 0.4 kg/m^2 + neem cake 0.2 kg/m^2 with spacing of 12 cm x 12 cm between seeds) while the combined effect of nutrient and sowing methods, the best level of the nutrient was found to be cowdung 0.4 kg/m^2 + neem cake 0.2 kg/m^2. The best sowing method was found to be broadcasting followed by dibbling in lines of 12 cm x 12 cm between seeds.
3. Ring width was superior for the treatment combination of N_2S_3 (cowdung 0.4 kg/m^2 + neem cake 0.2 kg/m^2 with spacing of 12 cm x 12 cm between seeds). The best nutrient level was cowdung 0.4 kg/m^2 + neem cake 0.2 kg/m^2. The best sowing method was dibbling in lines of 12 cm x 12 cm.
4. Fast growing seedlings had larger sized vessels compared to the slow growing ones. The vessel frequency was found to be low for fast growing seedlings.
5. Tissue proportion varied significantly through out the study period. In the initial period vessel percentage and parenchyma percentage were more and fibre percentage and ray percentage were less. At the end of the study period, the

vessel percentage and parenchyma percentage declined and fibre percentage and ray percentage increased.

6. By imposing the best nutrient and sowing method treatments as found out from the present study, good quality vigorous stumps can be produced in a short period of time.

7. In the initial period of growth, vessel percentage and parenchyma percentage was more and as the seedlings grow up the secondary thickening started and as a result the fibre percentage and ray percentage increased.

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* Originals not seen

APPENDIX-I

Weather data of the study area during the experimental period

Month	Rainfall (mm)	Rainy days	Mean max. temp. (°C)	Mean min. temp. (°C)	Relative humidity (morning)	Relative humidity (evening)	Mean RH (%)
Jan 2002	0	0	32.8	22.7	79	45	62
Feb	0	0	34.3	22.4	71	38	50
March	16.22	2	36.2	24.1	85	40	63
April	50.80	4	35.0	24.8	86	55	71
May	308.40	12	32.6	24.5	88	67	87
June	533.50	22	30.0	23.3	93	78	86
July	354.20	21	29.8	23.1	94	74	84
August	506.60	19	28.9	22.9	94	78	86
Sept	124.00	8	31.1	23.0	92	62	77
Oct	387.70	19	30.8	23.2	92	74	83
Nov	22.10	3	31.8	23.4	82	60	71
Dec	0	0	32.3	22.1	72	45	45

MORPHOLOGICAL AND ANATOMICAL PROPERTIES OF TEAK (*Tectona grandis* Linn. f.) SEEDLINGS AS INFLUENCED BY NURSERY TECHNIQUES

By

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ABSTRACT OF THE THESIS

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ABSTRACT

An experiment was carried out at College of Forestry, Kerala Agricultural University, Vellanikkara with the objective to evaluate the best nutrient levels and sowing treatments required for the production of good quality stumps based on anatomical properties of the seedlings with particular reference to wood formation due to cambial activity. The different nutrient and sowing methods were randomly allocated following completely randomized design.

From the experiment, it was found that the best nutrient and sowing method combinations were N_2S_3 (cowdung 0.4 kg/m^2 and neem cake 0.2 kg/m^2 with spacing of 12 cm x 12 cm between seeds). In terms of biometric characters and biomass characteristics of seedlings it was also found that in quick growing seedlings, vessel diameter was large and vessel frequency was less. Collar girth was positively related with ring width and negative related with vessel frequency.

Comparing the performance of nursery raised seedlings with root trainer raised seedlings it was found that the growth characteristics as well as the anatomical properties were inferior for root trainer raised seedlings. In the present study it was found that the best quality teak stumps could be produced by intensive cultural practices. Intensive management of nursery seedlings could produce vigourous seedlings and thereby it could produce good quality stumps in less time.

Results of the present study showed that traditional system of production of teak stumps were efficient, By imposing superior nutrient and sowing methods good quality, vigorous stumps can be produced to meet the immediate plantation requirements within a short period.