STANDARDISATION OF PLANTING STOCK PRODUCTION TECHNIQUES FOR TEAK (*Tectona grandis* Linn.f.)

by

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(2017-27-004)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"STANDARDISATION OF PLANTING STOCK PRODUCTION TECHNIQUES FOR TEAK (*Tectona grandis* Linn.f.)"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Certified that this thesis entitled **"STANDARDISATION OF PLANTING STOCK PRODUCTION TECHNIQUES FOR TEAK (*Tectona grandis* Linn.f.)"** is a record of research work done independently by Ms.Vijayalakshmi K.P. (2017-27-004) 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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INTRODUCTION

1. INTRODUCTION

Forest nurseries play a vital role in successful establishment of plantations. Owing to the large scale demand for quality forest plants coupled with the shortage of quality planting materials, it has become imperative that tree nurseries should also be managed professionally to produce the desirable quality nursery stock. Raising good quality seedling requires technical skills, including careful planning for all the major components such as the collection of quality seed, seed pre-treatment, appropriate growing media and containers, nursery hygiene and protection (Mohanan and Sharma, 2005). An adequate attention in developing healthy nursery plant stock will ensure their better establishment and survival in field. These plants will also give higher productivity in the long run than those plants which are produced through unscientific nursery practices (Chaturvedi and Jain 1994). Even though, forest tree seedling production system has been revolutionized in many countries, it is still in its infancy in India and largely depended upon conventional methods for planting material production of many forest tree species (Mohanan and Sharma, 2005).

Teak (*Tectona grandis* L. f.) is one of the most celebrated timber species of the tropics and is often regarded as the paragon of Indian timbers species associated to the family lamiaceae. Teak is known for its high quality timber often christened as the 'carpenters delight'. Valuable wood properties including high durability and resistance to pest and diseases, amenability to workmanship are the factors that endear this species due to its characteristic chemical 'tectonine' give highly estimated value (Sandermann and Dietrichs, 1959). Teak, shines and shimmers as a 'grand jewel' in the diadem of forest tree species that occurs naturally, although discontinuously, in deciduous forests between latitudes 9° - 26°N, and 73° - 104° E longitude, which includes central and southern India, Myanmar, northern Thailand and Laos (Kaosa-Ard, 1981; Kjaer, 1996). The ever increasing need for teak timber has resulted in raising large scale plantations, both within and outside its, natural distribution range. Today, teak ranks third among tropical hardwood species in terms of plantation area established world-wide. It covers 2.25 million ha with 94 per cent in tropical Asia, major area being in India and Indonesia while about 4.5 per cent of teak plantations are in tropical Africa and the rest are in tropical American Countries (Krishnapillay, 2000; Katwal, 2003).

The major deterrent in the large scale cultivation of teak is the inadequate availability of quality planting stock because of its poor germination (8-10%) and also the prolonged nursery period strongly because of seed dormancy (Slator *et al.,* 2013). The delay in germination seems to be due to the presence of water soluble germination inhibitors in the felty mesocarp and endocarp, the endocarp act as a physical barrier imposing mechanical resistance. Despite several efforts, satisfactory improvement in teak seed germination has not been reported (Mathew and Vasudeva, 2003). Apart from the conventional practices of alternate wetting and drying it would be desirable to use non-conventional strategies to break the mechanical dormancy in teak such as mechanical breaking, termite treatment *etc*. The complex nature of dormancy and the means of overcoming it are one of the major problems in the teak seed germination (Manonmani and Vanangamudi, 2003).

Production of quality planting material is one of the major challenges in teak plantation production. Apart from seed, the use of root-shoot cutting (stump) has been the prominent planting material for its cultivation for more than a century of plantation history of teak. Stump planting is the most common technique used by the forest department as well as the private ventures (Midgley *et al.,* 2007). Conventionally, the stump preparation involves, selection of healthy seedlings, from one-year-old seed bed, with collar diameter of 1-2 cm, and then the shoot and tap root will be cut retaining only 3 cm and 20 cm portion of the shoot and tap root, respectively, from the collar. All the lateral roots also will be removed without damaging the bark of the tap root (Jayasankar *et al.,* 1999). Studies suggest that the stump size has a prominent role in the survival and height growth of stump plant, the teak stump size over 0.5 inch diameter showed higher survival and more height growth (Anonymous, 1944). Furthermore, CIFOR (Centre for International Forestry Research) also emphasised the need for selecting larger seedlings with 2-3 cm collar diameter of teak seedling for making better teak stumps (Pramono *et al.,* 2011). However, the main drawbacks for the stump production are the longer duration of 12 to 18 months for preparation of stumps, poor quality stumps and the delayed seedling establishment. Hence, a systematic study is very much needed to refine the teak stump production technology as the production of good quality teak stumps is a pre-requisite for raising successful teak plantation. Such an intensive management of tree nurseries with successful production of good quality teak stumps will lead to successful teak plantations.

Apart from the teak stumps, there is a good demand for quality teak planting materials particularly by private farm lands and also for the specific purposes like avenue planting where the use of bigger teak saplings is very much preferred for outplanting. In the context of containerised seedling production, potting media is one of the important inputs and is primarily responsible for the healthy seedling production. To stay competitive and to satisfy the environmental concerns of using traditional growing media components such as river sand and farmyard manure (FYM), potential alternatives were investigated in the present study. In this context, composted coir pith and vermicompost and rice husk are reported to be an ideal medium in potting mixture having similar physical properties as that of sand (Raj *et al.,* 2015).

Traditional seedling production in polythene bags (polybags) using soil, sand and FYM may produce seedlings with good shoot development but with poor root systems (Miller and Jones, 1995). In India, raising of, teak seedlings in standard poly bags of size 25cm x 15cm capacity using a potting mixture of soil: sand: FYM in a 2: l: 1 ratio is in vogue and this conventional practice is associated with bulkiness of potting mixture, poor nutritional status, limited root fibrosity and root coiling resulting in small seedlings with less vigour. These problems can be addressed by the use of a balanced potting mixture and also by using an optimum type and size of the container.

Though the polythene bags are conventionally used for large-scale seedling production of forest plantation species, there exist some important limitations with these including root coiling, less fibrous root formation, poor aeration, the bulkiness of the potting medium, requirement for a large nursery area and difficulty in transportation. The use of root trainers as containers can address these problems to a great extent. Root trainers are easy to fill and have fewer problems with weeds. They are easy to manage, avoid water-logging, produce comparatively uniform growth, and give high survival and better growth in the field (Josiah and Jones, 1992). They are made in various shapes and sizes, either individually as single cells or in aggregates as blocks. Those with a volume of 50-100 cc are adequate for most conifers, while a larger volume of 300 cc, is appropriate for many broadleaved species (Jinks, 1994). Root trainers are used in India to produce high quality planting stock of several forestry species. In current teak nursery practices the concept of container size incorporates mainly the size and volume. Optimum container size depends on factors such as size of the seedling desired, type of growing media and length of the growing season. Advantage of containers over seedbed is that root coiling of seedlings can be avoided.

Kerala Forest Department (KFD), the largest producer of teak seedlings in Kerala has been resorting to other types of planting materials for mass production of teak. Among these, root trainer grown seedlings has received wider acceptance in view of their better root growth and mass production of uniform planting materials. At present, both the poly bag and rot trainer techniques are being practiced by the State Forest Departments. Root trainer grown teak has more prominent tap root system that will increase the resource accusation potential of the plant (Balagopalan *et al.,* 1998). Probably, the seed origin teak as in the case of root trainers, have prominent tap root to explore greater soil depths. The root trainer plants have a shorter nursery period than stump plants (Khedkar, 1999). The Forest Development Corporation of Maharashtra made trails with the assistance of World Bank for the development of root trainer teak plants (Khedkar and Subramanian, 1997).

In this background, these series of systematic investigations are framed to bring out the much needed refinements in the present package of materials and processes involved in teak seedling and stump production. This will address the most cardinal issues in quality teak seedling production such as, long duration of nursery period, the wastage of valuable seeds, non-uniformity of germination and subsequent poor growth and the assured quality of the planting material within the stipulated time and with a standardised set of materials and production technology.

Hence, the present study was undertaken at the Tree Nursery of College of Forestry, Vellanikkara, during 2018-2020, with the following objectives.

1. Standardisation of pre-treatment methods for enhancing teak seed germination.
2. Optimization of fertigation levels and sowing methods for quality teak stump production.
3. Optimization of potting media for producing quality teak seedlings.
4. Evaluation of containers for producing quality teak seedlings.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Forest nurseries play a vital role in successful establishment of plantations. Production of quality planting materials ensure faster filed establishment and influence the subsequent growth and yield of the crop. Teak (*Tectona grandis* Linn f.) is one of the most celebrated timber species of the tropics and is often regarded as the paragon of Indian timbers. Teak (Family: Lamiaceae) has wide distribution throughout India. Teak, often christened as the 'carpenters delight' is famed for its high-quality timber (Sandermann and Dietrichs, 1959). There are a lot of problems linked with teak drupes such as emptiness, poor and protracted germination and prolonged nursery period. In this context scientific interest in production of quality planting material is gaining momentum in recent years. Toady introduction of modern nursery methods such as pre-treatment with early germination, root trainers, improved polythene bag and fertigation systems are happening and these methods are being tested and compared for their efficiency (Ginwal *et al.,* 2002; Jaeyeob Jeong *et al*., 2010). In this background, information on the various aspects of seed dormancy, dormancy breaking treatment, quality stump production, different potting media and different containers have been briefly reviewed in this chapter.

2.1 SEED DORMANCY

It has been observed that physical seed coat dormancy is a frequent occurrence in seeds that are adapted to dry and wet seasons, including several leguminous genera such as *Acacia, Prosopis, Ceratonia, Robinia, Albizzia* and *Cassia*. In certain species, like *Tectona grandis* and *Pterocarpus angolensis*, the hard layer responsible for the dormancy is formed by the pericarp or fruit (Goor and Barney, 1976). Physical dormancy is well represented in hard coated seeds, which may be due to presence of one or multiple layers of palisade cells in the seed or fruit coat through which water cannot penetrate with ease (Baskin, 2000). Reduced germination of physically hard coated seeds are due to prevention of entry of either water in Malvaceae, Leguminoseae, Lilaceae,or gases in Graminaceae, fruit crops and forest trees and in certain cases both water and gases as in *Tilia cordata* and *Crataegus monogyna* (Gordon and Rowe, 1982). As against lack of germination due to inadequate environmental conditions, dormancy is a physiological state of the seed in which germination is blocked by a seed-related mechanism, this can be imposed by impermeable seed coats, by environmental light conditions, and due to immature embryos at dispersal (Mirian *et al.*, 2000).

Seed coat dormancy is common in the drier tropics, and of pre-treatment in done systematically is necessary to obtain rapid and uniform germination. Both physical dormancy and chemical dormancy caused by hard seed coat or pericarp with cutinized layers impermeable to water and, by inhibiting chemicals present in the seed covering respectively occur in seeds also it is likely that they exist together in the same seed (Baskin, 2004; 2005). The seed environment and development influences the depth of dormancy, deeply dormant seeds require appropriate pre-treatment to make them germinate, if required immediately after harvest. Hypothetically the dormant seeds can be stored longer than those which are non-dormant but in some cases the chemical composition of seed can have an impact on seed storability. Pre-sowing treatments are imposed to break seed dormancy, suitability of which depends on type and depth of dormancy. Various methods of breaking dormancy include scarification either by using acid or hot water, mechanical aberration and subjecting the seeds to stratification and simple water soaking. Dormancy due to hormonal imbalance and combined dormancy can be solved by changing the balance of growth inhibitors such as abscissic acid (ABA) and phenolic compounds and that of growth promoters such as gibberellins, ethylene and brassinosteroid (Baskin, 2004; 2005). Seed dormancy is the physiological state in which a viable seed does not germinate, even in the presence of favourable environmental condition. In case of teak seed, the seed coat is very hard and is formed by the pericarp or fruit.

Poor germination in teak has been attributed to some form of seed dormancy. Delay in germination would be due to the process of after ripening phenomenon observed in teak seeds (Eidmann, 1934). Lignification of pericarp and endocarp before fruit crop which limits gaseous exchange is an important factor causing in prolongation of seed dormancy (Joshi and Kelkar, 1971). Slator *et al.* (2013) reported that mechanical dormancy is present in *Tectona grandis* which results in delayed and sporadic germination by means of a valve structure that opens up for the radicle to emerge. Dias *et al.* (2009) reported the teak seed endocarp and mesocarp have a layer of palisade cells and with thick wall and they are covered on the outside by waxy cuticles, causing seed dormancy and also poor germination rate. Physiological immaturity of the seed and chemical inhibitors present in the pericarp contribute to the seed dormancy in *Tectona grandis* (Georgin *et al.*, 2014). Dhaka and Jha (2017) stated that, the major reasons for the low germination percentage in teak are physical, mechanical, chemical and embryo dormancy or combined dormancy. The dormancy in teak can be addressed to increase the germination percentage by different pre-treatment methods. Teak exhibits dormancy and this is mainly due to a number of complex, possibility inter related factors. Teak seed dormancy period various from four to six weeks even upto a maximum of three years in the case of seed lots collected from the same source.

2.2 SEED PRE TREATMENT

Seeds of many tree species germinate easily when subjected to favourable condition of moisture and temperature but it is not the case with all, many tree species seeds undergo certain degree of seed dormancy. Where dormancy is strong, some form of seed pre-treatment is required in artificial germination, in order to obtain a reasonably high germination rate in a short time. The advantages from pre-treatment include saving in seed and seed-bed space, predictable and concentrated period of transplanting, more uniform stock need to be weighed against the cost and trouble of treating (Bonner, 1984).

2.2.1. Mechanical scarification

A prototype machine for teak fruit scarification was successfully developed by *Maharashtra van sanshodhansanstha* for removing the mesocarp. The scarified drupes are fully devoid mesocarp under 2-3 hours of scarification at 50-55 rpm (Grewal *et al.,* 1993) that improves the germination rate. Bapat and Phulari (1995) developed a teak fruit treatment machine prototype-II that fully remove the mesocarp, exposing the seeds, when the drupes were subjected to scarification at 500 rpm for 10-15 minutes, this gave more advantage of time involved in scarification

In India, mechanical scarification is extensively used successfully to overcome seed coat dormancy in species such as *Acacia catechu*, *A. nilotica* sub sp. *indica*, *Albizzia falcataria*, *A. lebbek*, *Cassia fistula*, *C. javanica, C. nodosa, Delonix regia, Dichrostachys cinerea, Santalum album, Terminalia arjuna* and *T. tomentosa* (Pattanath, 1982). Mohammad and Abdulrahman (2019) reported that effect of mechanical scarification in *Delonix regia* seeds improves germination rate, seedling growth and also seedling height. *Elaeocarpus serratus* seed characterized by hard seed coat, and is characterised with consequent poor water uptake and low germination, by making vertical cracks mechanically on nuts faces helps to improve the germination percentage (Raji and Siril, 2018).

Mechanical scarification with a nail clips combined with water soaking are highly useful in addressing the coat-imposed dormancy resulting in prompt and high germination rate in *Leucaena leucocephala* (Koobonye *et al*., 2018). Seeds of lupines have impermeable seed coat, the resultant dormancy can be overcome by pre-treatment method of Mechanical scarification to give rapid and high imbibition, germination percentage and seedling establishment (Karaguzel *et al.,* 2004). The hard and bristly pericarp of *Pterocarpus angolensis* can be cracked open by beating with clubs (Boaler, 1966). Abrasion with sand-paper is observed to be the best effective treatment in increasing and accelerating germination in a number of hard-coated species (Nisa and Qadir, 1969). Pricking seeds of *Eucalyptus pauciflora* resulted in 28 per cent germination but cutting either side on the seed and thereby isolating the embryo, gave 87 to 91 per cent germination (Bachelard, 1967). Laurie, (1974) reported that *Pterocarpus angolensis* can be chipped at one edge by knife to improve germination; whereas the hard seed coat of Eusideroxylon is cracked by hammer.

Sautu *et al.* (2006) showed that seeds of *Colubrina glandulosa, Sapindus saponaria, Pseudosamanea guachapele, Enterolobium cyclocarpum* and *E. schomburgkii* showed increased germination when subjected to mechanical scarification. It was also observed that submergence in warm water (70˚ C) increased germination percentages of *Apeiba aspera, Luehea seemannii*, and *Guazuma ulmifolia*, however it did not improve germination in seeds of *Apeiba tibourbou.* Boitshwarelo *et al.* (2014) in an experimental study showed that mechanical scarification significantly ($p < 0.01$) increased the germination of *A. quanzensis* seeds. Maximum germination percentage (100%) was attained within the shortest time of 2.5 days.

Oyebamiji *et al.* (2014) found that the best method of germinating the *S. mombin* seeds is mechanical treatment *i.e.* sandpaper scarification at both distal and at the micropyle end.

2.2.2 Termite treatment

Termites play an important role in breaking seed coat dormancy in many parts of the tropics. Termites soften the tough wings of *Pterocarpus angolensis* pods (Groome *et al.,* 1957) and made them ready to germinate. In Thailand, spreading of teak fruits on the ground in a 5 cm thick layer and covering with cardboard for five weeks resulted in complete removal of exocarp and subsequently seeds started to germinate (Bryndum *et al.,* 1966). Hard seed coats of *Berchemia discolour* were softened by *Isoptera* spp. (Gere *et al.*, 2015), long exposure may often result in complete digestion of hard seed coat.

The soaked drupes of teak were subjected to bacterial action from street drain or cattle shed spawn for a period of eight week helps to the germination percentage (Singh, 1956). The mesocarp of *Tectona grandis* fruits being removed by white ants, helps in improving the germination per cent and germination rate (Bryndum, 1966). Dadwal and Jamaluddin (1988) reported the role of some fungi on weathering of teak fruits and they reported that Seytalidium sp decomposed the epi and mesocarps in 21 days and such decomposed drupes exhibited early and high germination. *Pinus hungeana* seeds given 5 days soaking in a spore solution of the fungus *Aspergillus niger*, gave 75 per cent germination in 40 days compared with 15 per cent in the control, it was also observed that termites effectively broke down the tough winged fruit of *pterocarpus angolensis* hastening the germination process.

Biological scarification by termite showed a germination percent of 98.61% in teak (Omokhua *et al.,* 2015). The use of bio-regulators like cow dung slurry in enhancing seed germination and seedling growth of numerous plant species was reported by Tendolkar 1978; Singh *et al.* (1989); Pampanna and Sulikeri (2001). Cow dung slurry coating for two days increases the germination of Melia seeds to 15-20 per cent; seeds collected from goat droppings showed an enhanced germination in Melia that is 60-75 per cent in 35 days. Cutting the hard endocarp of seeds, burying the seeds in pits for about a year and soaking seeds in cold water for a weak is also suggested to improve the germination. Melia seeds subjected to cow dung slurry treatment showed a germination of 31.5 per cent (Anand *et al.,* 2012).

2.2.3 Acid scarification

Generally concentrated sulphuric acid is used to break seed coat dormancy. Though this treatment has been found to be more effective than hot water treatment in some species, the main disadvantages is that great care is expected in handling of the acid and is not safe for use by untrained workers. Since the toughness of the seed coat is found to vary between seed lots from different sources and sometimes even among individuals of the same species, the optimum period of immersion as well as concentration of the acid to be used can be determined only by experiment.

Teak fruits soaked in sulphuric acid having concentration of 5%, 10% and 20% yielded good germination results although the treatments did not show any significant change from control (Chakobkai, 1962; Savinthoru, 1963). Another study by Shintorn (1963) showed that in a comparative analysis, by soaking the teak fruits in varying concentration of sulphuric acid for a specific time period of 30 minutes at 5%, 10%, 15% and 20% concentration of the acid recorded germination percentage of 16.5, 18.7, 16.7, 16.25 and 18.25 respectively, as in the earlier case the treatments did not show any significant change from control. Bamrungrach (1964) also reported that the germination of teak seeds was not influenced by the concentration of the acid, but lower concentration gave better germination results though not significant from control. Ngulube (1986) after conducting experiments has reported that 3.8 percent germination in teak fruits after immersing the seeds in 98 per cent concentrated sulphuric acid for 2 hours.

Chemical scarification by sulphuric acid gave the highest germination percent in *Albizia procera* and *Albizia falcataria* Sajeevukumar *et al*. (1995). Jones *et al.,* (2010) noted that removal of seed coat was the best way for enhancing germination percentage and speed of germination in *Acacia cyclops* and *Acaia cyanophylla.* Ramdeo (1971) observed that 20-30 minutes soaking in concentrated sulphuric acid proved to better the germination of *Leucaena glauca* seeds. He further indicated beneficial effect of sulphuric acid scarification for 25-30 minutes followed by soaking in water for 24 hours in *Albizia richardiana*.

Red sanders pods scarified with concentrated sulphuric acid for 4 minutes and sown in soil have recorded 5 per cent germination Geetha (1996). In another study germination of five cultivars of alfalfa seeds increased from 45 when untreated to 85 per cent when soaked in concentrated sulphuric acid for30 min. (Tomer and Maguire, 1989). The positive effect of acid scarification was reported in forage legumes, such as *Lupinus angustifolius* (Burns, 1959), *Centrosema pubescens* (Pe *et al*., 1975), *Vigna mungo* and *V. umbellate* (Tomer and Singh, 1993), *Ornithopus compressus* and *O. pinnatus* (Fu *et al*., 1996), *Trigonella corniculata* (Pandita *et al*., 1999) and *Tamarindus indica*, *L. leptophyllus* (Alderete-Chavez *et al*., 2010a), *Crotalaria retusa* (Alderete-Chavez *et al*., 2010).

Acid scarification for five minutes has been found ineffective on seeds of *Medicago orbicularis* (Crawford, 1976 and Russi *et al*., 1992) and *Medicago. scutellata* (Uzun and Aydin, 2004). Treating the seeds with concentrated sulphuric acid for five minutes proved to be the best in *Prosopis cineraria*, *Albizia falcataria* and *Leucaena leucocephala* in terms of germination (Gopikumar and Chandran, 2002). Pandrangi *et al*. (2003) scarified seeds of alfalfa with various concentrations of sulfuric acid (0.1, 0.2, 0.5, 1.0, or 2.0 N) under several treatment timings (2.5, 5, 10, 15, 20, 30, 45 and 60 min) and reported that, generally, the longer durations of scarification reduced the germination percentage to the tune of 95 to 74%. Martin and De La Cuadra (2004) reported that the hard seed caused dormancy of *Metrosideros polymorpha* could be successfully addressed by acid treating the seeds for 15 min. they observed a significant reduction in hardness of seed (from 84 to 7%) and increase in germination (from 10 to 89%). Balouchi and Sanavy (2006) also showed the positive effect of sulphuric acid (96%) scarification on seeds of *M. polymorpha* and *M. rigidulawirhthe*. Germination of *M. polymorpha* and *M. rigidula* increased from 13 per cent when untreated to 96 per cent after treating with sulphuric acid for 10 min. Acid scarification is considered as one of the most effective methods used for seed coat softening. Sulfuric acid is the most popular and effective chemical to reduce hard seed of legumes (Pandrangi *et al*., 2003; Martin and De La

Cuadra, 2004; Uzun and Aydin, 2004; Patane and Gresta, 2006; Can *et al*., 2009).Concentration of acid, duration of scarification and species and cultivars used affect the effectiveness of acid scarification (Martin and De La Cuadra, 2004; Alderete-Chavez *et al*., 2011). EI-Azazi *et al.* (2013) revealed that significant differences in the germination percentage of *Acacia tortilis* seeds treated with various treatments for enhancing germination. The seeds scarified with sulfuric acid for 30 min enhanced germination from 25% to 75%. Falemara *et al*. (2014) studied that earliest mean days of emergence (8 days) was observed in *Adansonia digitata* when the seeds were subjected to acid treatment at 98 per cent conc. Khan (2015) stated that germination percentage of the seeds increased significantly when treated with H_2SO_4 for 10 to 15 min, where 80 per cent germination was observed in *Pterocarpus marsupium* after treatment.

2.2.4 Alternate wetting and drying

Seeds of some species have hard, cutinised seed coats which prevent the imbibitions of water and sometimes also the exchange of gases. Without imbibitions and gas exchange, embryo growth and germination are impossible. Physical seed coat dormancy is most common in species adapted to alternating dry and wet seasons, including legume genera such as *Acacia, Prosopis, Ceratonia, Robinia, Albizia*and *Cassia* (Bonner, 1984). The best treatment method, especially in hot climates, is alternate wetting and drying of seed. This is frequently used for teak fruits, as a pre planting seed treatment, this has been evident to accelerate seedling emergence in number of tree seeds and several grass species (Keller and Bleak, 1968; Bleak and Keller, 1972; 1974). The beneficial effect of such treatment is more pronounced where the soil moisture content is lower. The response to alternate wetting and drying treatment varies with species (Griswold, 1936; Bleak and Keller, 1972). Gunaga and Vasudeva, (2011) reported that alternate wetting and drying of *Calophyllum inophyllum* seeds in cow dung slurry for six days improves the germination percentage to 74%. Santosh *et al*. (2012), found that, *Terminalia chebula* two cycles of 24 hours soaking in cow dung slurry and 8 hours drying and two cycles of 12 h soaking and 8 h drying, followed by two cycles of 24 h soaking and 8 h of drying is able to break the hard epicarp and caused early and enhanced germination with good seedling length and biomass. Vazquez-Yanes and Orozco-Segovia, 1993 stated that the best technique to improve the germination percentage of teak is alternate wetting and drying for an interval of 24 hrs. Each as it is easy to apply and also large quantities of seeds can be treated at the same time. In his study, Billah *et al.,* 2015 showed that, in teak pre-sowing treatment is better than the control, pit method and soaking in normal water for 72 hours were best for attaining highest germination within the shortest period of time and it was helpful in large-scale low-cost production.

Alternate wetting and drying of teak seeds for four days is advised as a pre sowing treatment (Omokhua *et al.,* 2015) for breaking seed dormancy. Wetting and drying (12 h alternative for a week) had the most effect on *Portulaca oleracea*, it increased the germination percentage (40) and velocity of germination (13/day) hence the method is highly recommended for the plant. Pamei *et al.,* 2017 studied that the effect of pre-sowing treatment for teak i.e. alternate wetting and drying shows more effective in germination and quality seedling parameters and also its showed the maximum seedling height, root length, collar diameter and number of leaves.

2.3 TEAK STUMP PRODUCTION

Conventionally the planting technique for teak involves raising seedlings. In seedling origin teak, plantation activities are mainly concentrated in stump planting, polybag seedlings and root trainer grown seedlings. Among these stump planting is mostly practiced for the plantation activities. Teak is also reproduced through seeds, but germination is often dismal due to the hard seed coat which limits the production of a large number of seedlings in a defined time. The propagation of teak by using cuttings has been reported by Nautiyal *et al*. (1992), but has several limitations and only provides a few propagules from selected individuals. This type of propagule produced from the rooted cutting shows higher amount of adventitious root (Monteuuis, 1995; Monteuuis *et al*., 1995) which might resist the resource use potential of the plant. The vegetative methods of teak propagation could not make much head way. Tissue culture of the species began in the seventies (Devi *et al*., 1994; Gupta *et al*., 1980). Muralidharan and Pandalai (2000) reported that the performance of stump origin teak plants had high growth performance and survival count than micro propagated propagules. Micro propagation of teak from mature trees has remained problematic. Poor explant response and rapid explant browning are major problems faced in micro propagation of teak. Auykim *et al.* (2017) reported that coppicing from the stump remained in the clear felled area of teak plantations were retained for the next crop in Thailand. This practice utilizes natural regeneration from the cut stump of a harvested tree and can contribute to rapid restoration of forest cover after clear cutting (Sukwong *et al*., 1976). The primary advantage of coppicing for short rotations are that it is easy, offers a low cost of establishment and accelerates early growth (Chowdhury *et al*., 2008; Bailey and Harjanto, 2005).

A stump is a seedling with all leaves and root hairs removed, leaving only a portion of main stem and roots. In Kerala after the first plantation raised in 1842 by direct sowing/planting natural seedlings, stump planting was introduced by T.F. Bourdillon during 1891 which remained as the major teak propagation activity for more than a century (Pushpom, 2004; Prabhu, 2003). However, recently the Kerala Forest Department introduced root trainer technology as an alternative strategy to improve the productivity of teak in Kerala. Stump planting offers several benefits such as easy transport to considerable distances while maintaining stump viability and being easy and quick to plant; consequently, this technique is used in several countries (Midgley *et al*., 2007; Thaiutsa, 1999). Stump planted teak usually show good growth and establishment during the early growth phase. The main drawback of stump preparation is the longer duration, it requires one year for preparation of stump as per the conventional practice and in a standard nursery bed of size 10 m x1 m, 5kg of seeds to be broadcasted.

Stump is the most common technique used by the forest department as well as the private ventures as planting material (Midgley *et al*., 2007). Stump preparation involves, selection of one-year-old healthy seedlings with collar diameter of 2-3cm, and the shoot and tap root will be cut retaining only 3 cm and 20 cm portion of the shoot and tap root respectively, from the collar. All the lateral roots also will be carefully removed without damaging the bark of the tap root (Jayasankar *et al*., 1999). Studies suggest that the stump size has a prominent role in the survival and height growth of stump plant, the teak stump size over 0.5 inch diameter showed higher survival and more height growth (Griffith, 1939; Anonymous, 1944). The removal of tap root will induce the production of lateral roots. Reports suggest that growth of the seedling increased significantly with increase in stump diameter, shoot length and root length. This may be due to higher stored food materials in the stump. Mutnal *et al.* (2010) found that the stump diameter of 1.5 cm with shoot length 6 cm and root length of 8-12 cm is more suitable for production of quality planting material for teak plantation. Pramono *et al.* (2011) also reiterated the recent practice of selecting larger seedlings with 2-3 cm collar diameter for making better teak stumps.

2.4.1. Optimization of fertigation levels for quality teak stump production

Like plants in the plantation, nursery plants also require all major and minor nutrients in ample quantity. If there is deficiency of nutrients, it is likely to affect the plant performance and ultimately the quality of propagation material. Thus the nutrients must be present or to be supplemented in the growing media. Judicious nutritional management is an essential tool to ensure not only increased the plant growth but also to sustain productivity over many generation / rotation (Bowen and Nambiar, 1984). Optimum fertilizer dosage is one of the most important factors to increase the growth, without affecting the quality thereby enhancing the economic returns. Fertigation dosage can cause considerable shifts in seedling physiological process that results in increased vegetative growth of seedling viz. collar diameter, height, number of leaves, shoot and root length and biomass (Feleafel *et al.,* 2011).

2.4.2 Fertilization influence on seedling growth and development

Application of fertilization at seedling stage in the nursery helps to improve the production of healthy quality stock with higher biomass and root system (Jha *et al.,* 2000). Application of nitrogen upto 100 ppm has significantly increased biomass in all seedling parts of *Dalbergia sissoo*. The increase in biomass after one year due to application of 100 ppm nitrogen over control of leaves, stem and twig, root and total seedling was 2.29,2.48,2.94 and 2.59 times respectively. Paroha *et al.* (2009) studied the effect of inoculation of bio-fertilizers and chemical fertilizer (NPK) on growth, biomass and nutrient uptake of teak (*Tectona grandis*). They applied factorial combination of bio-fertilizers (AM, PSB, Azotobacter) and chemical fertilizer (NPK) alone and in combination of both. In all the combinations, growth and nutrient uptake were found significantly higher in comparison to un-inoculated seedlings but showed variation with treatments. Integrated approach of bio-fertilizers and chemical fertilizers enhanced growth response due to higher uptake of N, P, Cu, Mn and Zn in teak seedlings treated by both.

Chauhan and Khosla (1978) applied calcium ammonium nitrate (CAN) to container grown seedlings of *Pinus roxburghii* at the rate of 0.5-0.2 g/plant as a single dose and also split dose. They concluded that the single dose increased shoot length and collar diameter but had little effect on the roots. Split doses proved significantly better and also increased root length and diameter. Brar and Katoch (1980) found that a dose of 50 kg N ha^{-1} increased height, collar diameter, internodal length and total biomass over all other levels in *Populus deltoids*. Rao (1985) reported that nitrogen application at the rate of 60 kg $ha\text{-}^{1}$ significantly increased green and dry shoot weight in *Celtis australis* and *Acacia mollissima* and increased plant height, nitrogen content and nitrogen uptake in *Bauhinia variegata*, respectively. Bhardwaj *et al.* (1986) while evaluating the effect of different levels of nitrogen viz., 25, 50, 75, 125 and 150 kg/ha in the form of CAN on Bauhinia *variegata* obtained maximum height of 35.10 cm and a diameter of 2.62 mm by applying 75 kg N ha^{-1} which was found to be significantly better over control. Hussain *et al.* (1986) and Sivasupiramaniam *et al.* (1986) stated that maximum dry weight of seedlings when N was applied at the rate of 20 and 25 kg/ha in *Albizia procera* and *Leucaena leucocephala,* respectively. Reinsvold and Pope (1987) observed that the application of nitrogen at the rate of 100 mg/plant increased the growth and biomass production of *Robinia pseudoacacia* seedlings.

Garg (2000) evaluated growth response of the seedlings of *Prosopis juliflora* (Swartz), at different container spacing and levels of P fertilizer. Results showed that seedlings raised in poly bags spaced at 10 cm had significant thick stem and higher biomass. There were distinct differences in shoot growth, root collar diameter and foliar P concentration caused by application of P fertilizer at 40 kg/ha. Such seedlings produced a decreased root: shoot ratio and were better in quality. Joshi (2001) studied the effect of nursery management practices on the stock quality and out-planting performance of some *Populus ciliate* clones. They found that the application of 75 kg N $ha\text{-}^{1}$ enhanced growth potential and produced superior quality nursery stock having maximum index value at a spacing of 45 x 30 cm. Lamani *et al.* (2003) studied the influence of N, P and K fertilizers on initial growth of *Acacia auriculiformis,* various levels of N, P and K fertilizers were applied to first year. *A. auriculiformis* plantation influence of fertilizers on the crop was assessed by measuring the growth parameters. Among various fertilizer doses tried 200:100:100 NPK kg ha-^{1} were found to be the most efficient in boosting various growth parameters such as height, collar diameter, crown diameter and volume under study conditions. Singh *et al.,* 2017 revealed that seedlings of *Pinus halepensis* on application of fertilizer with combination of 10 x10 cm spacing is the most promising treatment for producing more seedling height, Collar diameter, biomass per plant and healthy nursery stock.

Chopan *et al.,* 2018 reported that nitrogen addition rate of 18 mg seedling^{-1} week^{-1} was found best treatment for raising quality seedlings of *Phyllostachys pubescence*. At this addition seedling height increased by 35.53%, root collar diameter by 55.14%, fresh biomass by 83.34% and dry biomass by 191.30% as compared to control.

2.5 SPACING/ SEED BED DENSITY

Optimal spacing between seedlings is essential for the quality growth. Almost all nursery practices interact with seed bed density. In general, lesser the density, larger the stem and diameter and narrow / wide the shoot- root ratio (Driessche, 1984).

2.5.1 Spacing influence on seedling growth and development

Shoulders (1961) and Kaushal (1983) stated that seedling from low density beds recorded larger collar diameter in loblolly pine. Driessche (1982) reported that wider spacing increased first seasons shoot growth by 53 per cent for Douglas fir and by 71 per cent for *sitka spruce.* Seedling size was increased when spacing increased from 10x10 cm to 15 x 15 cm, decreased when spacing was increased to 20 x 20 cm in case of *Eucalyptus regnans* seedlings (Balneaves *et al.,* 1987). The effect of different spacing on growth and development in *Eucalyptus terticornis* found that seedlings spaced at 30 x 30 cm shows a significant increase in plant height, collar diameter, total dry matter (Malik, 1987).

Nalina *et al.* (2000) studied the effect of high density planting on the vegetative characters of banana cv. Robusta (AAA) and found that high density planting resulted in increased vegetative characters such as leaf number, Leaf area, and leaf area index. Suganthi (2002) maintained population densities of 2500, 3333, 4500 plants ha^{-1} in Red banana and reported that closer spacing resulted in lesser number of leaves with reduced leaf area than wider spacing. The maximum survival percent of (68.21%), collar diameter (2.50 mm), root dry weight (0.31g), shoot dry weight (0.68 g), shoot root ratio (2.12), total biomass (2.80 g) was recorded *in Cedrus deodara* seedling planted at 10 x 10 cm wider spacing and the minimum observation were recorded at 5 x 5 cm narrow spacing. Spacing of seedlings in nursery beds influenced almost all the growth parameters (Sofi, 2005). Singh *et al.*, 2017 revealed that seedlings of *Pinus halepensis* on application of fertilizer with combination of 10 x10 cm spacing is the most promising treatment for producing more seedling height, collar diameter, biomass per plant and healthy nursery stock.

2.6 POTTING MEDIA

Good quality plant development depends largely on the growing medium used. If a plant develops a good root system in a well-balanced substrate, this is not indicative that the plant is pampered with and will not adapt to the adverse life in the field. In fact, the inverse applies. To survive in the harsh environment of a field, often without additional care, a plant needs a well-developed and excellent root system. The development of a healthy root system depends not only on the genetic properties of the plant but to a wider extent on the physiochemical properties of the growth media (Jaenicke, 1999). However, the technology needs further optimization for the specific species of interest and growing media have to be developed and standardized depending on seedling crop, local climatic conditions and future planting technique (Mohanan and Sharma, 2005**).**

Yadav *et al.* (1982) investigated the growth of root system and dry weight of *Tectona grandis* in fifteen different potting media. Each media was filled in 25 polythene bags (6″x13″), which were placed in shade and transferred after 4 weeks to sunlight. After six months, results reveled that maximum dry weight of seedling (2.28 gm) was found in pure black natural soil while minimum (0.13 gm) in sand.

Maximum root length (35.60 cm) observed in medium having equal amount of black natural soil and sawdust. Shoot length was more (8.75 cm) in pure sawdust than in pure black natural soil (6.0 cm). Combination of sawdust with black natural soil produced more shoot length (3.75 cm) than with sand (3.5 cm). Syam, 1988 stated that higher germination noticed in vermiculite growing medium for teak seed germination then sand and the seedlings grown in that medium recorded better tap root growth and dry matter production. This may be due to the increased water absorption retention qualities of exfoliated vermiculite thereby increasing the amount of available water to seeds.

Bahuguna and Lal (1996) reported that overall performance of nursery seedlings of *Mallotus phillipinensis* was better in growing media Soil: Sand: FYM (1: 1: 1). Chapman, (1997) reported that seedling growing in old sawdust are equal in quality to those produced in Perlite. Therefore, aged sawdust could be considered a logical alternative to Perlite where old Sawdust is not available fresh sawdust could be composted. Rose and Haase (1998) studied the effect of six different growing media on Douglas fir (*Pseduotsuga menziesii*) and concluded that the seedlings grown in peat were significantly better performing in comparison to those grown in Ecotech coir: Vermiculite: Perlite (2: 1: 1), Ecotone coir: Peat moss: Vermiculite: Perlite (1: 1: 1: 1) or Lignocell coir: Vermiculite: Perlite: (2: 1: 1). Shrivastava *et al.* (1998) concluded that Compost, Sand and Soil in the ratio of 2: 1:2 is the best potting mixture for raising Eucalyptus hybrid seedlings in root trainers. Bhardwaj *et al* (1986) reported that soil, sand and FYM in equal proportion is the best potting medium for optimum germination and seedling growth of *Pinus roxburghii.*

Abirami *et al.*, 2010 studied the effect of twenty-one different growing media on seedling growth and vigour index of Nutmeg. The growing media soil: Coir dust: Sand: Vermicompost in equal ratio showed the best seedling characteristics. An experiment was conducted by AI- Menaie *et al*. (2010) to investigate the effect of 1: 1: 1, 2:1:1 and 3:1:1 mixtures of Sand: Peat moss and Potting soil (humus) on the growth of *Cassia nodosa* and *Cassia fistula* seedlings, both species of cassia showed better growth and development in the media containing the three components in equal proportion. Growing media of 70% forest soil + 15% humus + 15% pumice or creek sand gave best results of seedling growth parameters in *Crimean juniper* (*Juniperus excels* Bieb) (Gulcu *et al.,* 2010). The growing medium exerts significant influence on all the seedling growth aspects of Chilgoza pine (*Pinus gerardiana* Wall.), dry root weight, number of leaves, Shoot-root ratio, total dry weight, plant height, collar diameter, dry shoot weight and quality index were the best in medium of Chilgoza forest soil: Sand: Moss: FYM in the ratio of 1:1:1:1 (Malik and Shamet, 2009). A similar study was conducted by Juliana *et al.* (2009) to determine *the Lagestroemia floribunda* seedling growth performance in terms of leaf area, number, total dry mass and relative growth rate using three different growing media. The results depicted that the in Alluvial soil seedlings showed greatest proportion of dry mass in roots.

Aklibasinda *et al.* (2011) conducted a study to determine the effect of different growing media on scotch pine (*Pinus sylvestris*) seedling growth parameters such as collar diameter, seedling length, root length and number, dry root and shoot and dry biomass and the results revealed that the best growth attributes were shown by the media of 10% rice hulls to 90% peat material. Japanese cedar (*Cryptomeria Japonica*) seedlings when raised in root trainers with different growing media, for thirty month old seedlings, the maximum survival was recorded in Soil: Sand: FYM, 1:1:1 and the media, Peat moss + Vermiculite, 1:1 recoded maximum seedling height, shoot and root fresh weight (Khan *et al.,* 2011)**.** Qaisar *et al.* (2009) studied the effect of different growing mediums on Silver fir (*Abies pindrow*), growing media composed of Peat moss + Vermiculite in the ratio of 1:1 recorded the best seedling height, collar diameter, fresh weight and height increment. Qaisar *et al.* (2009) while evaluating growing media for quality seedling stock production in *Cedrus deodara* using root trainers observed that Soil: Sand: FYM: Dalweed in the ratio of 1: 2: 3:1gave the best results. Annapurna *et al.* (2007) conducted an experiment on the growth of seedlings of sandalwood at Institute of Wood Science & Technology (Karnataka), result revealed that significantly the best seedling growth in term of total dry weight (1.16 g) with potting medium consisting of sand and compost (25:75) at the age of 7 months. An investigation conducted by Sofi and Bhardwaj (2007) showed that potting mixture (Soil: Sand: FYM) in the ration of 1: 1:3 is the best for *Cedrus deodara* for getting the best seedling quality.

A medium consisting of Sand: Soil: Compost: Burnt rice husk: Charcoal in the ratio of 25:15:50:5:5 favoured the development of *Santalum album* L. in terms of collar diameter, root and shoot dry weight, total dry weight and quality index (Annapurna *et al.,* 2005). *Casurina eqisetifloia* seedling growth at five-month age in terms of height, collar diameter, total, and root dry weight and quality index was observed to be the best in mixture consisting of Sand: Soil: Compost: Burnt rice husk: Charcoal in the ratio of 30: 10: 50: 5: 5. (Rathore *et al.,* 2004). Various experiments have been carried out to check the efficiency of FYM, soil and sand composites in different ratios an effective growth media. Kannur and Devar (2003) studied the influence of growing media on seedling growth of *Tectona grandis* (Teak) and observed that soil, sand and FYM in the ratio of 1:1: 2 gave maximum growth and biomass followed by an equal proportion mixture. Tiwari and Saxena (2003) reported that *Dalbergia sissoo* seedling growth in potting mixture of Soil: Sand: FYM in the ratio of 1: 2: 2 and 1: 2: 1 indicated high growth, dry weight and quality index. *Mallotus phillipinensis* showed better growth in Soil: Sand: FYM (1: 1: 1) reported by Bahuguna and Lal (1996). The seedlings of plants like *Dendrocalamus strictus, Gmelina arborea, Dalbergia sisso*, *Acacia catechu* and *Bombax ceiba* were raised successfully in root trainers using soil, sand and FYM/compost in the ratio of 1: 2: 2 and 1: 1: 3 (Khedkar and Subramanian, 1996). The performance of Albizia and Acacia species were found to be best in the mixture of Soil: Sand: FYM in the ratio of 1: 1: 2 (Luna and Chamoli, 2006).

Bali *et al.,* 2013 undertaken to standardized the growing media for the optimum condition for germination and seedling growth of *Terminalia bellarica.* This experiment revealed that maximum germination, seedling height recorded maximum in silt loan soil and FYM combination.

Nutrient composition of rice husk ash was 80.26% Si, 0.38% P, 1.28% K, 0.21% Mg and 0.56% Ca (Hashim *et al.,* 1996: Frimpong-Manso *et al.,* 2011). Vermiculite possesses cation exchange properties, thus it can hold available to the growing plant ammonium, potassium, calcium and magnesium (Headlee *et al.,* 2014; Douds *et al.,* 2006).

2.7 EFFECT OF CONTAINERS

Containers or root trainers are made up of high-density polypropylene or polyethylene or expanded polystyrene material. They have ridges inside, for guiding the root growth to the drainage hole at the base. They can be employed in both coniferous and broad leaved species to deal with the problems of root coiling and distortion. during the last 50 years the containerized nursery production system have evolved to the wide variety of rigid walled containers in use today from simple tarpaper pots used in 1930's (Landis *et al.,* 1900). It is now an accepted fact that root trainer technology is the best for raising plants in nurseries. This had been adopted in west as early as 1940's but in India, its usage was not adopted till 1990's (Nanhorya *et al.,* 1999). Despite the introduction of root trainers and their advantages, the polybag seedling production system for its own advantages is going to stay as the bulk production method of planting stock quite some time. Attention of researcher is now concentrating on combining advantages of both the plant production systems (Gera *et al.,* 2001). Nowadays, the introduction of containers has made a magnificent impact on forest nursery seedling production. The root trainer technology application offers large number of healthy and uniform sized planting stock with superior quality.

Mohanan and Sharma (2005) illustrated the principles behind the root trainer technique: (1) this technique provide ambient conduction for the rapid development of primary roots and subsequent root system (2) this will induce early natural pruning of primary tap rood and also lead to the production of multiple secondary tap roots (3) maintain acute angle of secondary and tertiary root tips, and its subsequent pruning, so as to keep downward movement to attain massive network of root system. These facilitate the better performance in the field level by the extensive root system and more resource use potential (Khedkar, 1999). Mohanan (2000) further reported that the root trainer grown plants have more disease resistance and disease management is easier. Studies revealed that the root trainer seedlings have quick establishment of mycorrhiza in roots.

Malik and Shamet (2009) conducted an experiment on refinement of container type and revealed that maximum plant height, collar diameter, dry shoot weight, vigour index, dry root weight, shoot-root ratio, total biomass and quality index resulted when seedlings were raised in polybags of 20x10 cm proved best for most of seedling growth parameters than obtained in 275 00 root trainers. An experiment was conducted by Qaisar *et al.* (2009) on Silver fir (*Abies pindrow*) seedlings raised in four different root trainers i.e. 100,150, 250 and 300 cc. The results showed, that the root trainers of 300 cc capacity gave maximum height, collar diameter and dry shoot and root weight when the growth of seedlings was recorded after two years and six months of sowing. Singh, (2018) conducted a study on the influence of root trainers cell volume and seedling density and composition of growing media in relation to morphological biomass and seedling quality parameters of four-month old planting stock of *Acacia catechu*, *Azadirachta indica* and *Pongamia pinnata*. Results showed that a cell volume of 90 cc was not sufficient for proper seedling growth of *Acacia catechu* and *Azadirachta indica*. However, a clear-cut superiority of 300 cc cell volume was evident for *Acacia catechu*.

Gera *et al.* (2003) compared 150 and 300 cc root trainers were compared with the conventional nursery production system by raising seedlings of *Acacia catechu*, *Albizia lebbeck, Azadirachta indiac* and *Pinus roxburghii* on the basis of costs input and benefit output, a seedling raised in root trainer has better height, collar diameter and seedling quality parameters. Similarly, Venkatesh *et al.* (2002) conducted an experiment on *Acacia niloticain* which the container of 300 cc size registered superiority over 150 cc size polythene bags. In yet another study, Saxena (1997) compare the growth performance of *Gmelina arborea, Acacia catechu, Dalbergia sissoo and Bombax ceiba* seedlings for root trainers vs polythene bag and observed increased height and survival percent in root trainers over polythene bags in all species.

Annapurna *et al.* (2004) conducted a study on containers type and size effect on growth and quality of *Santalum album* L. in which maximum collar diameter was recorded in root trainer of volume 150 ml whereas maximum height was recorded in 600 ml also highest total dry weight, shoot and root dry weight were recorded in root trainers of 600 ml followed by 270 and 300 ml. Rathore *et al*. (2004) reported that at the age of 3 months seedlings of *Casuarina equisetifolia* raised in 300 cc single cell root trainers have the maximum growth parameter. Comparative study on the quality of bamboo seedlings in root trainers and polybags kept on the mounted angle showed the seedlings raised in 300 cc root trainers had superior quality parameter in comparison to same size polythene bag (Gera *et al.*, 2007). Similarly, Luna and Chamoli (2006) showed that in *Albizia procera, Eucalyptus tereticornis and Acacia catechu* seedlings raised in 300 cc root trainer produced maximum biomass than 200 cc and 150 cc containers.

In teak, Khedkar (1999) reported that teak plantation raised in root trainer technology showed interesting performance as it developed multiple tap root, also growth of root trainer teak plants was better and faster as compared to stump planting in the field. Khedkar and Subramanian (1997) reported that quality of teak raised in root trainer of 150 cc volume were sturdier, healthier and were had more collar girth than the stump origin plants. Teak seedling also developed numerous adventitious roots in the root trainers which would help in faster establishment.

Gera and Ginwal (2002) reported that assessment of seedling after one and a half year of planting *Dalbergia sissoo* showed root trainer (150 cc) raised seedlings performed better in all parameters except collar girth. Dominguez-Lerena *et al.,* 2006 reported that 300-400 cc container produced largest plants so these containers helps in larger *pinus pinea* seedling coming out of the nursery, which will increase growth following outplanting. Verma *et al.,* 2018 reported that largest sized polybags 20x15 cm and 25 x15 cm provided more favourable root environment which helps in enhanced growth and vigour of *Prosopis cineraria* seedlings. Bashir *et al.,* 2009 stated that 100 cm^3 and 150 cm^3 root trainers shown most cost effective when compared with *pinus wallichinana* seedling raised in 300 cm^3 root trainers. Luna and Chamoli (2006) concluded that 300 cc root trainer produced maximum biomass compared to 200 cc and 150 cc containing among *Albizia procera. Eucalypts tereticornis* and *Acacia catechu* seedlings. Ginwal *et al.* (2001) reported the root trainers 300 cc cell volume is the best size of root trainer for *Acacia nilotica*, but when there is a limitation and the objective is to raise more number of seedlings per unit area of the nursery space, the hiko tray 150 cc volume is equally good.

Ginwal *et al*. (2001) used multivariate approach to find out the ideal size/ volume and type of root trainer for raising. *Dalbergia sissoo* seedlings. Root trainers consisted of Hiko trays (90 cc, 150 cc and 300 cc), book type (200 cc) and single cell bullet (290 cc) were tried for 3 months in the nursery for two consecutive years. Seedlings so raised were planted in the field conditions. Performance of 150 cc Hiko trays was adjudged the best container to raise seedling for planting in field conditions while 300 cc Hiko trays performed well in nursery. According to them larger quantity media and bigger container is not necessarily a catalytic factor for better performance of seedlings in field conditions. Ferraz and Engel, 2011 stated that the increase in root trainer size provided expressive gains in the height of seedling, stem diameter, leaf area, shoot, root dry matter and quality index. Root trainer of 300 cc provided seedling characteristics greater than those produced in the other root trainer, making it possible to reduce by 70 days the production time of the seedlings. Plastic pots of size 4000 ml showed maximum seedling height, collar diameter and seedling survival rate as compared with 1600 ml poly bag and root trainer of 350 ml in *Terminalia bellarica* (Bali *et al.,* 2013).

Similarly, Farhana *et al.* (2010) in a comparative growth analysis of *Albizia procera* seedlings grown in polybags, nursery bed and root trainers observe that, seed germination and seedling growth when assessed for shoot length, root length, collar diameter, total dry matter production and leaf number, seedling developed in polybags of 23 x 15 cm size were the best performers in respect to germination and other growth parameters. However, root-shoot ratio was higher in root trainers in comparison to any other treatment.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present investigation titled 'Standardisation of planting stock production techniques for teak (*Tectona grandis* Linn.f.)' was aimed at the comprehensive studies on important methods of quality seedling production of teak viz. standardisation of pre-treatments for enhancing seed germination, optimization of fertigation levels and sowing methods for quality teak stump production, optimization of potting media and evaluation of containers for producing quality teak seedlings.

3.1 STUDY AREA

The present study was conducted at the College of Forestry, Kerala Agricultural University, Thrissur, and Kerala during the period conducted 2017 to April 2020. Geographically, the area is located at 40 m above mean sea level at $10^0$32'N latitude and $76^0$26'E longitude. The area experiences a warm humid climate with distinct rainy season. The soil of the experimental site is oxisol. The predominant parent material is metamorphic gneiss. The soils and sub soils are porous and extremely well drained.

3.2 SEED COLLECTION AND GRADING

Teak seeds were collected from Nellikkutha, Nilambur North Forest Division. The seed lot collected from the plantation were thoroughly hand mixed to ensure the homogeneity of each lot before grading. Seeds were size-graded using teak grading machine having a sieve size of 9 mm mesh and kept separately in containers (Plate 1). These graded seeds of above 9 mm were used for the experiments. The thesis work was carried out as per the following four experiments (Fig 1).

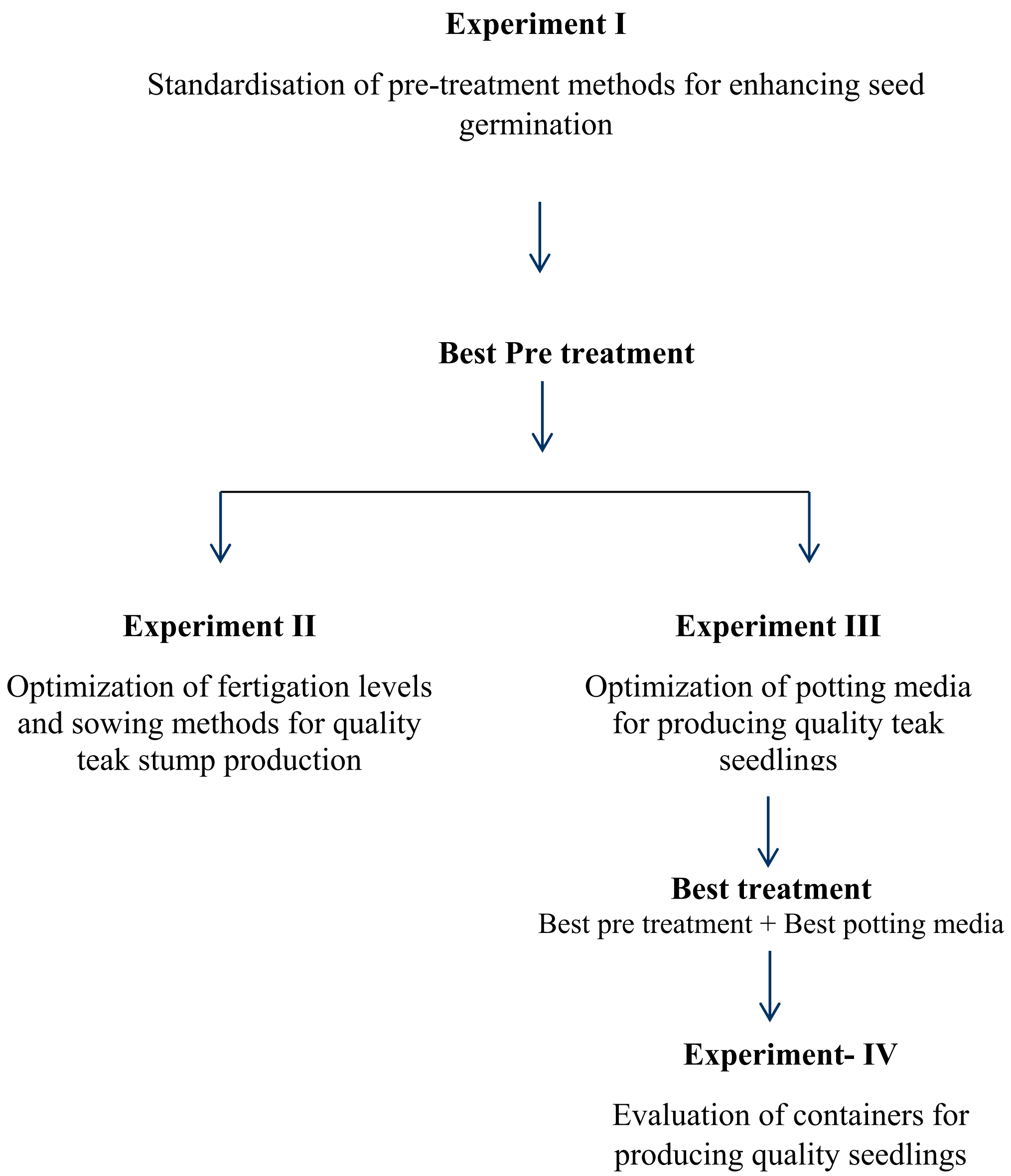


Fig 1. Flow chart of the experiments

3.3 EXPERIMENT I. STANDARDISATION OF PRE-TREATMENT METHODS FOR ENHANCING TEAK SEED GERMINATION

Teak seed germination studies were conducted in a factorial completely randomised design experiment with scarification methods as factor 1 and soaking treatments as the factor 2 (Table 1 and 2). The different treatments under both these factors were decided by taking the most successful treatments prevalent for the teak seed pre-treatment.

Plate 1.Teak seed grading

Plate 2. Teak seed mechanical scarifier

Plate 3. Mechanically scarified seeds

Plate 4. Termite scarified seeds

Plate 5. Untreated seeds (Control)

Three levels of factor 1 (Scarification methods) and eight levels of the factor 2 (Soaking treatment) constituted to make a total of twenty-four treatment combinations with four replications each.

3.3.1 Treatments

FACTOR-1

Table 1. Scarification methods applied for enhancing *Tectona grandis* seed germination

Factor1: Scarification methods (SM)	**Treatments**	
	SM1	Mechanically scarified seeds
	SM2	Termite scarified seeds
	SM3	Untreated seeds (Control)

FACTOR-2

The scarified seeds, as per the above treatments, were subjected to the following soaking treatments.

Table 2. Soaking Treatments applied for enhancing *Tectona grandis* seed germination

Factor 2: Soaking treatments (ST)	**Treatments**	
	ST1	Water soaking for 24 hours (WS 1 day)
	ST2	Water soaking for 72 hours (WS 3 days)
	ST3	Alternate wetting (12 hours) and drying(12 hours) one cycle for one day (AWD 1 day)
	ST4	Alternate wetting (12 hours) and drying(12 hours) three cycle for three days (AWD 3 days)
	ST5	Alternate wetting (12 hours) and drying (12 hours) seven cycle for 7 days (AWD 7 days) (standard practice/control)
	ST6	Acid scarification with 80% conc. H_2SO_4 for 5 min
	ST7	Acid scarification with 80% conc. H_2SO_4 for 15 min
	ST8	Acid scarification with 80% conc. H_2SO_4 for 25 min

Design	: Factorial CRD
Total treatments	: 24
Replication	:Four (100 seeds /replication)
Total experimental units	: 96

3.3.1.1 Mechanically scarified seeds:

A specially designed scarifying machine was used for mechanical scarification of seeds (Plate 2.) (Bapat and Phulari, 1995). This teak seed scarifying machine, like a huller or rice husker, is an agricultural machine used to automate the process of removing the chaff (the outer husks) of grains of rice. This particular machine is developed in the same concept of husks removing of paddy. The huller uses steel rollers to remove the husk. The same method is used with inducting 'chain link mesh' instead of huller. Chain link mesh is rolled inside of hulling equipment. Before scarification process, the teak seeds were soaked uniformly with water till the mesocarp gets softened. Around 2-3 days are needed for softening the mesocarp. After the seed gets softened, a specially designed machine was used to remove mesocarp of the seed. During scarification process sufficient water is used to reduce the amount of breakage of the teak seeds. After removal of mesocarp, the seed were again spread on the platform, then air dried and used for seed germination studies.

3.3.1.2 Termite scarified seeds

A moist and dark area was cleared and dried twigs, leaves and newspaper pieces were spread out to initiate termite activity. After three days, seeds were spread in this area covered with newspaper dry leaves and twigs. Seeds were slightly moistened during the initial two days and left undisturbed up to 10 days till the mesocarp was completely eaten away by the termites (Chacko, 1998). The seeds were then collected and used for the nursery studies.

Plate 6. Nursery bed preparation for seed sowing

Plate 7. Standard nursery bed prepared (10m x 1m)

3.3.2. Seed sowing in the nursery bed

The treated teak seeds-both mechanical and termite scarified and the untreated seeds (control), (Plate 3, 4 and 5) were subjected to germination evaluation in standard nursery beds (10m x 1m), (Plate 7). The nursery bed was prepared by adding well rotten and pulverized farm yard manure to the soil and firmly levelled. The soil was uniformly mixed with well decomposed and pulverized farm yard manure before sowing (Plate 6). For each of the treatment 400 seeds (100 seeds /replication) used for line sowing. The nursery beds were watered regularly on daily basis.

3.3.4 Germination characters

3.3.4.1 Germination percentage (%)

The number of seedlings produced in each replication was counted, and average was expressed in per cent.

$$\text{Germination (\%)} = \frac{\text{Number of normal seedlings}}{\text{Total number of seed sown}} \times 100$$

3.3.4.2 Mean Daily Germination (MDG)

The mean daily germination is calculated as the cumulative percent of full seed germination at the end of germination test, divided by the number of days from sowing to the end of the test

3.3.4.3 Peak Value of germination (PV)

Peak value of germination actually denotes the speeds of germination, which is the maximum mean daily germination, recoded at any time during the period of test

3.3.4.4 Germination Value (GV)

The Germination Value (GV) was calculated using the following formula suggested by (Czabator, 1962)

$$GV = MDG \times PV$$

3.3.5. Seedling Characters

The following seedling characters were recorded 30 days after sowing (30 DAS).

3.3.5.1 Collar diameter

Collar diameter of the seedlings was measured using a digital vernier calliper and the two diametrically opposite readings were noted and the mean recorded in millimetre.

3.3.5.2 Shoot length

The length of the shoot was measured from the tip of the main shoot to the collar region by using a meter scale and recorded in centimetre.

3.3.5.3 Root length

The length of the root was measured from the collar region to the tip of main tap root using a measuring scale and the mean length recorded in centimetres.

3.3.5.4 Total seedling length

All normal seedlings of each treatment were measured for length from root tip to shoot tip and the average was expressed in centimetres.

3.3.5.5 Seedling dry weight

The leaves stem and roots were separately dried in hot air oven maintained at $75^0 \pm 2^0$C to a constant weight. The dry weight was determined using electronic balance. From this the total dry weight was determined. The values were expressed as 'g seedlings^{-1}'.

3.3.5.6 Vigour Index

In the case of seeds sown in the nursery bed, the germinated seedlings were grown in the field up to one month. At the end, 10 seedlings from each replication were uprooted to measure the total dry weight. Vigour index (VI) was computed using the following formula and expressed as whole number (Abdul-Baki and Anderson, 1973).

Vigour index = Germination percentage x Total dry weight

3.4 EXPERIMENT II- OPTIMIZATION OF FERTIGATION LEVELS AND SOWING METHODS FOR QUALITY TEAK STUMP PRODUCTION

The best seed pre-treatment emerged successful from experiment- I *i.e.* Termite scarified seeds+ alternate wetting (12 hours) and drying (12 hours) three cycles for 3 days (SM2 X ST4) was used for this experiment. Fertigation with different spacing for seed sowing combination for quality stump production trail was conducted on teak seedling. The experimental design followed was split plot design with fertigation intervals treatments as main plot and seed sowing spacing as sub plots replicated thrice (Plate 8.). Treatment details as given below.

A. Main plot treatments

The main plot treatments include four fertigation intervals as given below (Table 3).

Table 3. Details of fertigation interval treatments applied to *Tectona grandis* seedlings raised for stump production

Fertigation intervals (F) NPK 19:19:19 @ 0.2% concentration	Fertigation at 7 days interval	F1
	Fertigation at 14 days interval	F2
	Fertigation at 21 days interval	F3
	No Fertigation (control)	F4

B. Sub - plot treatments

The sub plot included four levels of seed sowing methods (Table 4).

Table 4. Details of seed sowing spacing adopted for *Tectona grandis* seedlings raised for stump production.

Seed sowing spacing (S)	Spacing at 10cm x 10cm	S1
	Spacing at 15cm x 15cm	S2
	Spacing at 30cm x 30cm	S3
	Broadcasting(standard practices/ Control)	S4

Plot size:

Main plot size : 4mx1m (4m^2)

Sub plot size : 1mx1m

Replication : 3

Total number of main plots : 4 x 3= 12

Total experimental units : 4 x 4 x 3= 48

The main plot treatments (fertigation intervals) were laid out in 4m x1m bed area. In each of the main plots, the sub plot treatments (seed sowing spacing) were allocated randomly. There were a total of 16 combinations of fertigation intervals and seed sowing spacing which was replicated thrice such that there were total of 48 experimental units. As envisaged in the programme, the seed pre-treatment emerged as the best in experiment-I, *i.e.,* SM2 X ST4 (Termite scarified seeds+ alternate wetting (12 hours) and drying (12 hours) three cycle for 3 days) was taken for further investigation under this experiment. After the pre-treatment, seeds were sown in different spacing at 10cm x 10cm, 15cmx 15cm, 30cm x 30cm and broadcasting control was (@ 5kg/ standard bed), after the germination of seedlings, fertigation started at different days of interval (Plate 9 and 10). For fertigation, NPK 19:19:19 @ 0.2 % concentration used at the rate of 5 L per one square meter area.

Plate 8. Nursery bed preparation for teak stump

Plate 9. Initial growth of teak seedlings teak stump


A. 40 days growth


B. 50 days growth


C. 60 days growth


D. 80 days growth


E. 120 days growth


F. 180 days growth

Plate 10. Different growth stages of seedlings grown for teak stump production

From each subplot, six plants were labelled and tagged for taking seedling growth attributes i.e. number of leaves, height and collar diameter at 60, 120 and 180 days after sowing.

Simultaneously from all the treatments, three seedlings each (one seedling each at every sampling) per replication (16x3) were destructively sampled at 60, 120 and 180 days interval. At first the leaves were plucked for leaf area determination, and then the seedlings were taken out with the root system intact, washed thoroughly in running tap water and dried. The leaf area was measured quickly using a lea area meter (Model LI3100 LI –cor, Nebraska, USA) (Plate 11). The same leaves were subsequently used for the determination of leaf dry weight. All the biometric observations such as number of leaves, leaf area, shoot length, Root length, and collar diameter, number of primary lateral roots, length of the primary lateral roots, leaves dry weight, root biomass, shoot biomass, total biomass and Root: Shoot biomass ratio was determined. The observations were taken at 60, 120 & 180 days interval.

Plate 11. Leaf area meter

3.4.1 Root growth potential of stumps

At the end of 180 days after seed sowing, three seedlings per replication were taken to determine the root growth potential. Only those seedlings, which had a single taproot, were selected for this experiment and the plants with forked taproots were discarded. After pulling out the selected plants from nursery bed without disturbing the root system, observations on shoot length, taproot length, number of lateral roots, collar diameter, length of first, second and third longest lateral roots were made to find out the correlation between the seedling and stump characters. The shoot portion of these seedlings was detached with a sharp knife, leaving only three cm portion of shoot. Then all the lateral roots were cut off carefully, without damaging the bark of the taproots and the taproots was also cut at a distance of 20- 30 cm from the collar. The prepared stumps were planted in the polythene bag filled with finely sieved river sand and kept it in green house. After 28 days, stumps were taken out carefully with the newly produced intact roots system by splitting open the bags and washed thoroughly in running water. The washed seedling was then spread out on a table and the observations were recorded as follows.

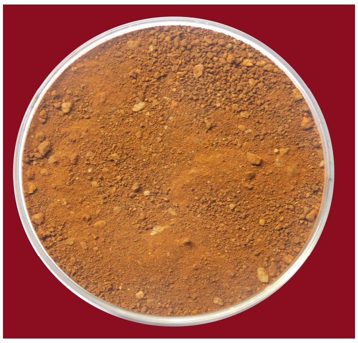
The number of fresh sprouts produced per stump was counted and mean sprouts number per stump was recorded. The length of sprouts was measured from the point of attached on collar to highest growing point and expressed in cm. the number of leaves on the sprouts also was recorded. The number of lateral and tertiary roots produced on the stump was recorded. Length of three longest lateral roots was recorded in cm. In order to determine the dry weight of lateral roots, it was detached from the taproot along with tertiary roots and dried in hot air oven maintained at 70^0C ± 2^0C till a constant weight achieved. The dry weight was determined using a high precision electronic balance machine.

3.5 EXPERIMENT III- OPTIMIZATION OF POTTING MEDIA FOR PRODUCING QUALITY TEAK SEEDLINGS

The best pre-treatment SM2 X ST4 (Termite scarified seeds X Alternate wetting (12 hours) and drying (12 hours) three cycle for three days) obtained from experiment I were used for this experiment and seeds were sown in standard seed beds of size 10m x1m for germination. The seedlings were transplanted in poly bag size of 25cm x 15cm at two leaf stage. Seedlings were subjected to the following potting media composition treatments (Table 5).

A. Perlite

B. Vermicompost

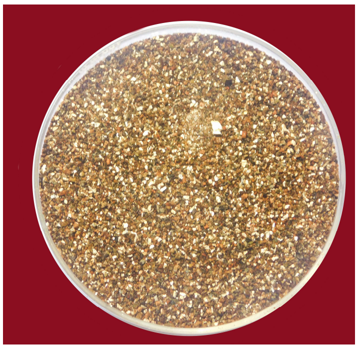


C. Soil

D. Rice husk

E. FYM

F. Sand



G. Vermiculite

H. Coir pith

Plate 12. Potting media used in the study

Table 5. Different potting media used for *Tectona grandis* seedling production

	Treatments	
	MT1	Soil+ coir pith compost+ FYM
	MT2	Soil+ coir pith compost+ vermicompost
	MT3	Soil+ rice husk+ vermicompost
	MT4	Coir pith+ vermiculite+ perlite
	MT5	Soil+ sand+ FYM (Control)
Replication		4 (25 seedlings /replication)
Design		CRD

In all the potting media treatments (Plate 11.), three different ingredients were taken by volume in the ratio 2:1:1 in the order of their mention.

Seedling growth observations *viz*., number of leaves, leaf area, collar diameter, shoot length, root length, total seedling length, number of primary lateral roots, length of the primary lateral roots, leaf dry weight, root dry weight, shoot dry weight, total dry weight, root biomass to shoot biomass ratio (Root: Shoot) recorded at monthly interval 30,60 and 90 days after planting (DAP).

3.5.1 Physiological observations

At the end of 30, 60 and 90 days after transplanting, six seedlings per replication were randomly selected to take physiological observations. Physiological attributes calculated using the below formulae:

3.5.1.1 Leaf Area Ratio (LAR)

Leaf area ratio as a measure of leaf area to the weight of the whole (Radford, 1967), it is expressed as cm^2g^1

$$LAR = \frac{Leaf\ Area}{Plant\ dry\ weight}$$

3.5.1.2 Leaf Weight Ratio (LWR)

It is the ratio of leaf dry weight to the plant dry weight. It is the measure of leafiness of the plant on a weight basis. It is expressed in g kg^{-1}

$$LWR - \frac{Leaf\ dry\ weight}{Plant\ dry\ weight}$$

3.5.1.3 Specific Leaf area (SLA)

It is the ratio assimilating area to its dry weight and expressed as cm^2 mg^{-1} (Kvet *et al.*, 1971).

$$SLA = \frac{Leaf\ area}{Leaf\ dry\ weight}$$

3.5.1.4 Specific Leaf Weight (SLW)

It is the ratio of leaf dry weight to its area of assimilating surface and expressed as

$$SPW = \frac{Leaf\ dry\ weight}{Leaf\ area}$$

3.5.1.5 Absolute Growth Rate (AGR)

Absolute growth rate is the dry matter production per unit time (g day^{-1}) which was calculated by using formula given by Radford (1967)

$$AGR = \frac{W2 - W1}{T2 - T1}$$

Where, W1 –Dry matter of the plant (g) at time T_1

W2 – Dry matter of the plant (g) at time T_2

3.5.1.6 Relative Growth Rate (RGR)

It is the rate of increase of dry weight per unit weight already present per unit time (Williams, 1946) and expressed as mg g^{-1}day-1

$$RGR = \frac{Loge\ W2 - Loge\ W1}{T2 - T1}$$

Where, W2 &W2 = Whole plant dry weight at T_1 and T_2

3.5.1.7 Net Assimilation Rate (NAR)

It is the rate of increase of leaf dry weight per unit area of leaf unit time (Williams, 1946) and expressed as mg cm^{-2} day^{-1}

$$NAR = \frac{Loge\ L1 - Loge\ L2}{L1 - L2}\ X\ \frac{W2 - W1}{T2 - T1}$$

Where, Log e L1 = Natural log of leaf area at stage 2

Log e L1 = Natural log of leaf area at stage 1

L2 & L1 = Leaf area at stage 2 & 1 respectively

W2 & W1 = Dry weight of the whole plant at stage 2 & 1 respectively

T2-T1 = Time interval between the two stages

3.5.1.8 Quality index (Dickson et al., 1960)

$$Quality\ index = \frac{Total\ dry\ weight\ of\ seedlings\ (g)}{\frac{Height\ of\ seedling\ (cm)}{Diameter\ of\ seedlings\ (mm)} + \frac{Shoot\ dry\ weight\ (g)}{Root\ dry\ weight\ (g)}}$$

3.6 EXPERIMENT IV: EVALUATION OF CONTAINERS FOR PRODUCING QUALITY TEAK SEEDLINGS.

The best seed pre-treatment emerged from Experiment- I i.e. Termite scarified seeds+ alternate wetting (12 hours) and drying (12 hours) three cycle for 3 days and the best potting media obtained from experiment-III, Soil+ rice husk+ vermicompost in 2:1:1 ratio (T3) were used in this experiment. Seeds were sown in seed beds of size 10m x1m for germination after two leaf stage seedlings were transplanted. Seedlings were subjected to the following different containers to be tested as follows treatments (Table 6).

Table 6. Types and size of containers used for *Tectona grandis* seedling production

Treatments	
T1	Poly bag of 30cm x25cm
T2	Poly bag of 30cm x20cm
T3	Poly bag of 25cm x 15cm (Standard practice/Control)
T4	Root trainer of 300 cc
T5	Root trainer of 200 cc
T6	Root trainer of 150 cc (Standard practice/Control)
Replications : 4 (25 seedlings /replication)	
Design: CRD	

3.7. STATISTICAL ANALYSIS

Completely Randomised Design, Factorial CRD and spilt plot designs were used in the experiment. Pearson's bivariate correlation was used for testing the relation between the root growth potential of the stumps and the seedling characters. Regression analysis was carried out between the collar diameter and seedling height. The data analysis was done using R environment in Agricolae (Mendiburu, 2015).

RESULTS

4. RESULTS

The present study was undertaken to compare the effect of different pre-treatment methods on seed germination and optimization of fertigation intervals and sowing methods at different spacing for quality teak stump production. Attempt was also made to select ideal potting media and to standardize container types and size for producing quality teak seedlings. The detailed results of the study are given below

4.1 STANDARDISATION OF PRE-TREATMENT METHODS FOR ENHANCING SEED GERMINATION

Nursery performance of pre-treatment methods for enhancing seed germination (scarification methods as factor 1 with three levels i.e. SM1- Mechanically scarified seeds, SM2- Termite scarified seeds, SM3- Untreated seeds (control) and the factor 2 with eight levels of soaking treatments viz. ST1- Water soaking for 24 hours (WS 1 day), ST2- Water soaking for 72 hours (WS 3 days), ST3- Alternate wetting (12 hours) and drying (12 hours) one cycle for 1 day (AWD 1 day), ST4- Alternate wetting (12 hours) and drying (12 hours) three cycle for 3 days (AWD 3 days), ST5- Alternate wetting (12 hours) and drying (12 hours) seven cycle for 7 days (AWD 7 days), ST6- Acid scarification with 80% concentrated H_2SO_4 for 5 minutes, ST7- Acid scarification with 80% concentrated H_2SO_4 for 15 minutes and ST8- Acid scarification with 80% concentrated H_2SO_4 for 25 minutes. Germination and growth characteristics of the teak seedlings were evaluated as a function of the pretreatments. The salient results are presented hereunder.

4.1.1 Effect of scarification methods and soaking treatments on seed germination characteristics of *Tectona grandis*

Effect of scarification methods (SM) and soaking treatments (ST) on seed germination showed significant effect in response to different treatments (p=0.000). The highest germination percentage was recorded in SM2 (Termite scarified seeds) 63.04 per cent followed by 54.29 per cent germination in SM1 (Mechanically scarified seeds) treatment while the germination per cent for SM3 (untreated seeds) was only 40.79 % (Table 7).

Table 7. Effect of scarification methods and soaking treatments on seed germination of *Tectona grandis*

Factors	Treatments	Germination (%)
1. Scarification Methods (SM)	**SM1**- Mechanically scarified seeds	54.29[b] (47.46)
	SM2- Termite scarified seeds	63.04[a] (52.56)
	SM3- Untreated Seeds (Control)	40.79[c] (39.69)
	F value	948.10**
	P value	<0.01
	CD (0.05)	1.03
2. Soaking Treatments (ST)	**ST1**- Water soaking for one day (control)	57.00[e] (49.02)
	ST2- Water soaking for three days	61.33[c] (51.55)
	ST3- Alternate wetting and drying for one day	59.44[d] (50.44)
	ST4- Alternate wetting and drying for three days	71.66[b] (57.84)
	ST5- Alternate wetting and drying for seven days (Standard practice)	73.77[a] (59.19)
	ST6- Acid scarification with 80% conc. H_2SO_4 for 5 min	38.66[f] (38.45)
	ST7- Acid scarification with 80% conc. H_2SO_4 for 15 min	31.11[g] (33.90)
	ST8- Acid scarification with 80% conc. H_2SO_4 for 25 min	28.66[h] (32.37)
	F value	882.51**
	P value	<0.01
	CD (0.05)	1.69
Interaction (SM X ST)	F value	246.70**
	P value	<0.01
	CD (0.05)	2.93

**Significant at 1% level * Significant at 5% level NS-Non Significant
Treatments with the same superscript do not differ significantly
Figures in parentheses indicate arc-sine values

Among the different soaking treatment studied, ST5 (AWD - 7days, the standard practice followed) recorded maximum germination per cent of 73.77 followed by ST4 ie. AWD for 3 days (71.66 %). The lowest germination percentage was noticed in ST8 (28.66). All the acid scarification with 80% conc. H_2SO_4 treatment were significantly lower (Table 7).

The Interaction effect between scarification methods and soaking treatments (SM X ST) was also significant w.r.to seed germination percentage (Table 8). The treatment combination SM2 X ST4 gave the highest value (92.33 %) followed by SM2 X ST5 (89 %), SM2 X ST2 (84.33 %), SM2 X ST3 (81 %). The lowest value (14.33 %) was recorded by the combination SM2 X ST8. Means for all the acid scarification treatments (ST6, ST7 and ST8) over different soaking methods were very low as compared to other treatments (Table 8).

The effect of scarification methods and soaking treatments on mean daily germination, peak value and germination value in teak seeds is given in Table 9. Among the scarification methods, the highest values of mean daily germination, peak value and germination value (1.343, 2.76 and 3.71 respectively) were recorded in SM2 (Termite scarified seeds) whereas the lowest and corresponding values for SM3 (untreated seeds) were 0.573, 1.12 and 0.64 respectively.

The soaking treatment exhibited significant difference with maximum mean daily germination of 1.49 (ST4) followed by ST5 (1.42), whereas minimum mean daily germination was recorded was as low as 0.34 (ST8). The highest peak values of 2.62 was recorded both in ST3 and ST4. The lowest peak value was recorded in ST8 and ST7 (0.34 and 0.35). Germination value also showed significant difference with highest germination value of 3.90 (ST4) followed by ST3 and ST5 (2.99 and 2.81 respectively) both were on par with each other. The lowest germination value was recorded in ST8 and ST7 (0.33 and 0.37) (Table 9).

Table 8. Interaction effect of scarification methods and soaking treatments on seed germination of *Tectona grandis*

SM / ST	Germination (%)							
	ST1	ST2	ST3	ST4	ST5	ST6	ST7	ST8
SM1	59.33^{fg} (50.38)	64.33^{f} (53.33)	62.67^{f} (52.34)	74.00^{e} (59.34)	77.00^{de} (61.34)	39.6^{ij} (39.04)	34.33^{jk} (35.87)	23.00^{l} (28.66)
SM2	77.33^{de} (61.57)	84.33^{bc} (66.68)	81.00^{cd} (64.16)	**92.33^{a} (73.93)**	**89.00^{ab} (70.63)**	45.00^{hi} (42.13)	**21.00^{l} (27.27)**	**14.33^{m} (22.25)**
SM3	34.33^{jk} (35.87)	35.33^{jk} (36.47)	34.67^{jk} (36.07)	48.67^{h} (44.24)	55.33^{g} (48.06)	31.33^{k} (34.04)	38.00^{j} (38.06)	48.67h (44.24)

Treatments with the same superscript do not differ significantly.
Figures in parentheses indicate arc-sine values

Scarification Methods (SM)

SM1- Mechanically scarified seeds

SM2- Termite scarified seeds

SM3- Untreated Seeds (Control)

Soaking Treatments (ST)

ST1- Water soaking for one day (Control)

ST2- Water soaking for three days

ST3- Alternate wetting and drying for one day

ST4- Alternate wetting and drying for three days

ST5- Alternate wetting and drying for seven days (Standard practice)

ST6- Acid scarification with 80% conc. H_2SO_4 for 5 min

ST7- Acid scarification with 80% conc. H_2SO_4 for 15 min

ST8- Acid scarification with 80% conc. H_2SO_4 for 25 min

Table 9. Effect of scarification methods and soaking treatments on seed germination characteristics of *Tectona grandis*

Factors	Treatments	Mean Daily Germination	Peak Value	Germination Value
1. Scarification Methods (SM)	**SM1-** Mechanically scarified seeds	1.00	1.74	1.74
	SM2- Termite scarified seeds	1.34	2.76	3.71
	SM3- Untreated Seeds (Control)	0.57	1.12	0.64
2. Soaking Treatments (ST)	**ST1-** Water soaking for one day (control)	1.12	2.08	2.33
	ST2- Water soaking for three days	1.29	1.80	2.32
	ST3- Alternate wetting and drying for one day	1.14	2.62	2.99
	ST4- Alternate wetting and drying for three days	1.49	2.62	3.90
	ST5- Alternate wetting and drying for seven days (Standard practice)	1.42	1.98	2.81
	ST6- Acid scarification with 80% conc. H_2SO_4 for 5 min	0.59	1.81	1.07
	ST7- Acid scarification with 80% conc. H_2SO_4 for 15 min	0.35	1.05	0.37
	ST8- Acid scarification with 80% conc. H_2SO_4 for 25 min	0.34	0.98	0.33

4.1.2 Effect of scarification methods and soaking treatments on seedling characteristics

4.1.2.1 Collar diameter

Among the scarification methods, SM2 and SM1 recorded significantly higher collar diameter (1.46 and 1.45 mm), which were on par with each other. While the control treatment SM3 (untreated seeds) recorded the lowest collar diameter of 0.81 mm (Table 10).

Soaking treatment showed statistically significant effect on seedling collar diameter. Among the soaking treatment ST4 (AWD 3 days) produced larger collar diameter (1.38 mm) followed by ST5-AWD 7 days (1.33 mm). The lowest collar diameter was observed in ST1 (1.16 mm), ST2 (1.16 mm), and ST6 (1.19 mm) which was on par with each other (Table 10).

The interaction effect between scarification methods and soaking treatments (SM X ST) also had significant effect on collar diameter of seedlings after the 30 days of germination (Table 11). The treatment combination SM1 X ST8 gave the maximum collar diameter (1.92 mm) followed by SM1 X ST7 (1.89 mm), which were on par with each other and next best was SM2 X ST4 and SM2 X ST5 (1.69 and 1.66 mm). The lowest collar diameter (0.52 mm) was recorded by both the combinations of SM3 X ST7 (Untreated seeds + Conc. H_2SO_4 for 15 minutes) and SM3 x ST8 (Untreated seeds + Conc. H_2SO_4 for 25 minutes).

4.1.2.2 Shoot length

Scarification methods and soaking treatments had a significant influence on the shoot length of teak seedlings (Table 10). Significant difference was observed between different scarification methods on shoot length of the seedlings. Significantly highest shoot length (6.43 cm) was recorded by SM2 (Termite scarified seeds) pretreatment. The SM3 (untreated seeds) treatment recorded the lowest shoot length of 4.36 cm.

Table 10. Effect of scarification methods and soaking treatments on seedling characteristics of *Tectona grandis* at 30 DAS

Factors	Treatments	Collar diameter (mm)	Shoot length (cm)	Root length (cm)	Total seedling height (cm)
1. Scarification Methods (SM)	**SM1-** Mechanically scarified seeds	1.45[a]	5.24[b]	11.43[b]	16.67[b]
	SM2- Termite scarified seeds	1.46[a]	6.43[a]	13.04[a]	19.48[a]
	SM3- Untreated Seeds (Control)	0.81[b]	4.36[c]	10.90[c]	15.27[c]
	F value	2494.31**	7619.70**	10911.51**	17479.7**
	P value	<0.01	<0.01	<0.01	<0.01
	CD (0.05)	0.021	0.03	0.03	0.04
2. Soaking Treatments (ST)	**ST1-** Water soaking for one day (Control)	1.16[f]	5.75[b]	11.81[d]	17.55[d]
	ST2- Water soaking for three days	1.16[f]	5.43[d]	11.76[d]	17.20[e]
	ST3- Alternate wetting and drying for one day	1.27c	5.77[b]	12.52[c]	18.29[c]
	ST4- Alternate wetting and drying for three days	1.38[a]	5.99[a]	13.36[a]	19.35[a]
	ST5- Alternate wetting and drying for seven days (Standard practice)	1.33[b]	5.61[c]	13.14[b]	18.76[b]
	ST6- Acid scarification with 80% conc. H_2SO_4 for 5 min	1.19[ef]	4.65[f]	11.02[e]	15.67[f]
	ST7- Acid scarification with 80% conc. H_2SO_4 for 15 min	1.22[d]	4.19[g]	10.66[f]	14.85[h]
	ST8- Acid scarification with 80% conc. H_2SO_4 for 25 min	1.21[de]	5.37[e]	10.02[g]	15.40[g]
	F value	43.74**	1008.64**	4615.62**	3972.98**
	P value	<0.01	<0.01	<0.01	<0.01
	CD (0.05)	0.03	0.05	0.49	0.07
Interaction (SM X ST)	F value	155.64**	665.96**	319.80**	692.06**
	P value	<0.01	<0.01	<0.01	<0.01
	CD (0.05)	0.060	0.09	0.08	0.13

**Significant at 1% level * Significant at 5% level NS-Non Significant

Treatments with the same superscript do not differ significantly

Table 11. Interaction effect of scarification methods and soaking treatments on collar diameter of *Tectona grandis* at 30 DAS

SM / ST	Collar diameter (mm)							
	ST1	**ST2**	**ST3**	**ST4**	**ST5**	**ST6**	**ST7**	**ST8**
SM1	1.21^{e}	1.22^{e}	1.26^{e}	1.47^{cd}	1.45^{cd}	1.22^{e}	1.89^{a}	1.92^{a}
SM2	1.49^{cd}	1.43^{cd}	1.53^{c}	1.69^{b}	1.66^{b}	1.41d	1.27^{e}	1.21^{e}
SM3	0.78^{i}	0.85^{hi}	1.05^{f}	0.98^{fg}	0.89^{ghi}	0.94^{gh}	0.52^{j}	0.52^{j}

Treatments with the same superscript do not differ significantly

Scarification Methods (SM)

SM1- Mechanically scarified seeds

SM2- Termite scarified seeds

SM3- Untreated Seeds (Control)

Soaking Treatments (ST)

ST1- Water soaking for one day (Control)

ST2- Water soaking for three days

ST3- Alternate wetting and drying for one day

ST4- Alternate wetting and drying for three days

ST5- Alternate wetting and drying for seven days (Standard practice)

ST6- Acid scarification with 80% conc. H_2SO_4 for 5 min

ST7- Acid scarification with 80% conc. H_2SO_4 for 15 min

ST8- Acid scarification with 80% conc. H_2SO_4 for 25 min

The effect of soaking treatment on teak seedling shoot length showed significant difference with the maximum value 5.99 cm (ST4-AWD-3 days) followed by ST1 (5.75 cm), which was on par with ST3 (5.77 cm) (Table 10). Minimum shoot lengths were recorded in all the three acid treatments (ST6, ST7 and ST8 with 4.65 cm, 4.19 cm and 5.37 cm respectively). The Interaction effect between the scarification methods and soaking treatments also had significant effect on shoot length of teak seedlings (Table 12). The treatment combination SM2 X ST4 gave the highest value (7.60 cm) followed by SM2 X ST5 (7.44 cm), SM2 X ST1 (7.38 cm). The lowest shoot length (3.93) was recorded by the combination SM3 X ST7 and SM3 X ST8 (Table 12).

4.1.2.3 Root length

Root length was influenced by scarification methods and soaking treatments (Table 10). The maximum root length was noticed in SM2 (13.04 cm) among the scarification methods, in which lowest root length recoded in SM3 (10.90 cm).

The soaking treatments showed significant difference in root length between the treatments, the highest root length being in ST4 (13.36 cm) and ST5 (13.14 cm). The lowest root length noticed in ST8 and ST7 (10.66 and 10.02 cm) (Table 10).

The interaction effect between the scarification methods and soaking treatments showed statistically significant effect on root length. The treatment combination SM2 X SM4 and SM2 X SM5 gave the higher root length (14.6 and 14.5 cm), which were on par with each other followed by SM2 X ST1 and SM2 X ST2 (13.5 cm). The lowest root length (9.5 cm) was recorded by the combination of SM3 x ST8 (Table 13).

4.1.2.4 Total seedling length

Scarification methods and soaking treatments showed significant effect with respect to total seedling length. Among the different scarification methods, highest total seedling length was recorded in SM2 (19.48 cm) followed by SM1 (16.67 cm)

Table 12. Interaction effect of scarification methods and soaking treatments on shoot length of *Tectona grandis* at 30 DAS

SM / ST	Shoot length (cm)							
	ST1	**ST2**	**ST3**	**ST4**	**ST5**	**ST6**	**ST7**	**ST8**
SM1	5.24^{f}	5.03^{gh}	5.56^{e}	5.56^{e}	4.78^{ijk}	4.53^{l}	4.03^{n}	7.24^{cd}
SM2	7.38^{bc}	7.06^{d}	7.23^{cd}	7.60^{a}	7.44^{ab}	5.18^{fg}	4.61^{kl}	4.96^{hi}
SM3	4.62^{kl}	4.23^{m}	4.53^{l}	4.81^{ij}	4.63^{jkl}	4.24^{m}	3.93^{n}	3.93^{n}

Treatments with the same superscript do not differ significantly

Scarification Methods (SM)

SM1- Mechanically scarified seeds

SM2- Termite scarified seeds

SM3- Untreated Seeds (Control)

Soaking Treatments (ST)

ST1- Water soaking for one day (Control)

ST2- Water soaking for three days

ST3- Alternate wetting and drying for one day

ST4- Alternate wetting and drying for three days

ST5- Alternate wetting and drying for seven days (Standard practice)

ST6- Acid scarification with 80% conc. H_2SO_4 for 5 min

ST7- Acid scarification with 80% conc. H_2SO_4 for 15 min

ST8-Acid scarification with 80% conc. H_2SO_4 for 25 min

Table 13. Interaction effect of scarification methods and soaking treatments on root length of *Tectona grandis* at 30 DAS

SM / ST	Root length (cm)							
	ST1	**ST2**	**ST3**	**ST4**	**ST5**	**ST6**	**ST7**	**ST8**
SM1	11.4^{f}	11.9^{e}	12.0^{e}	12.5^{d}	12.4^{d}	10.5^{g}	10.5^{g}	10.1^{h}
SM2	13.5^{b}	13.5^{b}	13.6^{b}	14.6^{a}	14.5^{a}	12.6^{d}	11.5^{f}	10.5^{g}
SM3	10.5^{g}	9.8^{i}	11.9^{e}	13.0^{c}	12.5^{d}	10.0^{hi}	10.0^{hi}	9.5^{j}

Treatments with the same superscript do not differ significantly

Scarification Methods (SM)

SM1- Mechanically scarified seeds

SM2- Termite scarified seeds

SM3- Untreated Seeds (Control)

Soaking Treatments (ST)

ST1- Water soaking for one day (Control)

ST2- Water soaking for three days

ST3- Alternate wetting and drying for one day

ST4- Alternate wetting and drying for three days

ST5- Alternate wetting and drying for seven days (Standard practice)

ST6- Acid scarification with 80% conc. H_2SO_4 for 5 min

ST7- Acid scarification with 80% conc. H_2SO_4 for 15 min

ST8- Acid scarification with 80% conc. H_2SO_4 for 25 min

and the shortest seedlings was SM3 (15.27 cm). Significant differences were observed with soaking treatments also. Among the different treatments, ST4 recorded the maximum total seedling height (19.35 cm) followed by ST5 (18.76 cm). The lowest total seedling height was noticed in ST7 (14.85 cm) (Table 10). The Interaction effect between scarification methods and soaking treatments (SM X ST) was also significant on total seedling height (Table 14). The treatment combination SM2 X ST4 and SM2 X ST5 gave the higher value (22.18 and 21.97 cm) followed by SM2 X ST1 (20.89 cm), SM2 X ST2 (20.58 cm), SM2 X ST3 (20.85 cm), these three were on par. The lowest value (13.90 and 13.46 cm) was recorded by the combination SM3 X ST7 and SM3 X ST8.

4.1.2.5 Total dry weight

The results of the scarification methods and soaking treatments exhibited significant difference on total dry weight of seedlings (Table 15). Among the different scarification methods, significantly higher dry weight of seedling was noticed in SM2 (0.20 g). Then followed by SM1 and SM3 (0.12 and 0.11 g) which were on par. With regard to soaking treatments, the seedlings with higher dry weight was recorded in ST4-AWD 3 days and ST5-AWD 7days (0.20 and 0.19 g) and which were on par with each other followed by ST1, ST2 and ST3 and the lowest dry weight was in ST8 (0.09 g).

The interaction between the scarification methods and soaking treatments showed significant effect on total dry weight ($p= 0.000$) (Table 16). The highest total dry weight recorded was 0.29 g (SM2 X ST4) followed by 0.277 g (SM2 X ST5). The lowest total dry weight (0.83 g) was noticed in (SM1 X ST7) and (SM1 X ST8).

4.1.2.6 Vigour index

All the pretreatments (scarification methods and soaking treatments) showed significant values for vigour index. Scarification treatment SM2 recorded high vigour index 14.91 and low vigour index was recorded in SM3 (5.16). Among the soaking treatments maximum vigour index was noticed in ST4 and ST5 (15.59 and 15.13) these two were on par with each other. ST1, ST2 and ST3 recorded the similar value

(10.39, 10.51 and 10.16), however all these three values were on par. The lowest vigour index noticed in ST8 (2.68) (Table 15).

Significant differences were noticed in their interaction effect also. SM2 X ST4 has recorded maximum vigour index (27.077) followed by SM2 X ST5 (24.623). Lowest vigour index was noticed in SM2 X ST8 (1.77) Table 17.

Table 14. Interaction effect of scarification methods and soaking treatments on total seedling length of *Tectona grandis* at 30 DAS

SM / ST	Total Seedling length (cm)							
	ST1	**ST2**	**ST3**	**ST4**	**ST5**	**ST6**	**ST7**	**ST8**
SM1	16.66^{hi}	16.95^{gh}	17.61^{de}	18.09^{c}	17.17^{fg}	15.07^{l}	14.55^{m}	17.29^{ef}
SM2	20.89^{b}	20.58^{b}	20.85^{b}	22.18^{a}	21.97^{a}	17.75^{d}	16.12^{j}	15.47^{k}
SM3	15.12^{l}	14.07^{m}	16.44^{ij}	17.79^{cd}	17.17^{fg}	14.21^{n}	13.90^{n}	13.46^{o}

Treatments with the same superscript do not differ significantly

Scarification Methods (SM)

SM1- Mechanically scarified seeds
SM2- Termite scarified seeds
SM3- Untreated Seeds (Control)

Soaking Treatments (ST)

ST1- Water soaking for one day (Control)
ST2- Water soaking for three days
ST3- Alternate wetting and drying for one day
ST4- Alternate wetting and drying for three days
ST5- Alternate wetting and drying for seven days (Standard practice)
ST6- Acid scarification with 80% conc. H_2SO_4 for 5 min
ST7- Acid scarification with 80% conc. H_2SO_4 for 15 min
ST8- Acid scarification with 80% conc. H_2SO_4 for 25 min

Table 15. Effect of scarification methods and soaking treatments on seedling characteristics of *Tectona grandis* at 30 DAS

Factors	Treatments	Total dry weight (g)	Vigour index
1. Scarification Methods (SM)	**SM1**- Mechanically scarified seeds	0.12^{b}	7.03^{b}
	SM2- Termite scarified seeds	0.20^{a}	14.91^{a}
	SM3- Untreated Seeds (Control)	0.11^{b}	5.16^{c}
	F value	742.10**	1576.49**
	P value	<0.01	<0.01
	CD (0.05)	0.005	0.37
2. Soaking Treatments (ST)	**ST1**- Water soaking for one day (Control)	0.17^{b}	10.39^{b}
	ST2- Water soaking for three days	0.15^{c}	10.51^{b}
	ST3- Alternate wetting and drying for one day	0.16^{c}	10.16^{b}
	ST4- Alternate wetting and drying for three days	0.20^{a}	15.59^{a}
	ST5- Alternate wetting and drying for seven days (Standard practice)	0.19^{a}	15.13^{a}
	ST6- Acid scarification with 80% conc. H_2SO_4 for 5 min	0.11^{d}	4.47^{c}
	ST7- Acid scarification with 80% conc. H_2SO_4 for 15 min	0.11^{d}	3.33^{d}
	ST8- Acid scarification with 80% conc. H_2SO_4 for 25 min	0.09^{e}	2.68^{e}
	F value	178.61**	564.90**
	P value	<0.01	<0.01
	CD (0.05)	0.008	0.60
Interaction (SM X ST)	F value	29.74**	152.64**
	P value	<0.01	<0.01
	CD (0.05)	0.01	1.05

**Significant at 1% level * Significant at 5% level NS-Non Significant

Treatments with the same superscript do not differ significantly

Table 16. Interaction effect of scarification methods and soaking treatments on total dry weight of *Tectona grandis* at 30 DAS

SM / ST	Total dry weight (g)							
	ST1	**ST2**	**ST3**	**ST4**	**ST5**	**ST6**	**ST7**	**ST8**
SM1	0.11^{ijk}	0.12^{hij}	0.14^{fghi}	0.17^{e}	0.16^{ef}	0.09^{kl}	0.08^{l}	0.08^{l}
SM2	0.25^{bc}	0.24^{cd}	0.22^{d}	0.29^{a}	0.28^{ab}	0.14^{fghi}	0.13^{ghij}	0.12^{hij}
SM3	0.15^{efgh}	0.11^{jkl}	0.13^{ghij}	0.15^{efgh}	0.15^{efg}	0.11^{ijk}	0.12^{ijk}	0.09^{kl}

Treatments with the same superscript do not differ significantly

Scarification Methods (SM)

SM1- Mechanically scarified seeds

SM2- Termite scarified seeds

SM3- Untreated Seeds (Control)

Soaking Treatments (ST)

ST1- Water soaking for one day (Control)

ST2- Water soaking for three days

ST3- Alternate wetting and drying for one day

ST4- Alternate wetting and drying for three days

ST5- Alternate wetting and drying for seven days (Standard practice)

ST6- Acid scarification with 80% conc. H_2SO_4 for 5 min

ST7- Acid scarification with 80% conc. H_2SO_4 for 15 min

ST8- Acid scarification with 80% conc. H_2SO_4 for 25 min

Table 17. Interaction effect of scarification methods and soaking treatments on vigour index of *Tectona grandis* at 30 DAS

SM / ST	Vigour index							
	ST1	**ST2**	**ST3**	**ST4**	**ST5**	**ST6**	**ST7**	**ST8**
SM1	6.72^{fgh}	7.83^{fg}	8.56^{f}	12.58^{e}	12.29^{e}	3.57^{fgh}	2.86^{kl}	1.91^{l}
SM2	19.33^{cd}	19.96^{c}	17.55^{d}	27.08^{a}	24.62^{b}	6.30^{ghi}	2.73^{kl}	1.77^{l}
SM3	5.15^{hij}	3.77^{jkl}	4.39^{fgh}	7.14^{fgh}	8.49^{f}	3.57^{jkl}	4.43^{ijk}	4.38^{ijk}

Treatments with the same superscript do not differ significantly

Scarification Methods (SM)

SM1- Mechanically scarified seeds

SM2- Termite scarified seeds

SM3- Untreated Seeds (Control)

Soaking Treatments (ST)

ST1- Water soaking for one day (Control)

ST2- Water soaking for three days

ST3- Alternate wetting and drying for one day

ST4- Alternate wetting and drying for three days

ST5- Alternate wetting and drying for seven days (Standard practice)

ST6- Acid scarification with 80% conc. H_2SO_4 for 5 min

ST7- Acid scarification with 80% conc. H_2SO_4 for 15 min

ST8- Acid scarification with 80% conc. H_2SO_4 for 25 min

4.2 OPTIMIZATION OF FERTIGATION LEVELS AND SOWING METHODS FOR QUALITY TEAK STUMP PRODUCTION

Fertigation with different spacing combination trail was conducted on teak seedlings in a split plot design with Fertigation Interval (F) as the main plot treatment (with NPK 19:19:19 @0.2% concentration) and seed sowing spacing (S) as a sub plot treatment. The main plot treatments were F1- Fertigation at 7 days interval, F2- Fertigation at 14 days interval, F3- Fertigation at 21 days and F4- No Fertigation (control) respectively. The subplot treatments are four different seed sowing spacing *viz.* S1 -10cm x10cm (with density of 1000 seedlings per standard bed size of 10m x 1 m), S2 -15cm x15cm (with density of 600 seedlings per standard bed size of 10m x 1m), S3 -30cm x30cm (with density of 90 seedlings per standard bed size of 10m x 1 m) and S4 - broadcasting control. Observations on *Tectona grandis* seedlings as function of the Fertigation interval and different sowing methods were recorded and the detailed results are depicted below.

4.2.1 Growth characteristics of *Tectona grandis* seedlings raised for stump production in the nursery

The effect of Fertigation interval and seed sowing methods at different spacing on the growth characteristics like Leaf parameters, collar diameter, shoot length, root length and total seedling length and primary lateral rots of *Tectona grandis* seedlings raised for stump production in the nursery at different stages of growth is depicted in below tables.

4.2.1.1 Leaf parameters

The response to fertigation interval and seed sowing methods on leaf production *viz.* number of leaves, leaf area and leaf dry weight of *Tectona grandis* seedlings raised for stump production in the nursery is presented in table 18.

4.2.1.1.1 Number of leaves

The maximum number of leaves in teak seedlings was observed in the fertigation interval (F2- Fertigation at 14 days interval) for 60 and 90 days periods of

Table 18. Effect of fertigation interval and seed sowing spacing on leaf parameters of *Tectona grandis* seedlings raised for stump production up to 180 days of growth

Treatments	Number of leaves			Leaf Area (cm^2)			Leaf Dry Weight (g)		
	60 days	120 days	180 days	60 days	120 days	180 days	60 days	120 days	180 days
Fertigation Interval (F)									
F1- Fertigation at 7 days interval	11.16[ab]	12.00	15.66[a]	2234.44[a]	4629.32[a]	8517.45[a]	13.10[a]	44.38[ab]	102.47[a]
F2- Fertigation at 14 days interval	12.91[a]	14.16	14.08[a]	1991.28[b]	2947.47[b]	7516.36[b]	11.94[b]	44.54[a]	62.78[b]
F3- Fertigation at 21 days interval	10.00[b]	13.16	15.83[a]	1757.36[c]	3181.25[b]	5371.38[c]	10.65[c]	41.67[b]	59.61[b]
F4- No Fertigation (control)	11.33[ab]	13.25	11.25[b]	1520.85[d]	1121.58[c]	3542.35[d]	9.17[d]	27.00[c]	49.85[c]
F value	4.60*	2.13	11.31**	99.54**	15.93**	988.88**	258.90**	103.20**	478.64**
P value	<0.05	0.19	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CD(0.05)	1.93	NS	2.18	106.33	1247.91	244.80	0.36	2.85	3.66
Seed sowing spacing (S)									
S1-Spacing at 10cm x10cm	11.33[b]	12.75[a]	11.33[c]	1456.18[c]	1896.91[b]	3529.33[c]	9.37[c]	29.40[c]	42.98[c]
S2-Spacing at 15cm x15cm	12.08[b]	14.41[a]	17.16[b]	1662.93[b]	2488.65[b]	7467.04[b]	11.05[b]	50.06[b]	84.29[b]
S3-Spacing at 30cm x30cm	13.33[a]	15.08[a]	22.41[a]	3955.43[a]	7017.43[a]	13400[a]	21.89[a]	63.74[a]	134.43[a]
S4-Broadcasting (Control)	8.66[c]	10.33[b]	5.91[d]	420.38[d]	476.64[c]	550.96[d]	2.55[d]	14.39[d]	13.02[d]
Mean	11.35	13.14	14.20	1875.98	2969.91	6236.88	11.22	39.40	68.68
F value	25.75**	6.96**	245.03**	3822.88**	58.35**	5837.50**	4740.89**	1923.85**	2040.16**
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CD (0.05)	1.13	2.34	1.33	70.32	1080.28	212.11	0.33	1.45	3.40
Fertigation X Seed sowing spacing (F XS)									
F value	1.66	1.099	8.25**	23.60**	5.60**	254.11**	48.14**	32.38**	91.39**
P value	0.15	0.399	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
CD (0.05)	NS	NS	2.66	140.64	2160.57	424.22	0.67	2.90	6.80

**Significant at 1% level - * Significant at 5% level NS-Non significant

Treatments with the same superscript do not differ significantly

observation, however the difference was not significant. At the end of 180 days after Fertigation application, all the three fertigation treatments F1, F2 and F3 gave the significantly higher number of leaves (15.83 and 15.66 and 14.08 respectively) which were on par with each other and the lowest number of leaves (11.25) was recorded in the no fertilized control plots.

Seed sowing at different spacing had highly significant effect on the number of leaves of *Tectona grandis* seedlings raised for stump production in the nursery (p=0.000). The average number of leaves of teak seedling were 8.66, 11.33, 12.08 and 13.33 for spacing S4 (broadcasting control), S1, S2 and S3 (30 cm x 30 cm) respectively after 60 days of sowing. At 120 days, all spacing treatments except the control (S4) were showing more or less uniform number of leaves and were on par with each other. However, at the end of 180 days after seed sowing, significantly distinct number of leaves (22.41) was recorded in the treatment 30 cm x 30 cm (S3) and the minimum number of leaves was as low as 5.91 corresponding to broadcasting treatment (control). The number of leaves recorded in the 30 cm x 30 cm plot (S3) were 13.33, 15.08 and 22.41 while the corresponding number of leaves observed in the broadcasting control plot were 8.66, 10.33 and 5.91 at 60, 120 and 180 days respectively.

The statistical analysis revealed that no significant interaction exists between fertigation intervals and different spacing for seed sowing methods at 60 and 120 days after seed sowing. But after 180 days, number of leaves showed highly significant interaction effect with respect to different fertigation interval and seed sowing methods (p=0.000).

The treatment combination F2 X S3 gave the maximum number of leaves (26.00) followed by F1 X S3 and F3 x S3 (23.00 and 22.67). The minimum number of leaves (3.67) was recorded by the combination of F4 x S4 followed by F2 X S4, F3 X S4 and F4 X S1 these four were on par with each other (Table 19).

Table 19. Interaction effect of fertigation interval and seed sowing spacing on number of leaves of *Tectona grandis* seedlings raised for stump production at 180 days.

F \ S	Number of leaves				
	S1	S2	S3	S4	Mean
F1	14.33[e]	16.33[de]	23.00[b]	9.00[f]	15.67
F2	10.67[f]	14.67[e]	26.00[a]	5.00[g]	14.08
F3	14.67e	20.00[c]	22.67[b]	6.00[g]	15.83
F4	5.67[g]	17.67[cd]	18.00[cd]	3.67[g]	11.25
Mean	11.33	17.17	22.42	5.92	

Table 20. Interaction effect of fertigation interval and seed sowing spacing on leaf area of *Tectona grandis* seedlings raised for stump production at 180 days

F \ S	Leaf area (cm^2)				
	S1	S2	S3	S4	Mean
F1	5,402.5[g]	8,810.2[d]	18,985.3[a]	871.8[k]	8,517.5
F2	4,233.9[h]	7,962.5[e]	16,920.3[b]	948.7[k]	7,516.4
F3	2,658.8[i]	7,778.8[e]	10,809.1[c]	238.9[l]	5,371.4
F4	1,822.2[j]	5,316.7[g]	6,886.2[f]	144.4[l]	3,542.4
Mean	3,529.3	7,467.0	13,400.2	551.0	

Table 21. Interaction effect of fertigation interval and seed sowing spacing on leaf dry weight of *Tectona grandis* seedlings raised for stump production at 180 days

F \ S	Leaf dry weight (g)				
	S1	S2	S3	S4	Mean
F1	75.17[d]	105.71[b]	213.85[a]	15.18[gh]	102.48
F2	41.78[f]	82.78[c]	110.90[b]	15.67[gh]	62.78
F3	36.16[f]	82.97[c]	108.57[b]	10.77[h]	59.62
F4	18.84[g]	65.73[e]	104.40[b]	10.46[h]	49.86
Mean	42.99	84.30	134.43	13.02	

Fertigation Interval (F)
F1- Fertigation at 7 days interval
F2- Fertigation at 14 days interval
F3- Fertigation at 21 days interval
F4- No Fertigation (control)

Seed sowing spacing (S)
S1-Spacing at 10cm x10cm
S2-Spacing at 15cm x15cm
S3-Spacing at 30cm x30cm
S4-Broadcasting (Control)

Treatments with the same superscript do not differ significantly

The leaf area of seedlings at different fertigation intervals showed high significance throughout the seedling growth ie. 60, 120 and 180 days after fertigation (p=0.000). The leaf area corresponding to various intervals (60, 120 and 180 days) was highest with maximum for the fertigation interval (F1: Fertigation at 7 days interval) which were 2234.4 cm^2, 4629.3 cm^2 and 8517.5 cm^2 respectively and were 14.52, 30.09 and 55.37 % more as compared to leaf area in the no fertigation (control) plot. The leaf area recorded for the no fertigation control plot were 1520.85, 1121.58 and 3542.35 cm2 corresponding to 60, 120 and 180 days, respectively (Table 18). At 120 days after fertigation the maximum leaf area recorded in F1 (4629.32 cm^2) followed by F3 (3181.25 cm^2) which was on par with F2 (2947.47 cm^2) and the lowest being with the no fertigation (control) treatment. At the end of 180 days after fertigation, the maximum leaf area recorded in F1 (8517.45 cm^2) followed by F2 (7516.36 cm^2), F3 (5371.38 cm^2) and the lowest leaf area of 3542.35 cm2 corresponding to no fertigation control (F4).

The effect of different seed sowing spacing on the leaf area of teak seedlings for the stump production showed highly significant variation (p= 0.000) at 60, 120 and 180 days after the sowing. The maximum leaf area was observed in the wider spacing treatment (S3- Spacing at 30cm x 30cm) at different stages (60, 120 and 180 days) which were 16.22, 28.79 and 54.97 % followed by S2 (Spacing at 15cm x15cm) and S1 (Spacing at 10cm x10cm) at all stages of growth compared to leaf area in the broadcasting control plot. In general, the leaf area showed tremendous increase with increase in the spacing for all the three intervals (60, 120 and 180 days) (p=0.000). The least leaf area growth was recorded for the control (broadcasting) treatments at all stages of growth periods. At the end of 180 days after seed sowing, the maximum leaf area recorded in S3 (13,400 cm^2) followed by S2 (7467.04 cm^2), S1 (3529.33 cm^2) and the lowest value of 550.96 cm^2 corresponding to broadcasting control (S4).

The results also showed significant interaction effect in leaf area between fertigation interval and different spacing at all the three stages of growth. The treatment combination F1 X S3 gave the maximum leaf area (18,985.3 cm^2) followed by F2 X S3 and F3 x S3 (16,920.3 and 10,809.1 cm^2). The minimum leaf (144.4 cm^2)

was recorded by the combination of F4 x S4 followed by F3 X S4, these two were on par with each other (Table 20).

4.2.1.1.3 Leaf dry weight

Leaf dry weight showing significant difference with respect to Fertigation interval treatment at all stages of growth (p=0.000). The maximum dry weight of teak seedlings was observed in the most frequent fertigation interval (F1-Fertigation at 7 days interval) followed by F2 and F3. For instance, the leaf dry weight of teak seedlings was 102.47, 62.78, 59.61 and 49.85 g per seedlings for fertigation intervals F1, F2, F3 and F4 respectively after 180 days of the seedling growth. (Table 18). The increase in leaf dry weight in the most frequent Fertigation interval (7 days interval) plot compared to no fertilized (control).

The seed sowing at different spacing had highly significant effect on leaf dry weight of teak seedlings throughout the seedling growth interval (p=0.000). The higher leaf dry weight of teak seedlings was observed in the wider spacing treatments (S3=spacing at 30cm x 30cm) followed by (S2=spacing at 15cm x 15cm) and (S1=spacing at 10cm x 10cm). The increase in leaf dry weight in the wider spacing plot i.e. (30 x 30 cm) compared to broadcasting control were (S3 -134.43 g S2-84.29 g; S1- 42.98 g) respectively at 180 days after seed sowing. The leaf dry weight noticed for the broadcasting control (S4) plot was 13.02 g corresponding to 180 days.

The interaction effect for leaf dry weight worked out between fertigation intervals and different spacing for seed sowing at different spacing was significant throughout the growth of seedlings. The treatment combination F1 X S3 gave the higher leaf dry weight (213.85 g) followed by F2 X S3 and F3 x S3 and F4 X S4 (110.90, 108.57 and 104.40 g), these four were on par with each other. The lowest leaf dry weight (10.46 g) was recorded by the combination of F4 x S4 followed by F3 X S4, F2 X S4, and F1 X S4 these were on par with each other (Table 21).

4.2.1.2 Collar diameter

Table 22 shows the effect of fertigation interval on the collar diameter growth of *Tectona grandis* seedlings. The maximum collar diameter growth was observed in the most frequent fertigation intervals treatment F1 (Fertigation at 7 days interval) at all stages of growth recorded. At 180 days, the treatment F-1 was significantly superior to all other treatments with respect to collar diameter. Moreover, at 180 days all the fertigation treatments were on par each other and statistically distinct from the no fertigation (control) treatment. The collar diameter growth corresponding to various stages of growth (60, 120 and 180 day) were maximum collar diameter for the most frequent fertigation interval (F1) which were 10.08, 16.03 and 23.31 mm more as compared to collar diameter growth in control. The corresponding collar diameter growth for the control treatments was very low (8.42, 12.78 and 15.89 mm) respectively at 60, 120 and 180 days.

Effect of seed sowing at different spacing on the collar diameter of *Tectona grandis* (p=0.000) showed statistically significant variation. The maximum collar diameter of teak seedling was observed in the wider spacing treatments S3 (Spacing at 30cm x 30cm) followed by S2 (Spacing at 15cm x 15cm) and S1 (Spacing at 10cm x 10cm). The collar diameter of *Tectona grandis* were in the ranges of 8.90 to 19.59, 10.03 to 24.83, 12.46 to 30.98 and 5.90 to 9.85 mm at 60, 120 and 180 days after the seed sowing for spacing treatments S1, S2, S3 and S4 respectively. Similarly, the collar diameter of teak seedling corresponding to various stages of growth period (60, 120 and 180 days) was highest in for the widest spacing S3 (12.46, 21.07 and 30.98 mm followed by S2 (10.03, 17.33 and 24.83 mm) and S1 (8.90, 13.89 and 19.59 mm) more as compared to collar diameter growth in the broadcasting control (S4).

Table 22. Effect of fertigation interval and Seed sowing spacing on collar diameter of *Tectona grandis* seedling raised for teak stump production up to 180 days of growth

Treatments	Collar diameter (mm)		
	60 days	120 days	180 days
Fertigation Interval (F)			
F1- Fertigation at 7 days interval	10.08	16.03[a]	23.31[a]
F2- Fertigation at 14 days interval	9.42	15.08[b]	23.40[a]
F3- Fertigation at 21 days interval	9.37	15.24[b]	22.66[a]
F4- No Fertigation (control)	8.42	12.78[c]	15.89[b]
F value	2.62	59.02**	80.15**
P value	0.14	<0.01	<0.01
CD(0.05)	NS	0.62	1.40
Seed sowing spacing (S)			
S1-Spacing at 10cm x10cm	8.90[c]	13.89[c]	19.59[c]
S2-Spacing at 15cm x15cm	10.03[b]	17.33[b]	24.83[b]
S3-Spacing at 30cm x30cm	12.46[a]	21.07[a]	30.98[a]
S4-Broadcasting (Control)	5.90[d]	6.83[d]	9.85[d]
Mean	9.36	14.78	21.31
F value	229.24**	983.57**	1034.04**
P value	<0.01	<0.01	<0.01
CD (0.05)	0.52	0.56	0.81
Fertigation X Seed sowing spacing (F X S)			
F value	5.26**	9.70**	19.90**
P value	<0.01	<0.01	<0.01
CD (0.05)	1.04	1.12	1.62

**Significant at 1% level - * Significant at 5% level NS-Non significant

Treatments with the same superscript do not differ significantly

Table 23. Interaction effect of fertigation interval and seed sowing spacing on collar diameter of *Tectona grandis* seedlings raised for stump production at 180 days

F \ S	Collar diameter (mm)				
	S1	**S2**	**S3**	**S4**	**Mean**
F1	21.87^{f}	26.07^{de}	34.88^{a}	10.43^{hi}	23.31
F2	24.72^{e}	26.39^{d}	32.01^{b}	10.49^{hi}	23.40
F3	20.29^{f}	28.79^{c}	31.75^{b}	9.82^{ij}	22.66
F4	11.51^{h}	18.10^{g}	25.30^{de}	8.68^{j}	15.90
Mean	19.60	24.84	30.98	9.86	

Treatments with the same superscript do not differ significantly

Fertigation Interval (F)

F1- Fertigation at 7 days interval
F2- Fertigation at 14 days interval
F3- Fertigation at 21 days interval
F4- No Fertigation (control)

Seed sowing spacing (S)

S1-Spacing at 10cm x10cm
S2-Spacing at 15cm x15cm
S3-Spacing at 30cm x30cm
S4-Broadcasting (Control)

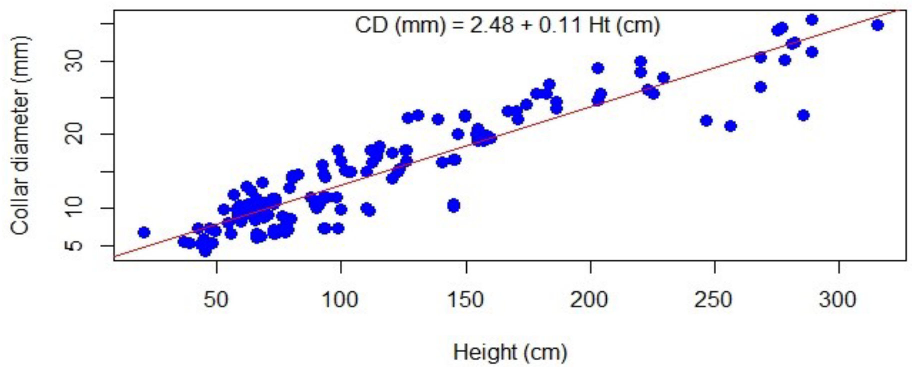


Fig 2. Shoot length-collar diameter relationship of teak saplings up to six months of nursery growth

The lowest collar diameter was recorded for the broadcasting control treatments with 5.90, 6.83 and 9.85 mm corresponding to 60, 120 and 180 days respectively.

The interaction effect on collar diameter between fertigation intervals and different spacing for seed sowing was significant at all stages of growth period (Table 23). At 180 days, the treatment combination F1 X S3 recorded the maximum collar diameter (34.88 mm) followed by F2 X S3 and F3 X S3 (32.00 and 31.75 mm) these two were on par with each other. The minimum collar diameter (8.68 mm) was recorded by the combination of F4 X S4 (No Fertigation x Broadcasting control).

4.2.1.3. Shoot length

Table 24. reveals that effect of fertigation interval showed statistically significant on growth of shoot length at 120 and 180 days observation after the fertigation application (p= 0.000), which were not significant at initial stage i.e. 60 days after the Fertigation application. At 120 days the maximum shoot length recorded in F1 (135.89 cm) followed by F2 (118.84 cm). The minimum shoot length was 95.66 cm noticed in (F4: No Fertigation (control)). At the end of observational period (180 days), the shoot length was 234.90, 189.39, 190.02 and 118.01 cm respectively for F1, F2, F3 and F4.

The seed sowing at different spacing recorded statistically significant effect of on shoot length at different stages of growth interval i.e. 60, 120 and 180 days interval (p=0.000). The shoot length was maximum for the wider spacing treatment (S3) followed by S2 and S1. The higher shoot length was recorded in seedlings plot subjected to wider spacing of seed sowing methods, at 60 days interval. The increase in shoot length in the wider spacing plot compared to broadcasting control where S3- 70.02, 144.01 and 258.80 cm followed by S2-66.98, 129.09 and 194.77 cm; S1- 63.06, 102.67 and 173.54 cm during 60, 120 and 180 days after the seed sowing at different spacing. The effect of spacing was more pronounced towards the later stages of growth. The lowest shoot length per seedling was observed for the broadcasting control treatments which were 43.04, 78.00 and 105.210 cm corresponding to 60, 120 and 180 days respectively (Table 24). At the end of 180 days

Table 24. Effect of fertigation interval and seed sowing spacing on growth of *Tectona grandis* seedlings raised for stump production in the nursery up to 180 days of growth

Treatments	Shoot length (cm)			Root length (cm)			Total seedling length (cm)		
	60 days	120 days	180days	60 days	120 days	180 days	60 days	120 days	180 days
Fertigation Interval (F)									
F1- Fertigation at 7 days interval	63.99	135.89[a]	234.90[a]	34.80[a]	48.38[a]	72.03[a]	98.79[a]	184.27[a]	306.94[a]
F2- Fertigation at 14 days interval	60.20	118.84[b]	189.39[b]	27.65[c]	41.81[b]	56.69[c]	87.85[bc]	160.65[b]	246.08[b]
F3- Fertigation at 21 days interval	60.74	103.38[c]	190.02[b]	30.58[b]	35.37[c]	58.81[b]	91.32[b]	138.75[c]	248.83[b]
F4- No Fertigation (control)	58.14	95.66[d]	118.01[c]	26.22[c]	30.41[d]	42.60[d]	84.36[c]	126.07[d]	160.94[c]
F value	2.06	1279.36**	385.81**	74.04**	257.72**	393.41**	11.24**	1764.12**	451.26**
P value	0.20	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CD(0.05)	NS	1.72	8.51	1.52	1.68	2.10	6.36	2.10	9.79
Seed sowing spacing (S)									
S1-Spacing at 10cm x10cm	63.03[b]	102.67[c]	173.54[c]	28.60[c]	38.51[b]	50.00[c]	91.63[c]	141.18[c]	223.55[c]
S2-Spacing at 15cm x15cm	66.98[ab]	129.09[b]	194.77[b]	32.04[b]	39.41[b]	54.15[a]	99.02[b]	168.50[b]	248.93[b]
S3-Spacing at 30cm x30cm	70.02[a]	144.01[a]	258.80[a]	38.90[a]	50.02[a]	90.24[a]	108.92[a]	194.03[a]	348.76[a]
S4-Broadcasting (Control)	43.04[c]	78.00[d]	105.21[d]	19.72[d]	28.04[c]	35.87[d]	62.76[d]	106.04[d]	141.56[d]
Mean	60.77	113.44	183.08	29.81	38.99	57.53	90.58	152.44	240.70
F value	64.37**	1862.39**	457.32**	221.91**	509.75**	1351.30**	123.68**	2055.22**	740.44**
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CD (0.05)	4.42	1.97	8.64	1.56	1.16	1.83	5.21	2.42	9.15
Fertigation X Seed sowing spacing (F XS)									
F value	5.01**	27.33**	18.38**	5.23**	61.41**	77.38**	4.25**	23.13**	27.08**
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CD (0.05)	8.84	3.94	17.28	3.12	2.32	3.67	10.42	4.85	18.31

**Significant at 1% level - * Significant at 5% level NS-Non significant

Treatments with the same superscript do not differ significantly

after seed sowing, the maximum shoot length was S3 (258.80 cm) followed by S2 (194.77 cm), S1 (173.54 cm) and the lowest value of 105.21 cm corresponding to broadcasting control (S4).

Significant differences were noticed in their interaction effect also. At 180 day, F1 X S3 has recorded highest shoot length (293.00 cm) followed by F2 X S3 (284.00 cm), which were on par with each other. The shortest shoot length was noticed in F4 X S4 (78.00 cm) followed by F2 X S4, F4 X S1 and F3 X S4, there were on par with each other (Table 25).

4.2.1.4. Shoot length-collar diameter relationship

The shoot length of the teak saplings up to six months of nursery growth is plotted against the collar diameter and prediction equations were attempted. The best fit equation, with collar diameter as independent and shoot length as dependent factor, was CD (mm) =2.48 + 0.11 Sl (cm) with a high correlation coefficient r=0.92 (Fig 2).

4.2.1.5. Root length

Fertigation effect on seedling root length showed highly significant response for teak seedlings raised for stump production (p-0.000). The maximum root length growth was observed in the F1-(Fertigation at 7 days interval) for all stages of growth (34.80, 48.38 and 72.03 cm respectively at 60, 120 and 180 days). The effect of root length between fertigation intervals F2 and F3 were varying at different stages. However, the treatment F4, (control) consistently recorded the lowest values throughout the growth of the seedlings. (Table 24). The increase in root length in the most frequent fertigation interval plot (F1) compared to No fertigation control were 8.58, 17.97 and 29.43 cm respectively during 60, 120 and 180 days after the fertigation application (Table 24).

Effect of different seed sowing at different spacing for seedlings raised for stump production in the nursery showed statistically significant variations (p-0.000). Maximum Significantly high root length of teak seedlings (38.90, 50.02 and 90.24 cm respectively at 60, 120 and 180 days of growth) was observed in wider spacing treatments (S3-Spacing at 30cm x 30cm) followed by (S2-Spacing at 15cm x 15cm)

Table 25. Interaction effect of fertigation interval and seed sowing spacing on shoot length of *Tectona grandis* seedlings raised for stump production at 180 days.

F \ S	Shoot length (cm)				
	S1	**S2**	**S3**	**S4**	**Mean**
F1	262.67^{c}	238.83^{d}	293.00^{a}	145.13^{g}	234.91
F2	179.50^{f}	203.33e	284.00ab	90.74^{ij}	189.39
F3	155.67^{g}	223.08^{d}	274.33^{bc}	107.00^{hi}	190.02
F4	96.33^{i}	113.85^{h}	183.87^{f}	78.00^{j}	118.01
Mean	173.54	194.78	258.80	105.22	

Table 26. Interaction effect of fertigation interval and seed sowing spacing on of *Tectona grandis* seedlings raised for stump production at 180 days

F \ S	Root length (cm)				
	S1	**S2**	**S3**	**S4**	**Mean**
F1	78.10^{c}	61.67^{d}	104.39^{a}	44.00^{fg}	72.04
F2	41.93^{fg}	44.72^{f}	99.38^{b}	40.74^{g}	56.69
F3	45.33^{f}	59.33^{d}	98.70^{b}	31.88^{h}	58.81
F4	34.67^{h}	50.92^{e}	57.38^{d}	26.88^{i}	42.93
Mean	50.01	54.16	89.96	36.35	

Table 27. Interaction effect of fertigation interval and seed sowing spacing on total seedling length of *Tectona grandis* seedlings raised for stump production at 180 days

F \ S	Total seedling length (cm)				
	S1	S2	S3	S4	Mean
F1	340.77^{c}	300.50^{d}	397.39^{a}	189.13^{g}	306.95
F2	221.43^{f}	248.05^{e}	383.38^{ab}	131.48^{i}	246.09
F3	201.00^{g}	282.41^{d}	373.03^{b}	138.88^{i}	248.83
F4	131.00^{i}	164.77^{h}	241.25^{e}	106.77^{j}	160.95
Mean	223.55	248.93	348.76	141.57	

Fertigation Interval (F)
F1- Fertigation at 7 days interval
F2- Fertigation at 14 days interval
F3- Fertigation at 21 days interval
F4- No Fertigation (control)

Seed sowing spacing (S)
S1-Spacing at 10cm x10cm
S2-Spacing at 15cm x15cm
S3-Spacing at 30cm x30cm
S4-Broadcasting (Control)

Treatments with the same superscript do not differ significantly

and (S1-Spacing at 10cm x 10cm). Whereas the root length was (32.04, 39.41 and 54.15 cm in S2) and (28.60, 38.51 and 50.00 cm in S1). The lowest root length recorded for the broadcasting control treatments (19.72, 28.04 and 35.87 cm) at 60, 120 and 180 days of growth of seedlings (Table 24).

The interaction effect between fertigation intervals and different spacing for seed sowing was significant throughout the growth of seedlings. At 180 days, the treatment combination F1 X S3 recorded the maximum root length (104.39 cm) followed by F2 X S3 and F3 X S3 (99.38 and 98.38 cm) these two were on two were on par with each other. The minimum root length (31.88 cm) was recorded by combination of F3 X S4 and next least was F4 X S1 (34.67 cm), these both were on par with each other (Table 26).

4.2.1.5. Total seedling length

Fertigation interval had significant effect on the total seedling length (Table 24) of *Tectona grandis* (p=0.000). The maximum total seedling length was recorded in the most frequent fertigation interval (F1: Fertigation at 7 days interval) followed by F2. Similarly, the increase in total seedling length is less with increasing in the interval of fertigation application. For instance, the total seedling length of teak seedlings was 98.79, 87.85, 91.32 and 84.36 cm for fertigation interval F1, F2, F3 and F4 respectively at 60 days of growth period. At the end of 180 days after seed sowing the maximum total seedling length was F1 (306.954 cm) followed by F2 (246.08 cm) and F3 (248.83 cm) which were on par with each other and lowest value was for F4 (160.94 cm) broadcasting control treatment.

The effect of seed sowing at different spacing showed highly significant effect on the total seedling length of *Tectona grandis* seedlings raised for stump production in the nursery. The maximum total seedling length noticed in different sowing spacing treatments (S3- Spacing at 30cm x 30cm) followed by (S2- Spacing at 15cm x 15cm) and (S1- Spacing at 10cm x 10cm) over the broadcasting control. The length of seedlings at all stages of growth (60, 120 and 180 days) was maximum for the wider spacing (S3) which were 108.92, 194.03 and 348.76 cm followed by S2 and S1. The total seedling length of teak seedling at 60 days was 91.63 cm, 99.02 cm, 108.92 cm and 62.76 cm for different spacing S1, S2, S3 and S4 respectively. The respective increase in total seedling length was from 91.63 to 223.53, 99.02 to 248.93, 108.92 to 348.76 and 62.46 to 141.56 cm for time interval from 60 days to 180 days after the seed sowing. The total seedling lengths recorded were the lowest for broadcasting control treatment (62.76, 106.04 and 141.56 cm corresponding to 60, 120 and 180 days of growth).

The interaction effect between fertigation interval and different spacing for seed sowing showed highly significant variation (p=0.000) at 60, 120 and 180 days. At 180 days the treatment combination F1 X S3 showed the maximum total seedling length (397.39 cm) followed by F2 X S3 and F3 X S3 (383.38 and 373.03 cm), these two were on par with each other. The minimum total seedling length (106.77 cm) was recorded by combination of F4 X S4 (Table 27).

4.2.1.6 Primary lateral root production in Tectona grandis seedlings raised for stump production in the nursery

4.2.1.6.1 Number of primary lateral roots

The effect of fertigation interval showed significant effect on number of primary lateral root production (p=0.000) (Table 28). The maximum number of primary lateral roots of teak seedlings observed in the fertigation interval F1 (Fertigation at 7 days interval) at all stages of growth interval. At initial stages of growth period (60 days) F2 and F3 were on par with each other, but during 120 and 180 days maximum number of primary lateral roots noticed in F1(Fertigation at 7 days interval) and next best was F3 (Fertigation at 21 days). The total number of primary lateral roots were 41.40, 51.40 and 58.93 respectively during 60, 120 and 180 days after fertigation in F1 treatment.

Table 28 depicted that seed sowing at different spacing had significant effect on the number of primary lateral roots of *Tectona grandis* (P=0.000). The maximum number of primary lateral roots was observed in the seed sowing at wider spacing treatments (S3- spacing at 30cm x 30cm) followed by S2 (Spacing at 15cm x15cm) and S1 (Spacing at 10cm x10cm) over the control broadcasting. The number of

Table 28. Effect of fertigation interval and seed sowing spacing on Primary lateral root production in *Tectona grandis* seedlings raised for stump production up to 180 days of growth

Treatments	Number of primary lateral roots			Length of primary lateral roots (cm)		
	60 days	120 days	180 days	60 days	120 days	180 days
Fertigation Interval (F)						
F1- Fertigation at 7 days interval	41.40[a]	51.40[a]	58.93[a]	26.25[a]	38.47[a]	51.42[b]
F2- Fertigation at 14 days interval	34.30[b]	40.65[c]	49.59[c]	16.90[b]	34.88[b]	56.77[a]
F3- Fertigation at 21 days interval	35.30[b]	45.88[b]	54.88[b]	24.59[a]	40.35[a]	44.90[c]
F4- No Fertigation (control)	31.95[c]	40.17[c]	47.35[c]	17.56[b]	30.17[d]	36.34[d]
F value	194.84**	47.91**	34.30**	66.47**	40.48**	70.29**
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CD(0.05)	1.88	2.63	3.08	2.02	2.43	3.63
Seed sowing spacing (S)						
S1-Spacing at 10cm x10cm	35.10[b]	45.30[b]	53.51[b]	18.77[b]	36.54[b]	44.41[c]
S2-Spacing at 15cm x15cm	36.36[b]	43.80[b]	49.12[c]	18.38[b]	32.69[c]	52.20[b]
S3-Spacing at 30cm x30cm	50.78[a]	60.93[a]	73.83[a]	36.72[a]	54.20[a]	67.99[a]
S4-Broadcasting (Control)	20.72[c]	28.06[c]	34.28[d]	11.43[c]	20.45[d]	24.83[d]
Mean	35.74	44.52	52.69	21.32	35.97	47.36
F value	405.20**	601.15**	727.00**	312.23**	879.57**	693.73**
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CD (0.05)	1.78	3.19	1.76	1.78	1.37	1.98
Fertigation X Seed sowing spacing (F XS)						
F value	17.20**	20.36**	17.29**	33.81**	47.61**	22.62**
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CD (0.05)	3.56	2.62	3.53	3.56	2.74	3.97

**Significant at 1% level - * Significant at 5% level NS-Non significant

Treatments with the same superscript do not differ significantly

primary lateral roots of teak seedling was 53.51, 49.12, 73.83 and 34.28 cm for different spacing treatments S1, S2, S3 and S4 respectively at 180 days after the seed sowing. Similarly, the number of primary lateral roots of teak seedlings corresponding to various time interval (60, 120 and 180 days) was highest for the wider spacing (S3) which were 50.78, 60.93 and 73.83 followed by S2 (36.36, 43.80 and 49.12) and S1 (35.10, 45.30 and 53.51) treatments, which were on par with each other. The least number of primary lateral roots recorded in the broadcasting control treatment (S4) was 20.72, 28.06 and 34.28 corresponding to 60, 12 and 180 days.

The table also showed significant interaction effect on number of primary lateral roots between fertigation intervals and different spacing for seed sowing throughout the growth of seedlings.

4.2.1.6.2 Length of primary lateral roots

The effect of varying fertigation intervals and seed sowing method at different spacing on the length of primary lateral roots production for *Tectona grandis* seedlings raised for stump production in the nursery presented in Table 28. The maximum length of primary lateral roots was observed in the Fertigation interval F1, which was on par with F3 at 60 and 120 days after the fertigation application. Length of primary lateral roots of teak seedling after the 180 days of fertigation application were 51.42, 56.77, 44.90 and 36.34 cm for fertigation interval F1, F2, F3 and F4 respectively. The lowest length of primary lateral roots was observed for control treatment (F4) which were 17.56, 30.17 and 36.34 cm respectively at 60, 120 and 180 days.

Length of primary lateral roots showed significant effect on seed sowing at different spacing (p=0.000). Higher length of primary lateral roots was associated with the seedlings plots subjected to seed sowing at wider spacing. It followed a consistent increase in length of primary lateral roots with increase in seed sowing spacing. The maximum length of lateral roots varied from 24.83 (control) to 67.99 cm (S3) after the 180 days of seed sowing. The length of primary lateral roots in wider spacing (S3) were 36.72, 54.20 and 67.99 cm during 60, 120 and 180 days after the seed sowing followed by S2 and S1. The lowest length of primary lateral roots was observed for the broadcasting control treatment (S4) which were 11.43, 20.45 and 24. 83 cm corresponding to 60, 120 and 180 days (Table 28).

The length of primary lateral roots showed significant interaction effect between fertigation interval and different spacing for seed sowing methods at different observation periods. The treatment combination F2 X S3 gave the maximum length of primary lateral roots (83.11 cm) followed by F3 X S3 and F1 x S3 (69.50 and 66.63), these two were on par with each other. The minimum length of primary lateral roots (13.20 cm) was recorded by the combination of F4 x S4 followed by F2 X S4, F1 X S4, F3 X S4 and F3 x S1 these four were on par with each other (Table 30).

4.2.1.7. Biomass production in Tectona grandis seedlings raised for stump production in the nursery

Effect of fertigation interval and sowing at different spacing on biomass production attributes viz. shoot dry weight, root dry weight and total dry weight up to 180 days of seedling growth is depicted in Table 29.

4.2.1.7.1 Shoot dry weight

The fertigation intervals showed statistically significant effect on the shoot dry weight of *Tectona grandis* seedlings (p=0.00) during growth at 60, 120 and 180 days. The present study indicated that the maximum shoot dry weight was observed in the F1 (Fertigation at 7 days interval) for all the three stages of growth. The mean shoot dry weight of teak seedling varied from 105.80 to 258.92 g after the 180 days of fertigation intervals application. The shoot dry weight in the most frequent fertigation interval plot (F1) were 20.74, 83.95 and 258.92 g during 60, 120 and 180 days after the fertigation application followed by F2. The lowest shoot dry weight was observed for the no fertigation control (F4) which were 16.73, 47.31 and 105.80 g at 60, 120 and 180 days respectively (Table 29).

The seed sowing at different spacing had significant effect on the shoot dry weight of *Tectona grandis* which varied at all stages of growth (p=0.000). The highest shoot dry weight of teak seedling observed in the widest spacing treatment (S3-Spacing at 30cm x 30cm) followed by S2 (Spacing at 15cm x15cm)

Table 29. Effect of fertigation interval and seed sowing spacing on biomass production of *Tectona grandis* seedlings raised for stump production up to 180 days of growth

Treatments	**Shoot Dry Weight (g)**			**Root Dry Weight (g)**			**Total Dry Weight (g)**		
	60 days	**120 days**	**180 days**	**60 days**	**120 days**	**180 days**	**60 days**	**120 days**	**180 days**
Fertigation Interval (F)									
F1- Fertigation at 7 days interval	20.74[a]	83.95[a]	258.92[a]	4.18	18.52[c]	79.18[b]	24.92[a]	102.47[a]	338.11[a]
F2- Fertigation at 14 days interval	19.08[b]	78.05[b]	210.47[b]	4.05	25.00[a]	86.07[a]	23.14[a]	103.06[a]	296.54[b]
F3- Fertigation at 21 days interval	18.86[b]	70.27[c]	189.43[c]	4.46	21.97[b]	59.31[c]	23.32[a]	92.24[b]	248.75[c]
F4- No Fertigation (control)	16.73[c]	47.31[d]	105.80[d]	4.06	15.16[d]	58.66[c]	20.79[b]	62.47[c]	164.46[d]
F value	12.96**	390.65**	1052.61**	0.85	445.58**	405.58**	9.90**	406.27**	914.55**
P value	<0.01	<0.01	<0.01	0.51	<0.01	<0.01	<0.01	<0.01	<0.01
CD(0.05)	1.58	2.81	6.81	NS	0.69	2.39	1.87	3.27	8.53
Seed sowing spacing (S)									
S1-Spacing at 10cm x10cm	15.90[c]	55.32[c]	130.05[c]	3.59[c]	14.23[c]	44.94[c]	19.50[c]	69.56[c]	175.00[c]
S2-Spacing at 15cm x15cm	19.52[b]	88.86[b]	219.37[b]	4.63[b]	23.10[b]	87.74[b]	24.16[b]	112.00[b]	307.11[b]
S3-Spacing at 30cm x30cm	35.76[a]	110.50[a]	381.17[a]	7.40[a]	33.80[a]	128.83[a]	43.17[a]	144.31[a]	510.01[a]
S4-Broadcasting (Control)	4.22[d]	24.90[d]	34.03[d]	1.12[d]	9.47[a]	21.71[d]	5.35[d]	34.38[d]	55.74[d]
Mean	18.85	69.89	191.16	4.19	20.16	70.80	23.04	90.06	261.97
F value	500.37**	3648.65**	6789.22**	240.45**	1280.05**	2121.45**	664.00**	4700.75**	6826.13**
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CD (0.05)	1.70	1.81	5.22	0.48	0.87	3.00	1.76	2.04	6.87
Fertigation X Seed sowing spacing (F XS)									
F value	7.86**	27.10**	205.22**	8.45**	27.04**	101.16**	9.62**	28.57**	191.65**
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CD (0.05)	3.40	3.63	10.45	0.97	1.74	6.00	3.53	4.09	13.75

**Significant at 1% level - * Significant at 5% level NS-Non significant

Treatments with the same superscript do not differ significantly

and S1 (Spacing at 10cm x10cm). The shoot dry weight of *Tectona grandis* were 130.05, 219.37, 381.17 and 34.03 g per seedling for seed sowing at different spacing S1, S2, S3 and S4 respectively after the 180 days of sowing (Table 29). The shoot dry weight in the wider spacing plot (S3) were 35.76, 110.50 and 381.17 g followed by S2 (19.52, 88.86 and 219.37 g) and S1 (15.90, 55.32 and 130.05 g) respectively as against 4.22, 24.90 and 34.03 g in S4) during 60, 120 and 180 days after the seed sowing.

The interaction effect between fertigation intervals and different spacing for seed sowing was significant effect on shoot dry weight at all stages of growth period.

4.2.1.7.2 Root dry weight

The fertigation intervals had statistically significant influence on root dry weight of *Tectona grandis* seedlings at different time interval (120 and 180 days) except at initial stage (60 days) of growth (Table 29). The maximum root dry weight was recorded in the fertigation interval treatment (F2: Fertigation at 14 days interval) followed by F1 (Fertigation at 7 days interval), whereas F3 and F4 both were on par with each other at the end of 180 days growth period. The lowest root dry weight was recorded for the control treatments 4.06, 15.16 and 58.66 g corresponding to 60, 120 and 180 days.

Seed sowing at different spacing on root dry weight showed significant response for teak seedlings raised for stump production in nursery. A consistence increase in root dry weight was noticed with increasing spacing. At different stages of growth, root dry weight for teak seedling were in the ranges from 1.12 to 7.40, 9.47 to 33.80 and 21.71 to 128.83 g, the lowest and highest values being in S4 and S3 treatments respectively (Table 29). At the end of 180 days the highest root dry weight of teak seedling growth was 128.83 g (S3- Spacing at 30cm x 30cm) followed by 87.74 g (S2- Spacing at 15cm x 15cm), 44.94 g (S1-Spacing at 10cm x 10cm) and 21.71 g (S4-broadcasting control).

The interaction effect between fertigation intervals and different spacing for seed sowing was significant effect on root dry weight at all stages of growth period. The treatment combination F2 X S3 gave the maximum root dry weight (167.82 g) followed by F1 X S3, F3 x S3 (157.19 and 95.29 g). Lowest root dry (13.87 g) was recorded by the combination of F4 x S4 followed by F3 X S4, F1 X S4 these all were on par with each other (Table 31).

4.2.1.7.3 Total dry weight

Table 29 shows the effect of fertigation intervals on the total dry weight of *Tectona grandis*. Effect of fertigation interval showed highly significant effect on total dry weight of teak seedlings. The maximum total dry weight was observed in F1 (Fertigation at 7 days interval) and F2 (Fertigation at 14 days interval) for all stages of growth period. At the initial stage i.e. at 60 days there were no significant difference in total dry weight between the treatments and were on par with each other. The lowest total dry weight production was observed for the unfertigation control treatment F4. At 180 days of growth, the total dry weight increased with decreasing fertigation interval (164.46, 248.75, 296.54 and 338.11 g) respectively for no fertigation, 21 days, 14 days and 7 days of fertigation interval.

Total dry weight had statistically significant effect with different seed sowing spacing (p=000). Total dry weight corresponding to various stages of growth periods (60, 120 and 180 days) were maximum for the wider spacing treatment (S3) which were 43.17, 144.31 and 510.01 g as against the broadcasting (S4) with 5.35, 34.38 and 55.74 g. At 180 days of growth, the maximum total dry weight was noticed in the widest spacing S3 (510.01 g) followed by S2 (307.11 g), S1 (175.00 g) and S4 (55.74 g).

The interaction effect between fertigation intervals and different spacing for seed sowing was significant effect on total dry weight at all stages of growth period. The treatment combination F1 X S3 gave the maximum total dry weight (685.38 g) followed by F2 X S3, F3 x S3 (581.15 and 485.03 g). Lowest total dry (35.74 g) was recorded by the combination of F4 x S4 followed by F3 X S4, F1 X S4 these all were on par with each other (Table 32).

Table 30. Interaction effect of fertigation interval and seed sowing spacing on length of primary lateral roots of *Tectona grandis* seedlings raised for stump production at 180 days.

F / S	Primary lateral roots				
	S1	S2	S3	S4	Mean
F1	53.42^{de}	56.78^{d}	66.63^{b}	28.86^{g}	51.42
F2	53.93^{de}	62.06^{c}	83.11^{a}	27.99^{g}	56.77
F3	30.63^{g}	50.20^{e}	69.50^{b}	29.30^{g}	44.91
F4	39.67^{f}	39.78^{f}	52.73^{e}	13.20^{h}	36.35
Mean	44.41	52.20	67.99	24.84	

Table 31. Interaction effect of fertigation interval and seed sowing spacing on root dry weight of *Tectona grandis* seedlings raised for stump production at 180 days

F / S	Root dry weight (g)				
	S1	S2	S3	S4	Mean
F1	67.88^{e}	68.09^{e}	157.19^{b}	23.60^{i}	79.19
F2	44.63^{f}	100.75^{c}	167.82^{a}	31.08^{h}	86.07
F3	37.26^{g}	86.43^{d}	95.29^{c}	18.30^{ij}	59.32
F4	30.03^{h}	95.70^{c}	95.04^{c}	13.87^{j}	58.66
Mean	44.95	87.74	128.84	21.71	

Table 32. Interaction effect of fertigation interval and seed sowing spacing on total dry weight of *Tectona grandis* seedlings raised for stump production at 180 days

F / S	Total dry weight (g)				
	S1	S2	S3	S4	Mean
F1	268.58^{f}	336.91^{d}	685.38^{a}	61.61^{k}	338.12
F2	206.53^{h}	330.76^{d}	581.15^{b}	67.73^{jk}	296.54
F3	148.99^{i}	330.09^{d}	458.03^{c}	57.91^{k}	248.75
F4	75.93^{j}	230.71^{g}	315.49^{e}	35.74^{l}	164.47
Mean	175.01	307.12	510.01	55.75	

Fertigation Interval (F)	**Seed sowing spacing (S)**
F1- Fertigation at 7 days interval	S1-Spacing at 10cm x10cm
F2- Fertigation at 14 days interval	S2-Spacing at 15cm x15cm
F3- Fertigation at 21 days interval	S3-Spacing at 30cm x30cm
F4- No Fertigation (control)	S4-Broadcasting (Control)

Treatments with the same superscript do not differ significantly

4.2.1.8. Root: shoot ratio

Effect of fertigation interval had influence on root: shoot ratio of *Tectona grandis* seedlings at different time interval (Table 33). The maximum value of root: shoot ratio was recorded in the highest fertigation interval treatment F1 (Fertigation at 7 days interval) for all different stages of growth followed by F2 and F3, which were

Table 33. Effect of fertigation interval and seed sowing spacing on root-shoot ratio of *Tectona grandis* seedling raised for teak stump production up to 180 days of growth

Treatments	Root: shoot		
	60 days	120 days	180 days
Fertigation Interval (F)			
F1- Fertigation at 7 days interval	0.54	0.36[a]	0.30[b]
F2- Fertigation at 14 days interval	0.48	0.35[ab]	0.31[b]
F3- Fertigation at 21 days interval	0.50	0.34[b]	0.30[b]
F4- No Fertigation (control)	0.44	0.32[c]	0.37[a]
F value	3.87	12.47**	46.54**
P value	0.07	<0.01	<0.01
CD(0.05)	NS	0.016	0.016
Seed sowing spacing (S)			
S1-Spacing at 10cm x10cm	0.45[b]	0.36[a]	0.29[b]
S2-Spacing at 15cm x15cm	0.47[b]	0.31[c]	0.29[b]
S3-Spacing at 30cm x30cm	0.55[a]	0.34[b]	0.34[a]
S4-Broadcasting (Control)	0.48[b]	0.36[a]	0.35[a]
Mean	0.49	0.34	0.32
F value	5.15**	44.58**	25.92**
P value	<0.01	<0.01	<0.01
CD (0.05)	0.05	0.010	0.017
Fertigation X Seed sowing spacing (F X S)			
F value	3.93**	65.03**	32.09**
P value	<0.01	<0.01	<0.01
CD (0.05)	0.11	0.02	0.03

**Significant at 1% level - * Significant at 5% level NS-Non significant

Treatments with the same superscript do not differ significantly

Table 34. Effect of fertigation interval and seed sowing spacing on root growth potential of *Tectona grandis* stumps prepared with 180 days old seedlings

Treatments	Root growth potential of teak stumps						
	No. of sprouts/ stump	Length of sprouts (cm)	No. of leaves / stump	No. of lateral roots / stump	No. tertiary roots /stump	Length of lateral roots(cm)	Dry weight of lateral roots (g)
Fertigation Interval (F)							
F1- Fertigation at 7 days interval	8.00^{ab}	5.36^{a}	25.00^{a}	21.50^{a}	72.34^{a}	17.45^{a}	6.25^{ab}
F2- Fertigation at 14 days interval	8.66^{a}	4.85^{b}	25.25^{a}	20.75^{a}	68.92^{b}	17.49^{a}	6.51^{a}
F3- Fertigation at 21 days interval	5.83^{c}	4.35^{c}	20.75^{c}	19.41^{b}	60.33^{c}	17.25^{a}	5.95^{b}
F4- No Fertigation (control)	7.00^{bc}	4.06^{d}	23.08^{b}	19.16^{b}	54.60^{d}	16.12^{b}	6.01^{b}
F value	9.79**	52.81**	24.80**	13.47**	147.00**	7.06*	5.91*
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.05
CD(0.05)	1.36	0.27	1.44	1.04	2.30	0.84	0.35
Seed sowing spacing (S)							
S1-Spacing at 10cm x10cm	7.91^{b}	4.82^{b}	21.50^{c}	20.33^{b}	68.52^{c}	$18\ .45^{b}$	6.64^{b}
S2-Spacing at 15cm x15cm	8.16^{b}	5.07^{b}	25.25^{b}	19.91^{b}	73.28^{b}	18.75^{b}	7.06^{a}
S3-Spacing at 30cm x30cm	9.58^{a}	6.67^{a}	33.33^{a}	23.75^{a}	86.75^{a}	21.29^{a}	7.32^{a}
S4-Broadcasting (Control)	3.83^{c}	2.07^{c}	14.00^{d}	16.83^{c}	27.64^{d}	9.83^{c}	3.69^{c}
Mean	7.35	4.66	23.52	20.20	60.05	17.08	6.81
F value	46.53**	333.95**	125.41**	94.82**	1199.24**	591.29**	138.62**
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CD (0.05)	1.05	0.30	2.09	0.84	2.14	0.59	0.41
Fertigation X Seed sowing spacing (F X S)							
F value	1.52	2.49*	2.99**	4.90**	8.68**	12.45**	5.24**
P value	0.19	<0.05	<0.01	<0.01	<0.01	<0.01	<0.01
CD (0.05)	NS	0.61	4.19	1.69	4.29	1.19	0.83

**Significant at 1% level - * Significant at 5% level NS-Non significant

Treatments with the same superscript do not differ significant

4.2.3.2 Length of sprouts

Fertigation interval had significant effect on length of sprouts after the 28 days of the stumps planting (p=0.000). The maximum length of sprouts obtained in F1 (5.36 cm) followed by F2 (4.85 cm). The shortest length of sprouts produced by F4 (4.06 cm),

Among the different seed sowing spacing, the maximum length of sprouts recorded in S3 (spacing at 30 x 30 cm) after the 28 days of stump planting. Whereas S1, S2 (4.82 and 5.07 cm) showed almost similar values, which were on par with each other. The minimum length of sprouts (2.07 cm) is produced by broadcasting control (S4). The table also showed that significant interaction between fertigation intervals and seed sowing spacing for the length of sprouts (Table 34).

4.2.3.3 Number of leaves

The maximum number of leaves observed in the most frequent fertigation interval treatment F1 (Fertigation at 7 days interval) and F2 (Fertigation at 14 days interval), which were (25.00 and 25.25) on par with each other, followed by F4 (23.08). The minimum number of leaves 20.75 were recorded in the treatment F3.

Effect of seed sowing spacing had significant effect on number of leaves produced by stump after 28 days planting (p= 0.000). The highest number of leaves was produced by stump prepared from S3 (spacing at 30 x 30 cm) which was 33.33 followed by S2 (25.25) and S1 (21.50). The least number of leaves produced by S4 (14.00) broadcasting as control. Interaction between the effect of fertigation interval and seed sowing spacing showed statistically significant effect on number of leaves after 28 days of stump planting.

4.2.3.4 Lateral roots per stumps

The fertigation intervals had significant effect on lateral roots per stump for the teak stump production after the 28 days of transplanting (p=0.05). The maximum number of lateral roots obtained by F1 and F2 (21.50 and 20.75), which were on par with each other.

Among the seed sowing spacing, the maximum number of lateral roots per stumps produced by S3 (23.75), the widest spacing treatment adopted. The lowest numbers of lateral roots per stump after 28 days of stump planting was 16.83 in S4, the broadcasting-control treatment. Interaction between fertigation intervals and seed sowing methods at different spacing showed significant effect on lateral roots per stump production after the 28 days of stump planting.

4.2.3.5 Tertiary roots per stump

Tertiary roots per stump production had significant effect on fertigation intervals for the stump growth potential after the 28 days of stump planting (p=0.000). Significantly higher number of tertiary roots per stump was recorded in the most frequent fertigation interval F1 (72.34). The fertigation intervals F2 (68.29) showed next best for number of tertiary roots per stumps and lowest number of tertiary roots per stumps recorded by F4 (54.60).

Among the seed sowing spacing, the widest spacing (S3-spacing 30 x 30 cm) recorded maximum number of tertiary roots per stumps (56.75) followed by S2 and S1 (73.28 and 68.52) after 28 days of growth of stump. The lowest number of tertiary roots per stump (27.64) was observed in SM4, the broadcasting control treatment. Among the fertigation intervals and seed sowing spacing showed significant interaction effect on tertiary roots per stump production.

4.2.3.6 Length of lateral roots

The effect of different fertigation intervals and seed sowing methods at different spacing on the length of lateral roots as an indicator of growth potential of the stumps made from 180 days old seedlings had significant effect. The fertigation intervals treatments showed marginal increase in the length of lateral roots, the maximum length of lateral roots recorded in F1, F2 and F3 (17.45, 17.49 and 17.25 cm), which were on par with each other. The lowest length of lateral roots (16.12 cm) recorded by the control treatment.

Between the seed sowing spacing the highest length of lateral roots produced by S3 (21.29 cm) followed by S2 and S1 (18.75 and 18.45 cm) which were on par with each other and the control (9.83 cm) showed the significantly lowest length as compared to all the three fertigated treatments. Interaction between the fertigation interval and seed sowing spacing had statistically significant effect on length of lateral roots (p=0.000).

4.2.3.7 Dry weight of lateral roots

Effect of fertigation intervals had significant effect on the dry weight of lateral roots of the stumps made of 180 days old seedlings (p=0.000). The maximum dry weight of lateral roots was produced in F1 and F2 (6.51 and 6.25 g), which were significantly distinct from the treatments F3 and F4 (5.95 and 6.01 g) were on par with each other.

The seed sowing spacing showed significant effect on the dry weight of lateral roots. The maximum dry weight of lateral roots produced (7.32 g) by S3 (spacing 30 x 30 cm) and S2 (7.06 g), which were on par with each other. The lowest value was for control as broadcasting (3.69 g). Interaction effect between the Fertigation intervals and seed sowing spacing had significant effect on dry weight of lateral roots.

4.2.4 Correlation between seedling characters and root growth potential of teak stump

The present study, correlation matrix drawn between important seedling characters and the RGP characters (Table 35) throws light on to the possible cumulative cause-effect relations of these characters, which may aid to predict the pattern of changes in one factor when the other factor is known /easily measurable. The number of leaves was not correlated with any of the RGR characteristics of the stump, it's ranged from 0.427 to 0.729, but in case of collar diameter most of the seedling characteristics like length of sprouts (0.912), number of leaves per stump

Table 35. Correlation matrix between growth of seedling characteristics (180 days old) and root growth potential of *Tectona grandis* stumps

RGP characters / Seedling characters	No. of sprouts	Length of sprouts (cm)	No. of leaves	Lateral roots per stump	Tertiary roots per stump	Length of lateral roots(cm)	Leaves dry weight	Root dry weight
Number of leaves	0.57**	0.71**	0.72**	0.66**	0.71**	0.62**	0.42**	0.65**
Collar diameter (mm)	0.75**	0.91**	0.83**	0.75**	0.92**	0.89**	0.70**	0.80**
Shoot length (cm)	0.69**	0.84**	0.78**	0.74**	0.86**	0.79**	0.62**	0.64**
Root length (cm)	0.60**	0.79**	0.78**	0.77**	0.75**	0.73**	0.63**	0.56**
Number of primary lateral roots	0.72**	0.81**	0.78**	0.83**	0.77**	0.79**	0.73**	0.69**
Length of primary lateral roots	0.81**	0.88**	0.84**	0.82**	0.89**	0.84**	0.68**	0.74**

**. Correlation is significant at the 0.01 level

(0.837), tertiary roots per stump (0.926), length of lateral roots (0.896) and root dry weight (0.807) was highly correlated with collar diameter. Shoot length is also one of the good parameter, easily measurable it is related to give good correlation with respect to length of sprouts (0.848) and tertiary roots per stump (0.862). In case of root length also not at all correlated with any of the RGP characters all were below 0.8 and maximum was 0.796 in length of sprouts. Length of primary lateral roots characters almost six RGP characters out eight very high correlations. In the row-wise the collar diameter, shoot length and length of primary lateral roots were dependable in predicting the possible vigour of the stump. In the column wise, the length of the sprouts and tertiary roots per stump was highly correlated with almost five seedling characteristics.

4.3 OPTIMIZATION OF POTTING MEDIA FOR PRODUCING QUALITY TEAK SEEDLINGS

Evaluation and optimization of potting media for producing quality teak seedlings study was conducted in a completely randomized design with different treatments viz. M1-Soil + coir pith compost + FYM, M2-Soil+ coir pith compost+ vermicompost, M3-Soil+ Rice husk+ vermicompost, M4-Coir pith+ vermiculite+ perlite and M5-Soil+ Sand+ FYM (Control). All the three ingredients in the order of mention in potting media treatments were taken by volume in the ratio 2:1:1. Growth observation of the *Tectona grandis* seedlings were evaluated as an effect of different potting media mixtures in different proportion. The salient results are presented hereunder.

4.3.1 Effect of potting media on shoot growth attributes of teak seedlings

Effect of potting media on different shoot growth attributes viz. shoot length, collar diameter and total seedling length up to 90 days of transplanting is furnished in table (Table 36).

4.3.1.1 Shoot length

The shoot length differs significantly with respect to different potting media treatments at all stages of growth. The treatment M3 (Soil+ Rice husk+ vermicompost

Table 36. Effect of potting media on the shoot growth parameters of *Tectona grandis* seedlings up to 90 days after transplanting

Treatment	Shoot length (cm)			Collar diameter (mm)			Total seedling length (cm)		
	30 DAP	60 DAP	90 DAP	30 DAP	60 DAP	90 DAP	30 DAP	60 DAP	90 DAP
M1	15.75^{b}	41.75^{b}	53.37^{b}	2.66^{b}	4.56^{c}	5.85^{c}	30.50^{b}	72.37^{c}	99.87^{c}
M2	17.37^{b}	58.25^{a}	85.43^{a}	2.60^{b}	4.80^{c}	7.45^{b}	39.37^{a}	90.25^{a}	127.43^{b}
M3	19.94^{a}	60.32^{a}	90.87^{a}	3.41^{a}	6.23^{a}	8.77^{a}	40.41^{a}	93.95^{a}	138.00^{a}
M4	7.06^{c}	9.62^{c}	13.12^{c}	1.58^{c}	2.30^{d}	2.62^{d}	31.87^{b}	43.08^{d}	55.58^{d}
M5 (Control)	19.87^{a}	46.28^{b}	50.76^{b}	2.66^{b}	5.49^{b}	6.69^{b}	42.50^{a}	80.03^{b}	95.51^{c}
F value	74.94**	125.9**	175**	26.81**	76.42**	74.64**	15.09**	79.21**	89.67**
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CD (0.05)	1.75	5.21	6.79	0.36	0.48	0.76	4.11	6.52	9.78

**Significant at 1% level   * Significant at 5% level   NS-Non Significant   DAP-Days after transplanting

Treatments with the same letter are not significantly different

M1- Soil+ coir pith compost+ FYM in 2:1:1 ratio

M2- Soil+ coir pith compost+ vermicompost in 2:1:1 ratio

M3- Soil+ Rice husk+ vermicompost in 2:1:1 ratio

M4- Soil+ vermiculite+ perlite in 2:1:1 ratio

M5- Soil+ Sand+ FYM in 2:1:1 ratio (Control)

in 2:1:1 ratio) was significantly superior throughout the seedling growth with maximum shoot growth of 19.94 cm, 60.32 cm and 90.87 cm respectively at 30,60 and 90 days interval. At 90 days, the treatments M3 (90.87 cm) and M2 (85.43 cm) were showing significantly higher shoot length. The lowest shoot length (13.12 cm) was recorded in M4 (coir pith + vermiculite + perlite) treatment, which was inferior to the control treatment.

4.3.1.2 Collar diameter

Collar diameter significantly differed with respect to different potting media at different stages of growth with respect to the treatments imposed. The treatment M3 obtained maximum collar diameter (3.41 mm, 6.23 mm, 8.77 mm) at 30, 60 and 90 days after transplanting. At, 30 DAP M1 (2.66 mm), M2 (2.60 mm), and M5 (2.66 mm) were on par with each other and all these three treatments significantly differed in collar diameter from the least performed (1.58 mm) M4 treatment (coir pith + vermiculite + perlite).

4.3.1.3 Total seedling length

The total seedling length differ significantly with respect to different potting media treatment at all stages of growth. Total seedling length at 30 days after transplanting M5 i.e. control showing maximum (42.50 cm) which was on par with treatment M2 (39.37 cm), T3 (40.41 cm) and M5 (42.50 cm) and the lowest was observed in M1 (30.50 cm) and M4 (31.87 cm).

At, 60 DAP among different treatments studied for total seedling length showing significantly differ from the different treatment, M3 produced longer seedling (93.95 cm), which was on par with the treatment M2 (90.25 cm), whereas M4 produced shorter with length 43.08 cm. The total seedling length after 90 days showing significantly differed with respect to potting media treatments. The treatment M3 recorded significantly highest total seedling length (138.00 cm) followed by M2 (127.43 cm), however M1 (99.87 cm) and Control (95.51 cm) showing on par with each other. The lowest total seedling length was observed in M4 (55.58 cm).

4.3.2. Effect of potting media on leaf growth attributes of teak seedlings

Effect of potting media on different leaf parameters viz. number of leaves and leaf area up to 90 days of transplanting is depicted in table 37.

4.3.2.1 Number of leaves

The number of leaves differ significantly with respect to different potting media treatment at 30 days after transplanting. At 30 days after transplanting M1 (9.75), M2 (11.62), M3 (10.75) and M5 (11.62) were on par with each other and all these four treatment are significantly different from M4 (8.125).

At 60 and 90 DAP the number of leaves did not showed any significant difference between all the different potting media.

4.3.2.2 Leaf area

The leaf area differs significantly with respect to different potting media treatment at all stages of growth. The treatment M3 was significantly larger throughout the seedling growth with larger leaf area of 378.24 cm^2, 1585.65 cm^2 and 2265.92 cm^2 with respectively 30, 60 and 90 days after transplanting. At, 30 DAP the maximum leaf area (378.24 cm^2) recorded in M3 followed by M1 (215.23 cm^2), M2 (179.01 cm^2) and M5 (178.79 cm^2) which were on par with each other and lowest leaf area recorded was treatment M4 (7.85 cm^2).

At 90 days after transplanting, the leaf area of teak seedling showed significant difference due to the different potting media treatments. The maximum leaf area (2265.92 cm^2) recorded in M3 followed by M2 (1846.02 cm^2), M5 (1336.45 cm^2) and M1 (1079.27 cm^2). The lowest performed treatment was M4 (176.47 cm^2).

Table 37. Effect of potting media on the leaf growth parameters of Tectona grandis seedlings up to 90 days after transplanting

Treatment	Number of Leaves			Leaf Area (cm^2)		
	30 DAP	60 DAP	90 DAP	30 DAP	60 DAP	90 DAP
M1	9.750^{b}	10.25	9.25	215.23^{b}	900.35^{c}	1079.27^{d}
M2	11.62^{a}	9.50	10.25	179.01^{c}	1301.19^{b}	1846.02^{b}
M3	10.75^{ab}	11.00	9.00	378.24^{a}	1585.65^{a}	2265.92^{a}
M4	8.125^{c}	10.62	10.62	7.85^{d}	88.03^{d}	176.47^{e}
M5 (Control)	11.62^{a}	11.75	8.50	178.79^{c}	1236.81^{b}	1336.45^{c}
F value	6.96**	1.37	1.68	178.8**	93.56**	129.9**
P value	<0.01	0.262	0.189	<0.01	<0.01	<0.01
CD (0.05)	1.60	NS	NS	28.29	171.07	200.52

**Significant at 1% level * Significant at 5% level NS-Non significant

DAP-Days after transplanting

Treatments with the same letter are not significantly different

M1- Soil+ coir pith compost+ FYM in 2:1:1 ratio

M2- Soil+ coir pith compost+ vermicompost in 2:1:1 ratio

M3- Soil+ Rice husk+ vermicompost in 2:1:1 ratio

M4- Soil+ vermiculite+ perlite in 2:1:1 ratio

M5- Soil+ Sand+ FYM in 2:1:1 ratio (Control)

4.3.3 Effect of potting media on the root growth attributes of teak seedlings

Effect of potting media on different root growth attributes viz. number of primary lateral roots, length of primary lateral roots, total root length up to 90 days of transplanting is represented in table (Table 38)

4.3.3.1 Number of primary lateral roots

Number of primary lateral roots did not showed significant difference with respect to different potting media at 30 days after transplanting At, 60 and 90 DAP the number of primary lateral roots differ significantly with respect to different potting media treatment. The treatment M3 was significantly superior throughout the seedling growth with maximum number of primary lateral roots of 54.87 and 62.25 respectively. At 90 days after transplanting, significantly high number of primary lateral roots was (62.25) recorded in M3 ((Soil+ Rice husk+ vermicompost), all the remaining treatments i.e. M1 (41.37), M2 (43.00), M4 (38.62) and M5 (32.62) were lower and on par with each other.

4.3.3.2 Length of primary lateral roots

Length of primary lateral roots had significant difference with respect to different potting media treatments at all stages of growth. The treatment M3 was significantly larger length of primary lateral roots with maximum of length of 11.17 cm, 20.49 cm, 21.25 cm respectively 30, 60 and 90 days interval. At 60 DAP, the treatment M1 (14.00 cm), M2 (14.66 cm), M4 (11.15 cm) and M5 (13.74 cm) were on par with each other.

At 90 days after transplanting the largest length of primary lateral root was 21.25 cm (M3) followed by M5 (18.02 cm). The lowest length of primary lateral root was recorded in M4 (12.79 cm).

Table 38. Effect of potting media on the root growth parameters of *Tectona grandis* up to 90 days after transplanting

Treatment	No. of Primary Lateral Roots			Length of Primary Lateral Roots (cm)			Root Length (cm)		
	30 DAP	**60 DAP**	**90 DAP**	**30 DAP**	**60 DAP**	**90 DAP**	**30 DAP**	**60 DAP**	**90 DAP**
M1	23.62	32.12^{c}	41.37^{b}	7.75^{b}	14.00^{b}	15.95^{bc}	14.75^{b}	30.62	46.49
M2	27.87	37.62^{bc}	43.00^{b}	7.37^{b}	14.66^{b}	15.33^{bc}	22.00^{a}	32.00	42.00
M3	28.00	54.87^{a}	62.25^{a}	11.17^{a}	20.49^{a}	21.25^{a}	21.47^{a}	33.62	47.12
M4	23.00	34.12^{c}	38.62^{b}	9.26^{ab}	11.15^{b}	12.79^{c}	24.81^{a}	33.46	42.46
M5 (Control)	25.75	44.25^{b}	32.62^{b}	9.20^{ab}	13.74^{b}	18.02^{ab}	22.62^{a}	33.75	44.75
F value	2.34	11.16**	8.00**	4.56*	5.63**	5.85**	7.43**	0.39	1.14
P value	0.074	<0.01	<0.01	<0.05	<0.01	<0.01	<0.01	0.811	0.352
CD (0.05)	NS	7.91	11.32	2.02	4.17	3.76	3.98	NS	NS

**Significant at 1% level * Significant at 5% level NS-Non Significant DAP-Days after transplanting

Treatments with the same letter are not significantly different

M1- Soil+ coir pith compost+ FYM in 2:1:1 ratio

M2- Soil+ coir pith compost+ vermicompost in 2:1:1 ratio

M3- Soil+ Rice husk+ vermicompost in 2:1:1 ratio

M4- Soil+ vermiculite+ perlite in 2:1:1 ratio

M5- Soil+ Sand+ FYM in 2:1:1 ratio (Control)

4.3.3.4 Root length

Root length showed significant difference with respect to different potting media at 30 days after transplanting. During 30 DAP the maximum root length recorded in M4 (24.81 cm) which was on par with treatment M2 (22.00 cm), M3 (21.47 cm), M5 (22.62 cm). The lowest root length (14.75 cm) recorded in potting media treatment M4. At 60 and 90 days after transplanting the root length did not showed statistically significant difference with respect to different potting media

4.3.4 Effect of potting media on the biomass components of teak seedlings

Effect of potting media on the biomass components viz. leaf dry weight, shoot dry weight and root dry weight and total dry weight of seedlings at 30, 60 and 90 days after transplanting was showed in table 39.

4.3.4.1 Leaf dry weight

Leaf dry weight differ significantly with respect to different potting media treatment at all stages of growth. The treatment M3 was significantly highest leaf dry weight recorded throughout the seedling growth with maximum leaves dry weight of 1.19 g, 4.02 g and 7.37 g and lowest performed treatment was M4 (0.04 g, 0.22 g and 0.60 g) with respect to the interval of 30, 60 and 90 days after transplanting. At, 60 days after transplanting treatment M2 (2.97 g) and M5 (2.45 g) were on par with each other. At 90 days after transplanting the maximum leaf dry weight (7.37 g) was recorded in M3 followed by M2 (5.67 g), M5 (3.56 g) and M1 (2.79 g) were on par with each other. The lowest leaf dry weight (0.60 g) was recorded in M4 treatment.

4.3.4.2 Shoot dry weight

Shoot dry weight differ significantly with respect to different potting media treatments at all stages of growth. The treatment M3 recorded maximum shoot dry

Table 39. Effect of potting media on the biomass components of *Tectona grandis* seedlings up to 90 days after transplanting

Treatment	Leaf Dry Weight (g)			Shoot Dry Weight (g)			Root Dry Weight (g)			Total Dry Weight (g)		
	30 DAP	60 DAP	90 DAP	30 DAP	60 DAP	90 DAP	30 DAP	60 DAP	90 DAP	30 DAP	60 DAP	90 DAP
M1	0.62^{b}	1.81^{c}	2.79^{c}	0.22^{c}	2.84^{c}	4.97^{d}	0.62^{c}	0.76^{b}	1.39^{b}	1.47^{bc}	3.61^{d}	6.36^{d}
M2	0.66^{b}	2.97^{b}	5.67^{b}	0.23^{c}	5.26^{ab}	11.14^{b}	0.71^{b}	1.28^{a}	2.93^{a}	1.61^{b}	6.54^{b}	14.07^{b}
M3	1.19^{a}	4.02^{a}	7.37^{a}	0.35^{a}	6.74^{a}	14.63^{a}	0.86^{a}	1.31^{a}	3.14^{a}	2.41^{a}	8.06^{a}	17.77^{a}
M4	0.04^{c}	0.22^{d}	0.60^{d}	0.05^{d}	0.29^{d}	0.88^{e}	0.13^{d}	0.17^{c}	0.52^{c}	0.23^{d}	0.47^{e}	1.40^{e}
M5(Control)	0.75^{b}	2.45^{b}	3.56^{c}	0.29^{b}	4.24^{bc}	6.62^{c}	0.21^{d}	0.91^{b}	3.11^{a}	1.26^{c}	5.15^{c}	9.73^{c}
F value	37.51**	56.69**	81.99**	40.54**	161.72**	259.7**	136.2**	14.39**	28.43**	85.51**	187.6**	511.2**
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CD (0.05)	0.19	0.53	0.83	0.05	2.32	0.95	0.07	0.35	0.64	0.24	0.61	0.81

**Significant at 1% level * Significant at 5% level NS-Non Significant DAP-Days after transplanting

Treatments with the same letter are not significantly different

M1- Soil+ coir pith compost+ FYM in 2:1:1 ratio

M2- Soil+ coir pith compost+ vermicompost in 2:1:1 ratio

M3- Soil+ Rice husk+ vermicompost in 2:1:1 ratio

M4- Soil+ vermiculite+ perlite in 2:1:1 ratio

M5- Soil+ Sand+ FYM in 2:1:1 ratio (Control)

weight of 0.35, 6.74 and 14.63 g with respect to the 30, 60 and 90 days after transplanting. The treatment M1 (0.22 g) and M2 (0.23 g) were on par with each other at 30 days after transplanting. At 90 days after transplanting, the maximum shoot dry weight (14.63 g) recorded in M3 followed by M1 (11.14 g). The lowest shoot dry weight noticed in M4 (0.88 g).

4.3.4.3 Root dry weight

The root dry weight differs significantly with respect to different potting media treatments at all stages of growth. At 30 days after transplanting, treatment M3 (0.86 g) recorded the highest root dry weight followed by M2 (0.71 g) and M1 (0.62 g) and the lowest root dry weight was recorded in M4 (0.13 g) which was on with control (M5- 0.21 g). At, 90 days after transplanting the treatment M3 recorded the maximum root dry weight (3.14 g) root dry weight was recorded followed by M2 (2.93 g) which were on par with each other and the lowest root dry was recorded in M4 (0.52 g) was observed.

4.3.4.4 Total dry weight

Total dry weight of seedling differs significantly with respect to different potting media treatments at all stages of growth. M3 recorded maximum total dry weight (2.41 8.06 and 17.77 g) at 30, 60 and 90 days interval. While the treatment M4 (0.23, 0.47 and 1.40 g) recorded lowest total dry weight at all stages of growth.

4.3.5. Effect of potting media on the root-shoot ratio and quality index growth of teak seedlings

Root: shoot ratio and quality index were influenced by different potting media with respect to all stages of growth (Table 40).

4.3.5.1 Root: shoot ratio

The Root: shoot ratio differ significantly with respect to different potting media treatment at all stages of growth. The treatment M4 was significantly higher throughout the seedling growth with maximum root: shoot ratio of 1.08, 0.59 and 0.63 respectively 30, 60 and 90 days after transplanting.

Table 40. Effect of potting media on the Root: Shoot ratio and Quality index of Tectona grandis seedlings up to 90 days after transplanting

Treatment	Root: Shoot ratio			Quality index		
	30 DAP	60 DAP	90 DAP	30 DAP	60 DAP	90 DAP
M1	0.74^{bc}	0.26^{b}	0.28^{b}	0.12^{b}	0.21^{c}	0.34^{c}
M2	0.82^{b}	0.25^{b}	0.26^{b}	0.10^{b}	0.31^{b}	0.75^{b}
M3	0.57^{c}	0.19^{b}	0.21^{b}	0.19^{a}	0.47^{a}	0.98^{a}
M4	1.08^{a}	0.59^{a}	0.63^{a}	0.01^{d}	0.25^{c}	0.06^{d}
M5 (Control)	0.22^{d}	0.21^{b}	0.52^{a}	0.07^{c}	0.31^{b}	0.65^{b}
F value	18.39**	26.93**	6.76**	41.64**	61.92**	69.19**
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CD (0.05)	0.21	0.09	0.20	0.03	0.05	0.12

**Significant at 1% level * Significant at 5% level NS-Non Significant

DAP-Days after transplanting

Treatments with the same letter are not significantly different

M1- Soil+ coir pith compost+ FYM in 2:1:1 ratio

M2- Soil+ coir pith compost+ vermicompost in 2:1:1 ratio

M3- Soil+ Rice husk+ vermicompost in 2:1:1 ratio

M4- Soil+ vermiculite+ perlite in 2:1:1 ratio

M5- Soil+ Sand+ FYM in 2:1:1 ratio (Control)

At 90 days after transplanting the maximum root: shoot (0.63) was recorded in M4 followed by M5 (0.52), which were on par with each other. The lowest root: shoot recorded in M3 (0.21).

4.3.5.2 Seedling quality index

The quality index differed significantly with respect to different potting media treatment at all stages of growth. The treatment M3 recorded significantly highest quality index of 0.19, 0.47 and 0.98 respectively at 30, 60 and 90 days after transplanting. At 30 days after transplanting, quality index of M1 (0.12) and M2 (0.10) showing on par with each other followed by M5 (0.07), the lowest quality index (0.01) recorded in M4. At 90 days after transplanting, quality index showing significant difference with respect to different treatment, the maximum quality index (0.98) recorded in M3 followed by M2 (0.75) and M5 (0.65), both were on par with each other. The lowest quality index recorded in M4 (0.06).

4.3.6 Effect of potting media on the seedling growth indices

Data obtaining to the seedling growth indices viz. specific leaf area, specific leaf weight, leaf area ratio, leaf weight ratio, absolute growth rate, relative growth rate and net assimilation rate of the seedlings at different stages of growth is recorded in table 41 and 42.

4.3.6.1 Specific leaf area (SLA)

The specific leaf area showed statistically significant difference with respect to different potting media treatment at 30, 60 and 90 days after transplanting. At 30 day after transplanting, the maximum specific leaf area was recorded in M1 (352.05 $cm^2\ g^{-1}$) which was on par with M2 and M3 (286.78 $cm^2 g^{-1}$, 330.36 $cm^2\ g^{-1}$) respectively. M4 (225.86 $cm^2\ g^{-1}$) showed lowest specific leaf area.

At 60 DAP, specific leaf area was showing significantly difference with respect to the different potting media. Treatment M5 (557.74 $cm^2\ g^{-1}$) recorded maximum

Table 41. Effect of potting media on the seedling growth indices of *Tectona grandis* up to 90 days after transplanting

Treatment	Specific Leaf Area (cm^2 g^{-1})			Specific Leaf Weight (gcm^{-2})			Leaf Area Ratio ($cm^2g^{1)}$			Leaf Weight Ratio		
	30 DAP	60 DAP	90 DAP	30 DAP	60DAP	90 DAP	30 DAP	60 DAP	90 DAP	30 DAP	60 DAP	90 DAP
M1	352.05^{a}	520.84^{ab}	391.01^{a}	0.002^{b}	0.0020^{b}	0.0025^{b}	147.78^{a}	250.11^{a}	168.87^{a}	0.42	0.49	0.43
M2	286.78^{abc}	444.38^{ab}	326.67^{bc}	0.003^{ab}	0.0023^{ab}	0.0031^{ab}	113.07^{b}	198.84^{b}	131.63^{b}	0.40	0.45	0.40
M3	330.36^{ab}	394.28^{b}	318.01^{c}	0.003^{b}	0.0025^{a}	0.0032^{a}	157.95^{a}	196.52^{b}	127.57^{b}	0.48	0.49	0.41
M4	225.86^{c}	401.81^{b}	299.58^{c}	0.005^{a}	0.0026^{a}	0.0034^{a}	37.47^{c}	188.64^{b}	128.09^{b}	0.19	0.47	0.44
M5(Control)	237.77^{bc}	557.74^{a}	386.15^{ab}	0.004^{ab}	0.0020^{b}	0.0026^{b}	141.56^{a}	248.09^{a}	137.91^{b}	0.59	0.47	0.36
F value	2.83*	2.69*	3.91**	6.44*	0.06*	0.42**	61.65**	6.84**	7.31**	0.68	0.26	1.85
P value	<0.05	<0.05	<0.01	<0.05	<0.05	<0.01	<0.01	<0.01	<0.01	0.45	0.638	0.209
CD (0.05)	94.52	127.01	60.39	0.0015	0.0004	0.0006	17.85	32.98	18.59	NS	NS	NS

**Significant at 1% level * Significant at 5% level NS-Non Significant DAP-Days after transplanting

Treatments with the same letter are not significantly different

M1- Soil+ coir pith compost+ FYM in 2:1:1 ratio

M2- Soil+ coir pith compost+ vermicompost in 2:1:1 ratio

M3- Soil+ Rice husk+ vermicompost in 2:1:1 ratio

M4- Soil+ vermiculite+ perlite in 2:1:1 ratio

M5- Soil+ Sand+ FYM in 2:1:1 ratio (Control)

Table 42. Effect of potting media on the seedling growth indices of *Tectona grandis* seedlings up to 90 days after transplanting

Treatment	Absolute Growth Rate (cm day^{-1})		Relative Growth Rate (g $g^{-1} day^{-1}$)		Net Assimilation Rate (g cm^{-2} day^{-1})	
	(30 DAP- 60 DAP)	(60 DAP – 90DAP)	(30 DAP –60 DAP)	(60 DAP-90DAP)	(30 DAP – 60 DAP)	(60 DAP – 90 DAP)
M1	0.07	0.09	0.03	0.02	0.00015^{d}	0.0001
M2	0.16	0.25	0.04	0.25	0.00029^{ab}	0.00016
M3	0.18	0.32	0.04	0.26	0.00022^{c}	0.00017
M4	0.01	0.03	0.03	0.03	0.00030^{a}	0.00024
M5(Control)	0.12	0.15	0.04	0.21	0.00023^{bc}	0.00012
F value	0.22	0.78	2.85	2.5	5.29*	3.32
P value	0.63	0.38	0.09	0.12	<0.05	0.076
CD	NS	NS	NS	NS	0.00006	NS

**Significant at 1% level * Significant at 5% level NS-Non Significant DAP-Days after transplanting
Treatments with the same letter are not significantly different

M1- Soil+ coir pith compost+ FYM in 2:1:1 ratio

M2- Soil+ coir pith compost+ vermicompost in 2:1:1 ratio

M3- Soil+ Rice husk+ vermicompost in 2:1:1 ratio

M4- Soil+ vermiculite+ perlite in 2:1:1 ratio

M5- Soil+ Sand+ FYM in 2:1:1 ratio (Control)

specific leaf area which was on par with M1 (520.84 cm^2 g^{-1}) and M2 (444.38 cm^2 g^{-1}). The lowest specific leaf area recorded in M3 (394.28 cm^2 g^{-1}).

At 90 days after transplanting specific leaf area showed significant difference with respect to the different potting media treatments. M1 (391.01 cm^2 g^{-1}) recorded maximum specific leaf area which is on par with M5 (385.15 cm^2 g^{-1}). Significantly lower value was recorded by M4 (299.58 cm^2 g^{-1}) which is on par with M3 and M2 (318.01 cm^2 $g^{-1}$and 318.01 cm^2 g^{-1}) respectively.

4.3.6.2 Specific leaf weight

The specific leaf weight differs significantly with respect to different potting media treatment at 30 days after transplanting. The highest specific leaf weight recorded in in M4 (0.005 g cm^{-2}), which was on par with M2 (0.003 g cm^{-2}) and M5 (0.004 g cm^{-2}) and the lowest specific leaf area recorded in M1 (0.002 g cm^{-2}).

However, 60 and 90 days after seedlings transplanting showing significant differ with respect to different potting media treatment, the maximum specific leaf weight recorded was in M4 (0.0026 and 0.0034 g cm^{-2}) at 60 and 90 DAP. The while specific leaf area of the seedlings significantly varied at different stages of growth.

4.3.6.3 Leaf area ratio

The leaf area ratio showing statistically significant difference with respect to different potting media treatment at all periods of growth. At 30 days after transplanting, leaf area ratio showing significant different between the treatment, maximum leaf area ratio was recorded in M3 (157.95 cm^2 g^{-1}), which was on par with M1 (147.78 cm^2 g^{-1}) and M5 (141.56 cm^2 g^{-1}). The minimum leaf area ratio recoded in M4 (37.47 cm^2 g^{-1}).

At 60 DAP, the maximum leaf area ratio (250.11 cm^2 g^{-1}) recorded in M1 which was on par with M5 (248.09 cm^2 g^{-1}) each other and the lowest leaf area ratio recorded in M4 (188.64 cm^2 g^{-1}) followed by M2 (198.84 cm^2 g^{-1}) and M3 (196.52 cm^2 g^{-1}), these three were on par with each other. M1 (168.87 cm^2 g^{-1}) showing maximum leaf area ratio at 90 days after transplanting while minimum leaf area ratio was observed in M4 (128.09 cm^2 g^{-1}), which was on par with other treatment.

4.3.6.4 Leaf weight ratio

Leaf weight ratio did not shown any significant difference with respect to potting media treatments at 30, 60 and 90 days after transplanting.

4.3.6.5 Absolute Growth Rate (AGR)

There were slight differences in the absolute growth rate with the maximum value for the Treatment M3. However, the treatments did not shown any significant difference with respect to potting media treatments at both 30 to 60 and 60-90 days intervals of seedling growth.

4.3.6.6 Relative Growth Rate (RGR)

Relative growth rate did not shown any significant difference with respect to potting media treatments at both the intervals of growth.

4.3.6.7 Net Assimilation Rate (NAR)

Significantly higher values were observed with different potting media treatments for net assimilation rate at first interval (30-60 days) of growth. The treatment T4 produced maximum net assimilation rate of 0.00030 g cm^{-2} day^{-1} and the lowest net assimilation rate was noticed in M1 (0.00015 g cm^{-2} day^{-1}).

4.3.7 Benefit-cost ratio of different potting media used for *Tectona grandis* seedlings up to 90 days of growth in the nursery

The cost of production calculated for potting media treatment M1- (Soil+ coir pith compost+ FYM) was ₹ 8.79, for M2- (Soil+ coir pith compost+ vermicompost) it was ₹ 9.82, for M3- (soil+ rice husk+ vermicompost) the cost was ₹ 9.09 and the treatment M4-(Coir pith+ vermiculite+ perlite) was the costliest with ₹ 13.02 per seedling as against ₹ 9.01 for the treatment M5 (Standard potting media used. (Soil+ sand+ FYM).

Table 43. Benefit-cost ratio of different potting media used for *Tectona grandis* seedlings up to 90 days growth in the nursery

Inputs and Outputs	Potting media used				
	M1	**M2**	**M3**	**M4**	**M5**
Total sum of production costs per seedling (₹)	8.79	9.82	9.09	13.02	9.01
Total sum of receipts per seedling (₹)	15.00	15.00	15.00	15.00	15.00
BC ratio	1.71	1.53	1.65	1.15	1.66

M1- Soil+ coir pith compost+ FYM in 2:1:1 ratio

M2- Soil+ coir pith compost+ vermicompost in 2:1:1 ratio

M3- Soil+ Rice husk+ vermicompost in 2:1:1 ratio

M4- Soil+ vermiculite+ perlite in 2:1:1 ratio

M5- Soil+ Sand+ FYM in 2:1:1 ratio (Control)

The highest Benefit-cost ratio among different potting media treatment was for M1- (Soil+ coir pith compost+ FYM) with B: C ratio of 1.71, for M2- (Soil+ coir pith compost+ vermicompost) it was 1.53, for M3- (soil+ rice husk+ vermicompost) it was 1.65 and for the treatment M4-(Coir pith+ vermiculite+ perlite) the B: C ratio was 1.15 as against 1.16 for the treatment M5 (Standard potting media used. (Soil+ sand+ FYM).

4.4 EVALUATION OF CONTAINERS FOR PRODUCING QUALITY TEAK SEEDLINGS

The experiment on standardization of optimal size of poly bags and root trainers was conducted in a completely randomized design with six treatments viz. T1- Poly bag of 30cm x 25cm, T2- Poly bag of 30cm x 20cm, T3-Poly bag of 25cm x 15cm (Standard size/control), T4-Root trainer of 300 cc, T5-Root trainer of 200 cc and T6-Root trainer of 150 cc (Standard size/control). The salient results on different growth attributes recorded at 30, 60 and 90 days of seedling growth are presented here under.

4.4.1 Effect of containers on shoot growth attributes of teak seedlings

Effect of type and size of containers on different shoot growth attributes viz. shoot length, collar diameter and total seedling length up to 90 days of transplanting is depicted in Table 44.

4.4.1.1 Shoot length

The shoot length showing significant difference with respect to different type and size of container treatments at all stages of growth. The treatment T_1 -Poly bag of 30cm x25cm was significantly superior throughout the seedling growth with maximum shoot length of 35.91 cm, 69.29 cm and 106.89 cm at 30, 60 and 90 days after transplanting. At, 30 DAP maximum shoot length (35.91 cm) was recorded in T1 which was on par with 33.60 cm (T2) and next best was recorded in T3 (21.21 cm) followed by 13.25 cm (T4). Minimum shoot length was recorded in T6 (7.13 cm), which was on par with T5 (8.90 cm). At, 60 days after transplanting showed significant differences, T1 with highest shoot length and next best was T2 (55.86 cm) and T3 (42.09 cm), lowest was observed in T6 (10.80 cm), which was on par with T5 (16.60 cm) and T4 (19.75 cm). At 90 days after transplanting the maximum shoot length (106.89 cm) was recorded in T1 followed by T2 (90.97 cm), T3 (47.17 cm) and T4 (27.09 cm). The minimum shoot length (16.89 cm) was noticed in T6.

Among the poly bags, maximum shoot length recorded in T1 -Poly bag of 30cm x 25cm at all stages of growth followed by T2 and T3 -Poly bag of 25cm x 15cm (Standard size/control). Among the different root trainers, the maximum shoot length (13.25 cm, 19.75 cm and 27.09 cm respectively at 30, 60 and 90 days after transplanting) was noticed in T4 -Root trainer of 300 cc and the shortest shoot length was noticed in T6 (7.13 cm, 10.80 cm and 16.89 cm).

4.4.1.2 Collar diameter

Effect of type and size of containers had significant effect on the collar diameter growth at different period of observation. The treatment T1 was superior throughout the seedling growth with maximum collar diameter of 2.79 mm, 9.96 mm, 13.50 mm at 30, 60 and 90 days after transplanting,

Table 44. Effect of the type and size of containers on the shoot growth parameters of *Tectona grandis* seedlings up to 90 days after transplanting

Treatment	Shoot length (cm)			Collar diameter (mm)			Total seedling length (cm)		
	30 DAP	60 DAP	90 DAP	30 DAP	60 DAP	90 DAP	30 DAP	60 DAP	90 DAP
T1	35.91[a]	69.29[a]	106.89[a]	2.79[a]	9.96[a]	13.50[a]	70.30[a]	108.71[a]	155.64[a]
T2	33.60[a]	55.86[b]	90.97[b]	2.27[bc]	8.45[b]	12.13[b]	62.40[b]	91.89[b]	128.67[b]
T3 (Control)	21.21[b]	42.09[c]	47.17[c]	2.13[c]	6.41[c]	7.23[c]	43.90[c]	72.45[c]	79.38[c]
T4	13.25[c]	19.75[d]	27.09[d]	2.70 [a]	4.62[d]	6.91[d]	26.73[d]	39.28[d]	50.90[d]
T5	8.90[d]	16.60[d]	22.17[e]	2.32[b]	3.73[de]	4.85[e]	17.97[e]	32.46[de]	39.10[e]
T6 (Control)	7.13[d]	10.80[d]	16.89[f]	1.71[d]	3.26[e]	4.15[f]	14.46[e]	23.64[e]	28.48[f]
F value	140.6**	179.8**	10488**	52.51**	130.7**	1278**	357.4**	159.8**	9152**
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CD (0.05)	2.99	10.06	1.06	0.15	1.30	0.30	3.53	15.45	1.53

**Significant at 1% level * Significant at 5% level NS-Non Significant DAP-Days after transplanting

Treatments with the same letter are not significantly different

T_1- Poly bag of 30cm x25cm

T_2- T_2- Poly bag of 30cm x20cm

T_3- Poly bag of 25cm x 15cm (Control)

T_4- Root trainer of 300 cc

T_5- Root trainer of 200 cc

T_6-Root trainer of 150 cc (Control)

At 90 days after transplanting, the maximum seedling collar diameter (13.50 mm) was recorded in T1 followed by T2 (12.13 mm). The minimum seedling collar diameter (4.15 mm) noticed in T6.

Among the different size of ploy bags (at 90 days after transplanting) the maximum collar diameter was recorded in T1 (13.50 mm) followed by T2 (12.13 mm) as against 7.23 mm in T3 (Poly bag of 25cm x 15cm) and next best was T2 (2.27 mm) over the control at 30 days after transplanting, same trend followed in 60 and 90 days after transplanting.

Among the different root trainers, maximum collar diameter showed in T4 (2.70, 4.62 and 6.91 mm) at all stages of growth ie. 30, 60 and 90 days after transplanting. The corresponding and lowest values of collar diameter noticed in control T6 were 1.71, 3.26 and 4.15 mm.

4.4.1.3 Total seedling length

The total seedling length showed significant difference with respect to different type and size of container treatments at all stages of growth. T1 recorded maximum total seedling length of 70.30 cm, 108.71 cm and 155.64 cm at different interval, i.e. 30, 60 and 90 DAP followed by T2 (62.40 cm, 91.89 cm and 128.67 cm). Shortest total seedling length noticed in T6 (14.46 cm, 23.64 cm and 28.48 cm) at 30, 60 and 90 days after transplanting.

Among the different poly bag size maximum total seedling length record in T1 and minimum total seedling length (43.90 cm) was recorded in T3 at 30 days after transplanting. At 90 days after transplanting the highest total seedling length (155.64 cm) was recorded in T1 and lowest total seedling length (79.38) was noticed in T3.

At 30 DAS, among the root trainer the maximum total seedling length (26.73 cm) was recorded in T4. The minimum total seedling length (14.46 cm) in T6 and T5 (17.97 cm), both were on par with each other. At 90 days after transplanting the maximum total seedling length (50.90 cm) was recorded in T4. The minimum total seedling length recorded in T6 (28.48 cm).

4.4.2 Effect of containers on leaf growth attributes of teak seedlings

Effect of type and size of containers on the leaf growth attributes viz. number of leaves and leaf area presented in Table 45.

4.4.2.1 Number of leaves

The number of leaves showing significant difference with respect to different type and size of container treatments at all stages of growth. At 30 days after transplanting T1 (12.75) recorded maximum number of leaves T2 (11.87), which were on par with each other. Minimum number of leaves observed in T6 (7.87). At 90 days after transplanting the maximum number of leaves (15.25) was recorded in T1 followed by T2 (13.12). The lowest number of leaves (10.37) was recorded in T6.

4.4.2.2 Leaf area

Effect of type and size of containers on seedling leaf area showed significant responses at growth periods of 30, 60 and 90 days interval. A gradual increase in leaf area with growth was observed in all different treatments. Among the six treatments, T1 produced maximum leaf area of 912.10 cm^2, 2361 cm^2 and 4025.95 cm^2 at 30, 60 and 90 DAP respectively. At all period of growth, minimum leaf area noticed in T6 (151.76 cm^2, 124.00 cm^2 and 239.35 cm^2) at 30, 60 and 90 days after transplanting.

Among the different poly bags, T1 showed maximum leaf area at all stages of growth followed by T2 (663.24 cm^2, 1644.81 cm^2 and 3817.52 cm^2). The minimum leaf area recorded in T3 (1260.95 cm^2).

Among different root trainers, T4 (301.73 cm^2, 305.07 cm^2 and 435.08 cm^2) recorded maximum leaf area at all stages of interval, lowest leaf area was recorded in T6 (151.76, 124.00 and 239.35 cm^2).

Table 45. Effect of the type and size of containers on the leaf growth parameters of *Tectona grandis* seedlings up to 90 days after transplanting

Treatment	Number of Leaves			Leaf Area (cm^2)		
	30 DAP	60 DAP	90 DAP	30 DAP	60 DAP	90 DAP
T1	12.75[a]	11.87[a]	15.25[a]	912.10[a]	2361.68[a]	4025.95[a]
T2	11.87[ab]	11.25[a]	13.12[b]	663.24[b]	1644.81[b]	3817.52[b]
T3(Control)	10.12[c]	8.37[b]	10.75[cd]	402.95[c]	609.37[c]	1260.95[c]
T4	11.00[bc]	9.12[b]	11.12[cd]	301.76[d]	305.07[cd]	435.08[d]
T5	10.12[c]	9.50[b]	11.37[c]	193.79[e]	185.56[d]	301.59[e]
T6(Control)	7.87[d]	8.75[b]	10.37[d]	151.76[f]	124.00[d]	239.35[f]
F value	18.82**	14.75**	37.87**	3733**	150.2**	9219**
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CD (0.05)	1.11	1.65	0.85	13.80	420.55	52.79

**Significant at 1% level * Significant at 5% level NS-Non Significant

DAP-Days after transplanting

Treatments with the same letter are not significantly different

T_1- Poly bag of 30cm x25cm

T_2- T_2- Poly bag of 30cm x20cm

T_3- Poly bag of 25cm x 15cm (Control)

T_4- Root trainer of 300 cc

T_5- Root trainer of 200 cc

T_6-Root trainer of 150 cc (Control)

4.4.3 Effect of containers on root growth attributes of teak seedlings

Effect of type and size of containers on the root growth attributes viz. number of primary lateral roots, length of primary lateral roots and the root length are presented in Table 46.

4.4.3.1 Number of primary lateral roots

The number of primary lateral roots showed significant difference with respect to different type and size of container treatments at all stages of growth except 60 days after transplanting.

The treatment T1 was significantly superior throughout the seedling growth period with maximum number of primary lateral roots of 47.12 54.62 and 58.12 respectively after the 30, 60 and 90 days transplanting.

At 30 days after transplanting T1 recorded maximum number of primary lateral roots, which was on par with T2 (40.00) and T4 (50.50), and the same trend was shown in 90 days after transplanting. Minimum number of primary lateral roots recorded in T6 (31.62, 36.25 and 40.87) at different stages i.e. 30, 60 and 90 days after transplanting.

At 90 days after transplanting among the poly bag, highest number of primary lateral roots noticed in T1and the lowest was recorded in T3 (50.62). Among the different root trainers, T4 (51.25) recorded maximum number of primary lateral roots and the minimum number of primary lateral roots (40.87) was noticed in T6.

4.4.3.2 Length of primary lateral roots

Length of primary lateral roots was significant due to different type and container size at all stages of growth. T1 recorded maximum length of primary lateral roots (29.58 cm, 35.12 cm and 38.96 cm) at 30, 60 and 90 days after transplanting. Smallest length of primary lateral roots was recorded in control T6 (11.57 cm, 12.81 cm and 13.06 cm) and T3 control (13.01 cm, 20.78 cm and 22.77 cm) respectively at 30, 60 and 90 days after transplanting.

Among the ploy bags, T1 performed the best with respect to the length of primary lateral roots followed by T2 (20.19 cm, 21.06 cm and 24.73 cm) at different stages of growth. The smallest length of primary lateral roots (22.77 cm) at 90 days was recoded in T3.

Table 46. Effect of type and size of containers on the root growth parameters of *Tectona grandis* seedlings up to 90 days

Treatment	No. of Primary Lateral Roots			Length of Primary Lateral Roots(cm)			Root Length (cm)		
	30 DAP	60 DAP	90 DAP	30 DAP	60 DAP	90 DAP	30 DAP	60 DAP	90 DAP
T1	47.12[a]	54.62	58.12[a]	29.58[a]	35.12[a]	38.96[a]	34.38[a]	39.42[a]	48.74[a]
T2	40.00[b]	53.50	57.75[a]	20.91[b]	21.06[b]	24.73[b]	28.80[b]	36.02[a]	37.69[b]
T3 (Control)	37.00[b]	42.75	50.62[b]	13.01[cd]	20.78[b]	22.77[c]	22.68[c]	30.36[b]	32.21[c]
T4	50.50[a]	53.37	51.25[b]	15.73[c]	18.50[bc]	19.80[d]	13.48[d]	19.53[c]	23.80[d]
T5	39.12[b]	49.37	52.75[b]	12.37[d]	14.07[cd]	15.67[e]	9.07[e]	15.86[cd]	16.92[e]
T6 (Control)	31.62[c]	36.25	40.87[c]	11.57[d]	12.81[d]	13.06[f]	7.32[f]	12.83[d]	11.59[f]
F value	26.73**	1.09	25.49**	41.89**	56.03**	655.7**	594.4**	114.7**	1275**
P value	<0.01	0.32	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CD (0.05)	3.79	NS	3.55	3.06	5.09	1.02	1.29	5.63	1.10

**Significant at 1% level * Significant at 5% level NS-Non Significant DAP-Days after transplanting

Treatments with the same letter are not significantly different

T_1- Poly bag of 30cm x 25cm

T_2- T_2- Poly bag of 30cm x 20cm

T_3- Poly bag of 25cm x 15cm (Control)

T_4- Root trainer of 300 cc

T_5- Root trainer of 200 cc

T_6-Root trainer of 150 cc (Control)

Among the root trainers, T4 (19.80 cm) recorded maximum length of primary lateral roots and the smallest length of primary lateral roots at 90 days (13.06 cm) was noticed in T6.

4.4.3.3 Root length

The total root length showed significant difference with respect to different type and size of container treatments at all stages of growth. T1 recorded maximum root length of 34.38 cm, 39.42 cm and 48.74 cm respectively throughout different interval at 30, 60 and 90 days after transplanting, followed by T2. Minimum root length was observed in T6 (7.32 cm, 12.83 cm and 11.59 cm) at 30, 60 and 90 days of growth period.

Among the poly bags, maximum root length was noticed in T1 (48.74 cm) followed by T2 (37.62 cm) at 90 days after transplanting and the minimum root length (32.21 cm) was recorded in T3. Among the root trainer treatments, maximum root length (23.80 cm) was recorded in T4 and the minimum root length (11.59 cm) noticed in T6 at 90 days after transplanting.

4.4.4. Effect of containers on biomass components of teak seedlings

Effect of type and size of containers on biomass component viz. leaf dry weight, shoot dry weight, root dry weight and total dry weight of seedlings up to 90 days of transplanting is represented in Table 47.

4.4.4.1 Leaf dry weight

Leaf dry weight showed significant difference with respect to different type and size of container treatments at all stages of growth. The seedling with higher leaf dry weight was noticed in T1 (2.02 g, 14.34 g and 27.64 g) at 30, 60 and 90 DAP, followed by T2. However, lightest seedling observed in T6 (0.27 g, 0.71 g and 1.11 g) at different stages i.e. 30, 60 and 90 days after transplanting respectively. At, 90 days after transplanting, the highest leaf dry weight recorded in T1 followed by T2 (24.01 g) and lowest leaf dry weight (1.11 g).

Among the different poly bags, maximum leaf dry weight was noticed in T1, which was on par with T2 at all stages of growth. With different size of root trainers, maximum leaf dry weight noticed in T4 (0.72, 1.97 and 2.11 g) and the minimum leaf dry weight recorded in T6 at all stages of growth.

4.4.4.2 Shoot dry weight

Among the type and size of container studied, shoot dry weight showed statistically significant difference at different intervals. The maximum shoot dry weight was noticed in T1 (2.82, 23.84 and 48.21g) respectively throughout the growth stages at 30, 60 and 90 days after transplanting followed by T2. Minimum shoot dry weight was recorded in T6 (0.35, 0.99 and 1.56 g) at all stages of growth.

At, 90 days the maximum shoot dry weight (48.21 g) was recorded in T1 followed by T2 (41.94 g). The minimum shoot dry weight (1.56 g) recorded in T6 followed by T5 (2.25 g), both were on par with each other.

Among poly bags, maximum Shoot dry weight was recoded in T1 followed by T2. Among the root trainers, T4 showed maximum shoot dry weight of 1.22 g, 2.83 g and 3.46 g respectively at 30, 60 and 90 days after transplanting over the control. Minimum shoot dry weight recorded in T6.

4.4.4.3 Root dry weight.

Effect of type and size of containers on root dry weight exhibited significant difference at all stages of growth. T4 (1.91 g) showed maximum root dry weight at early stage after 30 DAP, next best was T1 (0.90 g) followed by T2 (0.64 g) and T3 (0.39 g), Minimum root dry weight was recorded in T6 (0.29 g).

At, 60 and 90 DAP highest root dry weight was noticed in T1 (6.41 g and 12.16 g) respectively followed by T2 (4.09 g, 10.14 g). Lowest root dry weight recorded in T6 (0.58 g and 1.60 g).

Among the different poly bag maximum dry weight observed in T1 followed by T2 at all stages of growth. Among root trainers, T4 recorded maximum root dry weight (1.91, 2.27 and 3.31 g) at 30, 60 and 90 days after transplanting followed by T5 and T6, these both were on par with each other.

Table 47. Effect of type and size of containers on biomass components of *Tectona grandis* seedlings up to 90 days after transplanting

Treatment	Leaf Dry Weight (g)			Shoot Dry Weight (g)			Root Dry Weight (g)			Total Dry Weight (g)		
	30 DAP	60 DAP	90 DAP	30 DAP	60 DAP	90 DAP	30 DAP	60 DAP	90 DAP	30 DAP	60 DAP	90 DAP
T1	2.02[a]	14.34[a]	27.64[a]	2.82[a]	23.84[a]	48.21[a]	0.90[b]	6.41[a]	12.16[a]	3.72[a]	38.19[a]	60.37[a]
T2	2.04[a]	10.64[b]	24.01[b]	2.58[a]	16.51[b]	41.94[b]	0.64[c]	4.09[b]	10.14[b]	3.22[b]	27.16[b]	52.08[b]
T3(Control)	1.08[b]	4.13[c]	6.40[c]	1.35[b]	6.45[c]	9.45[c]	0.39[d]	1.81[cd]	3.41[c]	1.74[c]	10.59[c]	12.90[c]
T4	0.72[c]	1.97[cd]	2.11[d]	1.22[b]	2.83[cd]	3.46[d]	1.91[a]	2.27[c]	3.13[c]	3.14[b]	4.80[cd]	6.61[d]
T5	0.56[c]	1.05[d]	1.50[de]	0.63[c]	1.51[d]	2.25[e]	0.36[de]	1.70[cd]	1.94[d]	1.00[d]	2.56[d]	4.19[e]
T6(Control)	0.27[d]	0.71[d]	1.11[e]	0.35[d]	0.99[d]	1.56[e]	0.29[e]	0.58[d]	1.60[d]	0.64[e]	1.70[d]	3.16[e]
F value	71.05**	155.9**	2543**	118.9**	163.1**	5641**	336.2**	47.45**	596.1**	139.7**	161.3**	4322**
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CD (0.05)	0.25	2.56	0.68	0.26	4.14	0.81	0.09	1.37	0.53	0.31	6.68	1.12

**Significant at 1% level   * Significant at 5% level   NS-Non Significant   DAP-Days after transplanting

Treatments with the same letter are not significantly different
T_1- Poly bag of 30cm x25cm
T_2- T_2- Poly bag of 30cm x20cm
T_3- Poly bag of 25cm x 15cm (Control)
T_4- Root trainer of 300 cc
T_5- Root trainer of 200 cc
T_6-Root trainer of 150 cc (Control)

4.4.4.4 Total dry weight

Total dry weight showed significant difference with respect to different type and size of container treatments at all stages of growth. The treatment T1 showed significantly maximum total dry weight of 3.78 g, 38.19 g and 60.37 g respectively at 30, 60 and 90 days after transplanting followed by T2 (3.22, 27.16 and 52.08 g). Lowest total dry weight noticed in T6 (0.64 g) at 30 DAP. At 90 days after transplanting, the maximum and the minimum total dry weight recorded was 60.37 and 3.16 g respectively in the treatments T1 and T6.

Among the ploy bag size, maximum total dry weight recorded in T1 followed by T2. Minimum total dry weight (12.90 g) was recorded in T3 at 90 DAP. Among the root trainers, T4 showed maximum total dry weight compared to other size of root trainers with maximum total dry weight of 3.14 g. 4.80 g and 6.61g and the minimum values were 0.64, 1.71 and 3.16 g (in T6) at 30, 60 and 90 DAP.

4.4.5. Effect of containers on the root-shoot ratio and quality index growth of teak seedlings

Root: shoot ratio and quality index were influenced by type and size of containers with respect to all stages of growth (Table 48).

4.4.5.1. Root: shoot ratio

Among all different type and size of containers treatments, root: shoot ratio differ significantly at all stages of growth. The treatment T4 (1.60) showed significantly highest root: shoot ratio at 30 days after transplanting followed by T4 (0.89). Lowest root: shoot ratio observed in T2 (0.25), which was on par with T3 (0.28) and T1 (0.32). At 60 DAP, the maximum root: shoot ratio was noticed in T5 (1.10), which was significantly differing from other treatments. T4 gave a root-shoot ratio of 0.80, which was on par with T6 (0.59). Minimum value recorded in T2 (0.24) followed by T1 and T3 (0.25 and 0.28), these values were on par with each other (Table 48).

The root: shoot ratio at 90 days after transplanting showed significant difference between treatment with higher value of 1.03 in T6 followed by T5(0.86) and T4(0.89), however both these values were on par with each other. Lowest values recorded in T2 (0.24), which was on par with T1 (0.25) respectively.

4.4.5.2. Seedling quality index

The quality index of differ significantly with respect to different type and size of containers at all stages of growth. At, 30 days after transplanting the treatment T4

Table 48. Effect of type and size of containers on the Root: Shoot ratio and Quality index of *Tectona grandis* seedlings up to 90 days

Treatment	Root: Shoot ratio			Seedling quality index		
	30 DAP	60 DAP	90 DAP	30 DAP	60 DAP	90 DAP
T1	0.32^{d}	0.25^{c}	0.25^{d}	0.13^{b}	2.40^{a}	4.56^{a}
T2	0.25^{d}	0.24^{c}	0.24^{d}	0.10^{c}	1.67^{b}	4.21^{b}
T3 (Control)	0.28^{d}	0.28^{c}	0.35^{c}	0.08^{d}	0.65^{c}	1.08^{c}
T4	1.60^{a}	0.80^{b}	0.89^{b}	0.30^{a}	0.57^{c}	0.84^{d}
T5	0.58^{c}	1.10^{a}	0.86^{b}	0.09^{cd}	0.35^{c}	0.49^{e}
T6 (Control)	0.89^{b}	0.59^{b}	1.03^{a}	0.05^{e}	0.20^{c}	0.44^{e}
F value	53.03**	68.64**	130.2**	172.4**	97.23**	1217**
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CD (0.05)	0.20	0.23	0.09	0.01	0.46	0.15

**Significant at 1% level * Significant at 5% level NS-Non Significant

DAP-Days after transplanting

Treatments with the same letter are not significantly different

T_1- Poly bag of 30cm x25cm

T_2- T_2- Poly bag of 30cm x20cm

T_3- Poly bag of 25cm x 15cm (Control)

T_4- Root trainer of 300 cc

T_5- Root trainer of 200 cc

T_6-Root trainer of 150 cc (Control)

was significantly superior with maximum quality index of 0.30 followed by T1 (0.13), whereas minimum quality index noticed in T6 (0.05). At 90 days after transplanting T1 showed highest quality index of 4.56 immediately followed by T2 (4.21) and the lowest quality index (1.08) among poly bag sizes was observed in T3-Poly bag of 25cm x 15cm (Standard size/control). At 90 days of transplanting, the better root trainer treatment with respect to quality index was T4 (0.84) and a very low index of 0.49 and 0.44 for treatmentsT5 and T6.

At 90 DAP, the maximum quality index was noticed for T1 and the quality index was decreased in the order T1>T2>T3>T4>T5>T6. However, the treatments T5 (0.49) and T6 (0.44) did not differ significantly and were on par with each other. (Table 48).

4.4.6 Effect of containers on the growth indices of teak seedlings

The effect of type and size of containers on the growth analysis indices like specific leaf area, specific leaf weight, leaf area ratio, leaf weight ratio absolute growth rate, relative growth rate and net assimilation rate of the seedlings at different stages of growth depicted in Table 49 and 50.

4.4.6.1 Specific leaf area

The specific leaf area was showed statistically significant with respect to different type and size of containers at 30 and 90 days after transplanting, except 60 days DAP. At 30 and 90 DAP, T6 (control) showed significant difference with highest specific leaf area of 603.66 cm^2 g^{-1} and 218.26 cm^2 g^{-1} respectively. T1, T2, T3, T5 and T4, which were on par with each other at 30 days after transplanting. At, 90 days after transplanting second highest specific leaf area was recorded in T6 (218.26 cm^2 g^{-1}), which was on par with T5 (203.25 cm^2 g^{-1}) and T4 (206.20 cm^2 g^{-1}).

4.4.6.2 Specific leaf weight

Significant differences due to different type and size of containers was noticed in specific leaf weight at 90 days after transplanting. At the early stage i.e. 30 DAP, T2 (0.003 g cm^{-2}) showed maximum specific leaf weight, which was on par with T3

Table 49. Effect of type and size of containers on the seedlings growth indices of *Tectona grandis* seedlings up to 90 days after transplanting

Treatment	Specific Leaf Area ($cm^2\ g^{-1}$)			Specific Leaf Weight (gcm^{-2})			Leaf Area Ratio ($cm^2g^{1)}$)			Leaf Weight Ratio		
	30 DAP	60 DAP	90 DAP	30 DAP	60DAP	90 DAP	30 DAP	60 DAP	90 DAP	30 DAP	60 DAP	90 DAP
T1	454.28^{b}	165.12	146.00^{c}	0.0022	0.0061	0.0068^{a}	246.17^{a}	78.71^{a}	66.73^{c}	0.54^{ab}	0.47^{ab}	0.45^{a}
T2	348.17^{b}	155.21	159.02^{c}	0.0030	0.0064	0.006^{ab}	211.42^{bc}	79.91^{a}	73.33^{b}	0.62^{a}	0.51^{a}	0.46^{a}
T3(Control)	375.53^{b}	151.04	197.73^{b}	0.0027	0.0069	0.0050^{b}	235.61^{ab}	74.62^{a}	97.86^{a}	0.62^{a}	0.50^{ab}	0.49^{a}
T4	445.41^{b}	154.79	206.20^{ab}	0.0023	0.0065	0.0048^{b}	93.63^{d}	60.06^{b}	66.02^{c}	0.22^{c}	0.38^{c}	0.32^{b}
T5	347.71^{b}	179.95	203.25^{ab}	0.0028	0.0056	0.0049^{b}	192.71^{c}	60.52^{b}	72.63^{b}	0.55^{a}	0.33^{c}	0.35^{b}
T6(Control)	603.66^{a}	174.64	218.26^{a}	0.0018	0.0057	0.0046^{b}	244.81^{ab}	79.53^{a}	75.88^{b}	0.43^{b}	0.45^{b}	0.35^{b}
F value	6.30**	0.42	21.87**	0.08*	0.24	61.94**	23.36**	23.63**	37.53**	30.9**	37.41**	82.05**
P value	<0.01	0.068	<0.01	0.769	0.622	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CD (0.05)	110.70	NS	17.63	NS	NS	0.0006	34.23	10.39	5.43	0.12	0.05	0.04

**Significant at 1% level * Significant at 5% level NS-Non Significant DAP-Days after transplanting

Treatments with the same letter are not significantly different

T_1- Poly bag of 30cm x25cm

T_2- T_2- Poly bag of 30cm x20cm

T_3- Poly bag of 25cm x 15cm (Control)

T_4- Root trainer of 300 cc

T_5- Root trainer of 200 cc

T_6-Root trainer of 150 cc (Control)

(0.0027 g cm^{-2}) and T5 (0.028 g cm^{-2}). But after 90 days after transplanting, T1 (0.0068 g cm^{-2}) was recorded maximum specific leaf weight, remaining all other treatments were on par with each other with meager numerical difference.

4.4.6.3 Leaf area ratio

Leaf area ratio showed significant difference with respect to different type and size of container treatments at all stages of growth. T1 produced maximum leaf area ratio of 246.17 cm^2 g^{-1} at 30 days after transplanting followed by T2 (235.610 cm^2 g^{-1}) and T3 (244.81 cm^2 g^{-1}) and values were on par with each other, minimum leaf area ratio was noticed T4 (93.63 cm^2 g^{-1}).

At, 60 days after transplanting, treatment T2 (79.91 cm^2 g^{-1}) showed highest leaf area ratio, which were on par with T1 (78.71 cm2 g-1), T3 (74.62 cm^2 g^{-1}) and T6 (79.53 cm^2 g^{-1}). Lowest leaf area ratio was recorded in T4 (60.55 cm^2 g^{-1}) which was on par with T5 (60.06 cm^2 g^{-1}). At 90 DAP, leaf area ratio showed significant difference between the treatment, maximum leaf area ratio of 97.86 cm^2 g^{-1} observed in T3, followed by T6 (75.88 cm^2 g^{-1}), T2 (73.33 cm^2 g^{-1}) and T5 (72.63 cm^2 g-1), which were on par with each other. Lowest leaf area ratio noticed in T4 (66.02 cm^2 g^{-1}), which was on par with T1 (66.73 cm^2 g^{-1}).

4.4.6.4 Leaf weight ratio

Leaf weight ratio differs significantly with respect to different type and size of containers at all stages of growth. T2 (0.62) and T3 (0.62) recorded maximum leaf weight ratio at 30 days after transplanting, which was on par with T1 (0.54) and T5 (0.55). Lowest leaf weight ratio recorded in T4 (0.22). At, 60 days after transplanting highest leaf weight ratio observed in T2 (0.51), which was on par with T1 and T3. Lowest value recorded in T5 (0.33) which was on par with T4 (0.38).

Among the different treatments, leaf weight ratio was maximum in T3 (0.49) whereas T1 (0.45) T2 (0.46) recorded almost equal values and on par with each other at 90 days after transplanting. Lowest values noticed in T4 (0.32) whereas T6 and T5 recorded same values (0.35), which were on par with each other.

Table 50. Effect of type and size of containers on the seedling growth indices of *Tectona grandis* seedlings up to 90 days after transplanting

Treatment	Absolute Growth Rate (cm day^{-1})		Relative Growth Rate (g g^{-1} day^{-1})		Net Assimilation Rate (g cm^{-2} day^{-1})	
	(30 DAP –60 DAP)	(60 DAP – 90 DAP)	(30 DAP –60 DAP)	(60 DAP – 90 DAP)	(30 DAP – 60 DAP)	(60 DAP – 90 DAP)
T1	0.87^{a}	1.01^{a}	0.06^{a}	0.02^{b}	0.00057^{a}	0.00032^{b}
T2	0.57^{b}	1.04^{a}	0.06^{a}	0.03^{a}	0.00053^{ab}	0.00040^{a}
T3(Control)	0.21^{c}	0.15^{b}	0.05^{b}	0.01^{c}	0.00043^{bc}	0.00018^{c}
T4	0.06^{d}	0.05^{b}	0.01^{d}	0.008^{d}	0.00020^{d}	0.00015^{c}
T5	0.07^{cd}	0.04^{b}	0.03^{c}	0.012^{cd}	0.00038^{c}	0.00022^{c}
T6(Control)	0.03^{d}	0.05^{b}	0.03^{c}	0.02^{b}	0.00022^{d}	0.00030^{b}
F value	176.1**	121.8**	235.5**	45.83**	74.51**	41.85**
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CD	0.14	0.24	0.008	0.006	0.00009	0.00006

**Significant at 1% level * Significant at 5% level NS-Non Significant DAP-Days after transplanting

Treatments with the same letter are not significantly different

T_1- Poly bag of 30cm x25cm

T_2- T_2- Poly bag of 30cm x20cm

T_3- Poly bag of 25cm x 15cm (Control)

T_4- Root trainer of 300 cc

T_5- Root trainer of 200 cc

T_6-Root trainer of 150 cc (Control)

4.4.6.5 Absolute Growth Rate (AGR)

Absolute growth rate showed statistically significant difference with respect to different type and size of container at all stages of growth. At 30-60 days interval maximum absolute growth rate of 0.87 cm day^{-1}recorded in T1 followed by T2 (0.57 cm day^{-1}), whereas minimum absolute growth rate noticed in T6 (0.03 cm day^{-1}) which was on par with T5 and T4 (0.07 and 0.06 cm day^{-1}). At 60- 90 intervals, days after transplanting T1 and T2 showed maximum absolute growth rate of 1.01 cm day^{-1} and 1.04 cm day^{-1}followed by T3(0.15 cm day^{-1}), which was on par with T4, T5 and T6 with more or less similar value noticed.

4.4.6.6. Relative Growth Rate (RGR)

Relative growth rate differs significantly with respect to different treatment at all stages of growth. 30-60 days after transplanting the maximum relative growth rate recorded in T1 and T2 (0.06 g g^{-1} day^{-1}) both values were on par with each other followed by T2(0.05 g g^{-1} day^{-1}) and least growth rate noticed in T4 (0.01 g g^{-1} day^{-1}). At 60-90 DAP, T2 recorded maximum relative growth rate of 0.03 g g^{-1} day^{-1}and next best was T1 and T6 (0.02 g g^{-1} day^{-1}) both values were on par with each other. Lowest relative growth rate was recorded in T4 (0.008 g g^{-1} day^{-1}).

4.4.6.7 Net Assimilation Rate (NAR)

Among all different type and size of containers treatments, net assimilation rate showed significance difference with maximum net assimilation of T1 0.00057 g cm^{-2} day^{-1} at 30- 60 DAP, whereas T2 (0.00053 g cm^{-2} day^{-1}) was almost similar value recorded. Lowest value noticed in T4 (0.00020 g cm^{-2} day^{-1}), which was on par with T6 (0.00022 g cm^{-2} day^{-1}). At 60- 90 days after transplanting, T2 (0.00040 g cm^{-2} day^{-1}) recorded maximum net assimilation rate followed by T1 (0.00032 g cm^{-2} day^{-1}), which was on par with T6 (0.00030 g cm^{-2} day^{-1}) and lowest net assimilation recorded in T4 (0.00015 g cm^{-2} day^{-1}), which was on par with T3 and T5 respectively.

4.3.7 Benefit-cost ratio of different containers used for *Tectona grandis* seedlings up to 90 days of growth in the nursery

The cost of production calculated for the treatment T1- Poly bag of 30cm x25cm was ₹ 17.18, for T2 (poly bag of 30 x 20 cm) it was ₹ 11.12 per seedling, as against ₹ 9.09 for the control ie. Standard poly bag of size of 25cm x 15cm.

The production cost of root trainer stock was found (₹ 9.09 and 7.89 ₹/ plant) for T4-Root trainer of 300 cc and T5-Root trainer of 200 cc as against ₹ 6.99 per plant for T6-Root trainer of 150 cc - Standard size/control (Table 51). The receipts / sale price expected for different containers are the same (₹ 20/- per seedling) at present as there are no customer preference / price fixed for the teak seedlings in bigger containers.

Benefit-cost ratio calculated for different containers the treatment, T1- Poly bag of 30cm x25cm recorded cost benefit ratio was 0.87, for T2 (poly bag of 30 x 20 cm) the benefit cost ratio was 1.35, as against 1.65 for control ie. Standard poly bag of size of 25cm x 15cm.

The benefit cost ratio was found (2.20 and 2.53) for T4-Root trainer of 300 cc and T5-Root trainer of 200 cc as against 2.86 for T6-Root trainer of 150 cc - Standard size/control (Table 51).

Table 51. Benefit-cost ratio of different containers used for *Tectona grandis* seedlings up to 90 days growth in the nursery

Inputs and Outputs	Containers used					
	T1	T2	T3	T4	T5	T6
Total sum of production costs per seedling (₹)	17.18	11.12	9.09	9.09	7.89	6.99
Total sum of receipts per seedling (₹)	15.00	15.00	15.00	20.00	20.00	20.00
BC ratio	0.87	1.35	1.65	2.20	2.53	2.86

T_1- Poly bag of 30cm x25cm
T_2- T_2- Poly bag of 30cm x20cm
T_3- Poly bag of 25cm x 15cm (Control)
T_4- Root trainer of 300 cc
T_5- Root trainer of 200 cc
T_6-Root trainer of 150 cc (Control)

DISCUSSION

5. DISCUSSION

The comprehensive studies under the research work entitled 'Standardisation of planting stock production techniques for teak (*Tectona grandis* Linn.f.)' is aimed at screening of best methods of quality seedling production with four major objectives, the salient results of which are discussed hereunder.

5.1. EFFECT OF SCARIFICATION METHODS AND SOAKING TREATMENT

5.1.1. Effect on seed germination characteristics of *Tectona grandis*

Seed germination is a complex process in tropical forest species due to various known and unknown factors. Germination of the species could be influenced by both environmental and genetic factors. Here, the results of the effect of scarification methods and soaking as pre-treatments for improving the germination of teak seeds are discussed. In the present study, the highest germination percentage was recorded in SM2 (Termite scarified seeds) 63.04 per cent followed by SM1 (Mechanically scarified seeds) 54.29 per cent as against the 40.79 per cent in untreated seeds. The standard nursery practice for teak seed i.e. AWD- 7days (ST5) and AWD-3 days (ST4) gave germination percentages of 73.77 % and 71.66 % respectively (Fig 3). However, among the interactions, the treatment combination SM2 X ST4 (Termite scarified seeds + AWD-3 days) gave the highest germination percentage of 92.33 % (Fig 4) followed by the treatment combination SM2 X ST5 (89 %). The mechanical scarification with AWD 7 days resulted in a slight improvement of germination (77.00 % as against 73.77 in AWD 7 days alone) i.e. an increase of just 2.23 %. Similar trend followed in mean daily germination, peak value and germination value also. (Fig 5). Mechanical dormancy is present in teak and is enacted by valves which must be detached by the pressure of the growth potential of the germinating seed (Slator *et al.,* 2013). During termite treatment, termite found to feed upon upper seed coat (exocarp) of teak,

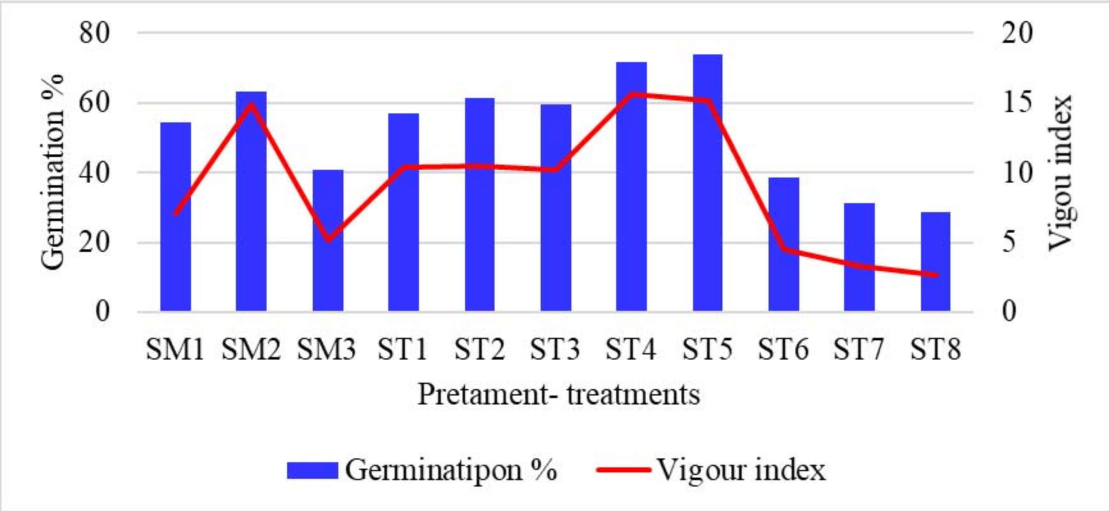


Fig 3. Effect of scarification methods and soaking treatments on germination percentage and vigour index of teak seedlings

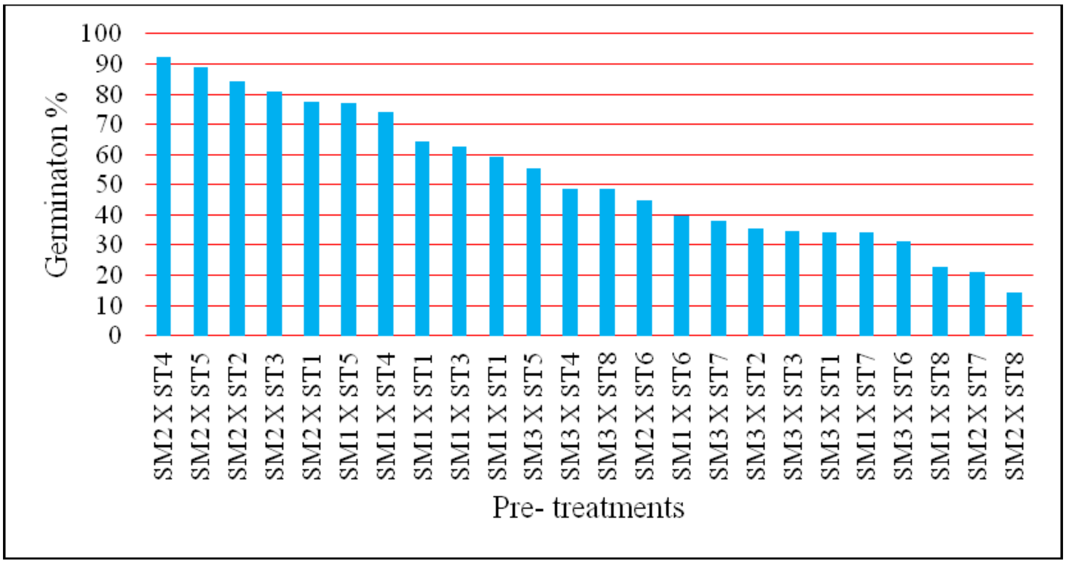


Fig 4. Interaction effect of scarification methods and soaking treatments on germination percentage

S1- Mechanically scarified seeds
S2- Termite scarified seeds
S3- Untreated Seeds (Control)
ST1- Water soaking for one day
ST2- Water soaking for three days
ST3- Alternate wetting and drying for one day
ST4- Alternate wetting and drying for three days
ST5- Alternate wetting and drying for seven days (Standard practice/control)
ST6- Acid scarification with 80% conc. H_2SO_4 for 5 min
ST7- Acid scarification with 80% conc. H_2SO_4 for 15 min
ST8- Acid scarification with 80% conc. H_2SO_4 for 25 min

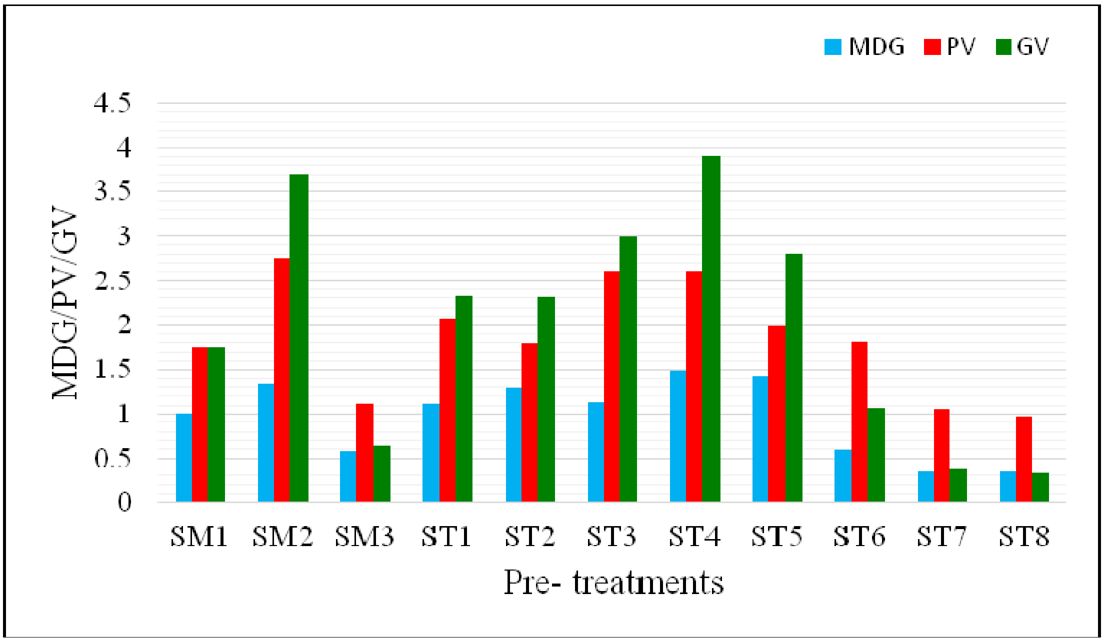


Fig 5. Effect of Scarification methods and soaking treatments on Mean Daily germination, Peak value and Germination value of teak

S1- Mechanically scarified seeds

S2- Termite scarified seeds

S3- Untreated Seeds (Control)

ST1- Water soaking for one day

ST2- Water soaking for three days

ST3- Alternate wetting and drying for one day

ST4- Alternate wetting and drying for three days

ST5- Alternate wetting and drying for seven days (Standard practice/control)

ST6- Acid scarification with 80% conc. H_2SO_4 for 5 min

ST7- Acid scarification with 80% conc. H_2SO_4 for 15 min

ST8- Acid scarification with 80% conc. H_2SO_4 for 25 min

In many cases, termites have an influence on increasing the germination through weakening of the coat and make tiny holes which might have facilitated the entry of water. Termites are an important agent for breaking down seed coat dormancy in many parts of the tropics. In Thailand, teak fruits were spread on the ground in a 5 cm thick layer immediately after collection and covered with cardboard. After about 5 weeks the termites had removed the exocarp and subsequent germination after alternate wetting and drying, was significantly improved in comparison with fruits sown with intact exocarp (Bryndum, 1966). Termites have been used in the past in a similar way to break down the tough winged and bristly fruit of *Pterocarpus angolensis* (Groome *et al.,* 1957). The use of termite as a biological scarification technique had the highest germination of 98.61% in teak (Omokhua *et al.,* 2015). In the present study, termite scarified seeds subjected to AWD 3 days showed the best seed germination. The reason behind this treatment effect might be due to expansion of cells during wetting and contraction during drying which resulted in weathering of the pod coat. Hence, weathering would have facilitated penetration of required quantity of water inside the drupe and accelerated the initial process of germination *viz*., breakdown of food material and synthesis of enzymes.

However, none of the acid scarification treatments were not found to influence germination. Several authors have reported that the use of concentrated Sulphuric acid in the treatment of tropical tree seeds improved seed germination under various conditions (Sajeevukumar *et al*., 1995; Jones *et al.,* 2010; Geetha, 1996; Oboho and Urughu, 2010; Pipinis *et al.,* 2011). However, when termite treated and mechanically scarified seeds are subjected to sulphuric acid treatments, they failed to improve the germination percentage in the present study. As per the reports, such a non response or reduction in germination may either be due to the short duration spent by the seeds in the concentrated acid to cause enough weakening of the seed coats or may be due long a duration causing damage to the embryo thereby failing germination (Salisbury and Ross, 1991). Some species of robust seeds were able to tolerate 30 minutes. and Caspian locust seed for one and half hours of scarification with conc. H_2SO_4 (Zoghi *et al*., 2011). But in the present study, the seed which was already termite scarified was not able to tolerate acid treatment for a minimum duration of even 5 minutes and might have failed to enhance germination or rather killed the seeds by subjecting to acid treatments. The acid might have reached the embryo within these short durations which might be the reason for low germination at 5, 15 and 20 min.

Therefore, this study led to recommend biological scarification of seeds using termite and also a combination of termite scarification followed by AWD 3 days, to foresters and private investors involved in large scale planting. Termite- aided mesocarp removal of teak fruits has already been recommended as an efficient and reliable pre-sowing treatment for early and enhanced germination in teak at Kerala Forest Research Institute, Peechi (Chacko, 1998). The recommended method is simple, cheap, environment friendly and less hazardous when compared to other treatments.

Mechanical scarification also showed advantage over the untreated seeds and followed as the next best treatment in most of the early seedling characteristics. Hence, in situations where the presence of suitable subterranean termite, as a biological means of pre sowing treatment, can't be assured, it is recommended to adopt the proven and successful method of mechanical scarification done using the mechanical Scarifier (Bapat and Phulari, 1995).

5.1.2. Effect on seedling characteristics

At present, the demand for quality teak planting material has been increasing but teak planting material of the desired quality is not available in sufficient quantity. There is significant demand for good-quality planting stock for plantation programmes in India. SM2 (Termite scarified) and SM1 (Mechanical scarified) recorded significantly higher collar diameter (1.46 and 1.45 mm) as against control treatment SM3 (untreated seeds) which recorded the lowest collar diameter of 0.81 mm after 30 days of germination. Same trend was observed in shoot length, root length, total seedling length, dry weight and vigour index. Pamei *et al.* (2017) reported that the effect of pre-sowing treatment for teak i.e. alternate wetting and drying shows more effective in germination and quality seedling parameters and also its showed the maximum total seedling height, root length, collar diameter. However, increase in vigour index might be due to higher germination percentage (Fig 3), since vigour index is the product of germination percentage x dry weight or total seedling height (Boaler, 1966).

5.2 OPTIMIZATION OF FERTIGATION LEVELS AND SOWING METHODS FOR QUALITY TEAK STUMP PRODUCTION

5.2.1 Effect of fertigation interval on *Tectona grandis* seedlings raised for stump production

In present study, fertigation of seedlings in the nursery beds influenced all the seedling growth parameters. All the seedling parameters showed significant increase in growth attributes with the most frequent fertigation interval (F1-fertigation at 7 days' interval) followed by F2 (fertigation at 14 days interval) and F3 (fertigation at 21 days interval) as against the no fertilizer (control) plots. At the end of 180 days after fertigation application, all the three fertigation treatments gave the significantly higher number of leaves and maximum leaf area recorded in the order F1> F2>F3>F4 (Table 18). Similar observation has been reported in a study on optimization fertigation frequency for Rosa hybrid (Qasim *et al.,* 2008) and maximum number of leaf per plant were also reported by Ashok and Rengasamy (2000) who studied the effect of N fertigation at different level on growth of cut rose. The increased number of leaves might be due to application of fertilizers through fertigation resulted in the increased plant growth by the increased availability of nutrients especially nitrogen as it had prominent role in leaf emergence (Leghari *et al.,* 2016), higher number of leaf production at higher fertigation levels indicates that enough reserve resources or assimilation of resources is a pre-requisite for higher leaf production (Mustaffa and Reddy, 2000). Improved number of leaves could be attributed to improved nutrient uptake and improved photosynthetic rate of plants. It is a proven fact that adequate supply of nitrogen promotes vegetative growth and helps to retain leaves for a longer time (Balakrishna *et al.,* 2005).

The leaf area corresponding to various intervals (60, 120 and 180 days) was highest with maximum for the fertigation interval (F1: Fertigation at 7 days interval) which were 2234.4 cm^2, 4629.3 cm^2 and 8517.5 cm^2 respectively and were 14.52, 30.09 and 55.37 % more as compared to control plot (Fig 6). At the end of 180 days after fertigation, the maximum leaf area recorded in F1 (8517.45 cm^2) followed by F2 (7516.36 cm^2), F3 (5371.38 cm^2) and the lowest leaf area of 3542.35 cm^2 corresponding to no fertigation control (F4). Although all fertigation treatments were effective in improving the teak seedling leaf area as compared to control, the effect of fertigation at 7 days interval was very pronounced particularly in improving leaf area as compared to other treatments. Many studies supported that application of fertigation lead to better leaf growth. The effect of nitrogen in enhancing the leaf area has been well established and increased levels usually have a positive relationship with growth. Increased leaf area in response to higher N and K application has been observed earlier by several workers (Lahav, 1972; Sindhupriya *et al.,* 2018; Qasim *et al.,* 2008). There was a continuous supply of nutrients in fertigation treatments as the fertilizers were applied in split doses during the entire growth period of the plants, which might have helped in meeting the requirements of nutrients during the critical period of growth as reported by Kachways (2014).

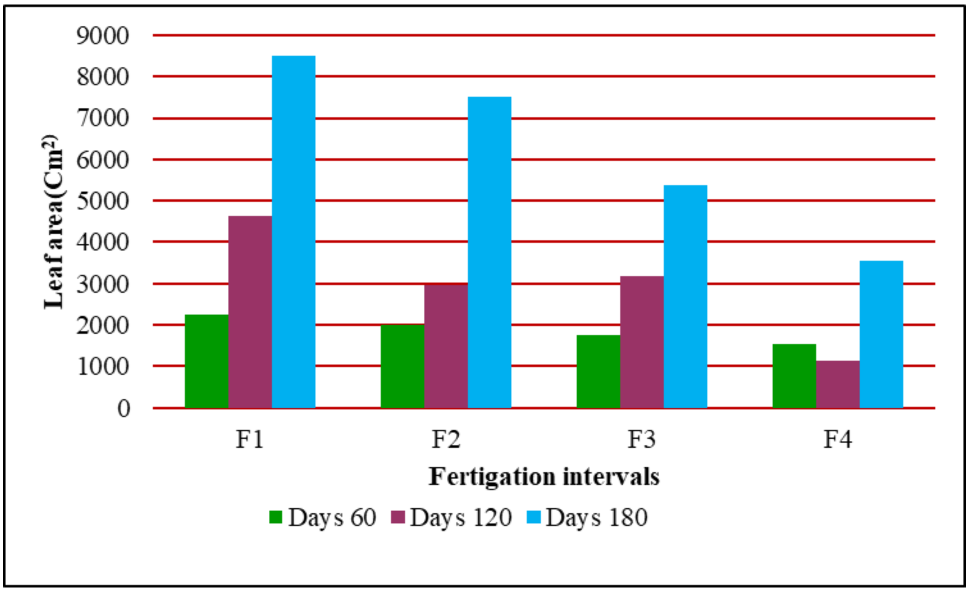


Fig 6.Effect of fertigation interval on leaf area of *Tectona grandis* seedlings raised for stump production

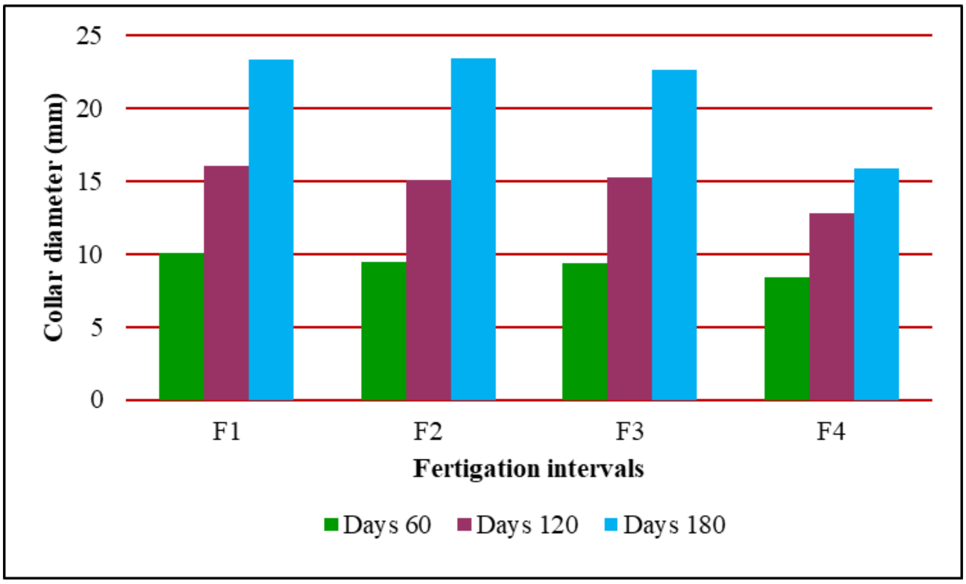


Fig 7. Effect of fertigation interval on collar diameter of *Tectona grandis* seedlings raised for stump production

F1- Fertigation at 7 days interval

F2- Fertigation at 14 days interval

F3- Fertigation at 21 days interval

F4- No Fertigation (control)

The collar diameter being the most important determinant for selecting the seedlings for stump production, the effect of fertigation is of greater relevance in its direct application in the field. The most frequent fertigation intervals treatment F1 (Fertigation at 7 days interval) performed best at all stages of growth. The positive effect of fertigation on teak seedling was dominant in the study (Fig 7). At 180 days, the treatment F1 was significantly superior to all other treatments with respect to collar diameter. Moreover, at 180 days, all the fertigation treatments were on par each other and statistically distinct from the no fertigation control treatment (Fig. 7). Such trends in collar diameter growth have been reported by many workers (Sheedy (1976); Khurana (1989)). It is very interesting to note that in the present study, at six months after sowing, all the fertigated treatments attained utilisable collar diameter of 2-3 cm criteria (as put forth by Griffith, 1939 and Jayasankar *et al*., 1999) for teak stump production. Pramono *et al.* (2011) also reiterated the recent practice of selecting larger seedlings with 2-3 cm collar diameter for making better teak stumps. Moreover, it is also proved that even the least frequent (F3) application gave the desired effect and it is recommended to follow fertigation with 0.2 % N:P:K in equal proportion at 21 days interval in practice.

With regard to the shoot length, there was no significant effect for fertigation at 60 days interval, but it became significant at 120 and 180 days (Fig 8), pointing to the fact that for production of larger seedlings, fertigation is of greater relevance. It is noteworthy that all the fertigated treatments gave shoot length of more than one meter at 120 days of growth. This is of greater relevance when it is targeted to produce taller seedlings. In the context of stump production also, the potential growth of the seedlings is very important. In the present study, at the end of observational period (180 days), the shoot length was reached 234.90 cm, 189.39 cm, 190.02 cm and 118.01 cm respectively for F1, F2, F3 and F4 (Fig 8). Nitrogen being the essential constituent of proteins, chlorophyll, nucleic acid and protoplasm, plays a significant role in plant growth. The increase in these growth parameters by application of nitrogen is understandable in view of the beneficial role of this element related with growth and development. Similar response for vegetative growth of other plant species to nitrogen application has been reported by Kaul *et al.* (1970) in *Eucalyptus* *globulus*, Prasad *et al.* (1984) in *Eucalyptus grandis*, Malik (1987) in *Eucalyptus tereticornis*. Reinsvold and Pope (1987) in *Robinia pseudoacacia*.

The total seedling length of teak seedlings was 98.79, 87.85, 91.32 and 84.36 cm for fertigation interval F1, F2, F3 and F4 respectively at 60 days of growth period. At the end of 180 days after seed sowing the maximum total seedling length was for F1 (306.94 cm) followed by F2 (246.08 cm) and F3 (248.83 cm) which were on par with each other and lowest value was for F4 (160.94 cm) broadcasting control treatment (Fig 9). Similarly, Sheedy (1976) reported an increase in height and diameter of three hybrids of poplars with NPK treatment at the rate of 56 kg ha^{-1}under nursery condition. Deol and Khosla (1983) also reported that application of 60 kg Nha^{-1} significantly enhanced plant height of *Populus ciliate* under nursery condition. Khurana (1989) reported that under nursery condition application of 75 kg N ha^{-1} for maximum height and diameter growth of selected provenances (pooled together) of *Populus ciliata*. Sofi (2005) also reported that application of N50+ 5t FYM ha^{-1} significantly enhanced all the plant growth parameters of the seedlings of *Cedrus deodara* under nursery conditions. Increase in growth attributes may be due to the general effect of NPK on vegetative growth and to their vital contribution in several metabolic process in plants related to growth. Moreover, their role in increasing meristematic activities and its importance in the metabolism of many constituents such as amino acids, chlorophyll, auxins, enzymes and general protein synthesis stimulates not only photosynthesis but also many metabolic intermediates synthesis, this is decided by, consequently stimulating the vegetative growth that prompt the plants to generate leaves, which are able to produce photosynthetic products accumulation required for growth, development and subsequently yield components (Goh and Haynes, 1986; Salisbury and Ross, 1991; Thompson and Troeh, 1978; Marschner, 1995; Feleafel *et al.,* 2014; Chopan *et al.,* 2018).

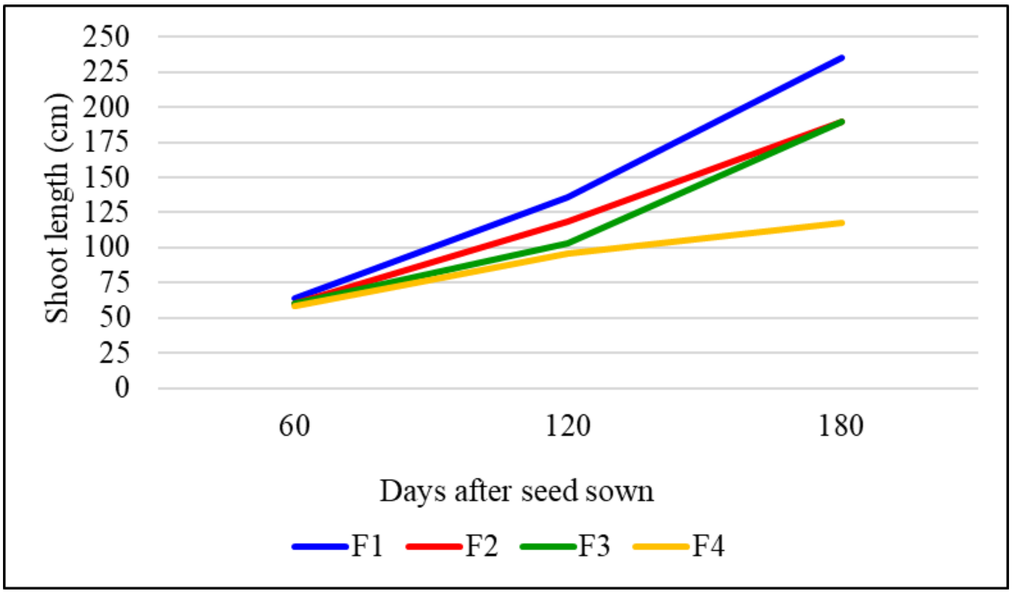


Fig 8. Effect of fertigation interval on shoot length of *Tectona grandis* seedlings raised for stump production

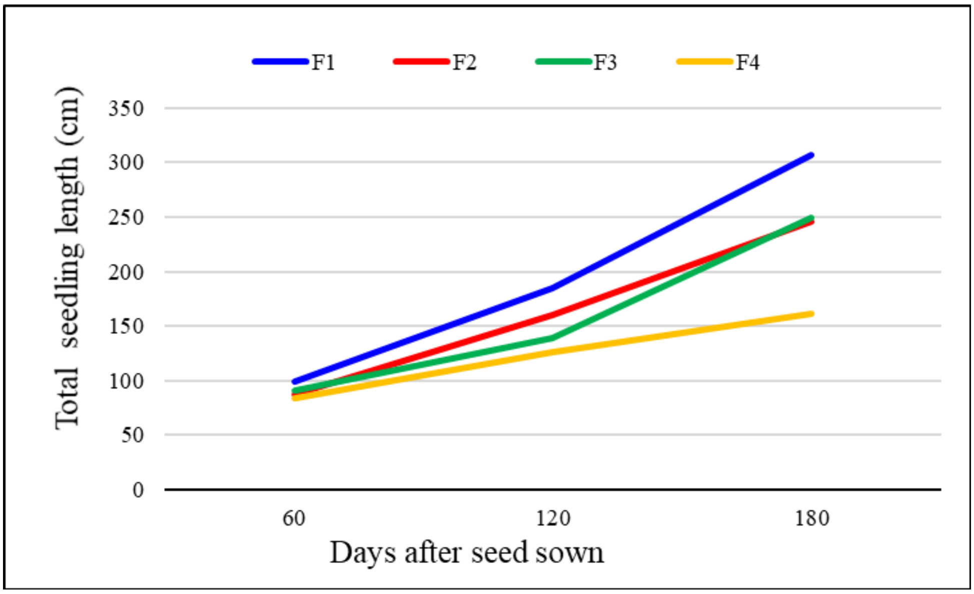


Fig 9. Effect of fertigation interval on total seedling length of *Tectona grandis* seedlings raised for stump production

F1- Fertigation at 7 days interval

F2- Fertigation at 14 days interval

F3- Fertigation at 21 days interval

F4- No Fertigation (control)

The maximum total dry weight was observed in F1 (Fertigation at 7 days interval) and F2 (Fertigation at 14 days interval) for all stages of growth period. The lowest total dry weight production was observed for the unfertigation control treatment F4. At 180 days of growth, the total dry weight increased (Fig 10) with increasing frequency of fertigation (164.46, 248.75, 296.54 and 338.11 g respectively for no fertigation, 21 days, 14 days and 7 days of fertigation interval). Optimum fertilizer dosage is one of the most important factors to increase the growth, without affecting the quality thereby enhancing the economic returns. Fertigation dosage can cause considerable shifts in seedling physiological process that results in increased vegetative growth of seedling viz. collar diameter, height, number of leaves, shoot and root length and biomass (Liu *et al.,* 2009). Fertilization can modify tissue nutrient content and amount of available reserves. The results are concordant with the findings of Deol and Khosla (1983), who reported application of 60 kg N $ha^{-1}$to the *Populus ciliate* nursery for maximization of growth and biomass. Malik (1987) reported the nitrogen application at the rate of 100 kg N ha^{-1} significantly increased the biomass production of *Eucalyptus tereticornis* in comparison to control. Similar response to nitrogen application has been reported by Hussain *et al.* (1986) in *Albizia procera*, Masoodi (1990) in *Acer oblongum*, Sehgal *et al.* (1992) in *Enterolobium timbouva*, Saleem *et al.,*1994 in *Celtis australis*, Sofi (2005) in *Cedrus deodara*.

Fertigation has been found as one of the most successful ways of application the water and nutrient, particularly, N, P, K and micronutrient. The right combination of nutrient concentration and the interval of fertigation is the key for better growth and quality of seedlings. Fertigation saves fertilizer nutrients as it permits applying for fertilizer in small quantity at a time matching with the plants nutrient need. This contributes to an improved availability of moisture, nutrients, and uniform distribution of fertigated nutrients in the root zone throughout the growth stages leading to better uptake of nutrients (Feleafel *et al.,* 2014; Chopan *et al.,* 2018).

5.2.2 Effect of seed sowing spacing on *Tectona grandis* seedlings raised for stump production

The study revealed that the spacing exerts significant effect on all the seedling growth parameters of teak seedlings. All the seedling attributes showed significant increase in growth characteristics with the increase in spacing. Seed sowing spacing had highly significant effect on the number of leaves, leaf area. At the end of 180 days after seed sowing, significantly distinct number of leaves (22.41) was recorded in the treatment 30 cm x 30 cm (S3) and the minimum number of leaves was as low as 5.91 corresponding to broadcasting treatment (control) (Fig 11). The maximum number of leaves was recorded in the widest spacing (30 cm x 30 cm) plot (S3) were 13.33, 15.08 and 22.41 while the corresponding number of leaves observed in the broadcasting control plot were 8.66, 10.33 and 5.91 at 60, 120 and 180 days respectively (Fig 11). Over the growth period (from 120 to 180 days), drastic reduction in the number of leaves was observed specifically in the broadcasted control treatment (Fig 11). This might be due to the overcrowding and suppression with advancing growth of the seedlings. If not complete mortality, this causes consequent deleterious effect on almost all aspects of the early seedling growth in the nursery (Jia *et al.,* 2011; Inman-Narahari *et al.,* 2016). The reason for higher number of leaves in case of lower seedling density might be due to the lesser competition for nutrients and light between the plants. Enhanced light interception due to wider spacing certainly had a positive effect on leaf number. Hence in wider spacing due to availability of more space and light, the crop might have pronounced more number of leaves per plant (Thapa *et al.,* 2019). It is inferred that, broadcasting control is not at all advisable to retain after 120 days and is unsuitable for preparation of stump from the point of view of number of leaves.

The maximum leaf area was also observed in the wider spacing treatment (S3- Spacing at 30cm x 30cm) at different stages (60, 120 and 180 days) which were 16.22, 28.79 and 54.97 % followed by S2 (Spacing at 15cm x15cm) and S1 (Spacing at 10cm x10cm) at all stages of growth compared to leaf area in the broadcasting control plot. In general, the leaf area showed significant increase with increase in the spacing for all the three growth intervals. The least leaf area growth was recorded for the control (broadcasting) treatments at all stages of growth periods. At the end of 180 days after seed sowing, the maximum leaf area recorded in S3 (13,400 cm^2) followed by S2 (7467.04 cm^2), S1 (3529.33 cm^2) and the lowest value of 550.96 cm^2 corresponding to broadcasting control (S4). Increase in leaf area with corresponding increase in spacing may be ascribed to decreased competition resulted in the nursery stock particularly for light and available above ground and below ground space required for the growth. Such effects were also reported by Nalina *et al*., 2000; Suganthi, 2002. Wider seedling spacing may be a simple way of increasing quality of nursery stock (Derr, 1955; Shoulders, 1961; Switzer and Nelson, 1963; Shipman, 1964). Improved outplanting performance through wider spacing has been demonstrated for broadcast-sown pine species and for drill-sown *Pinus radiata* (Benson and Shepherd, 1977).

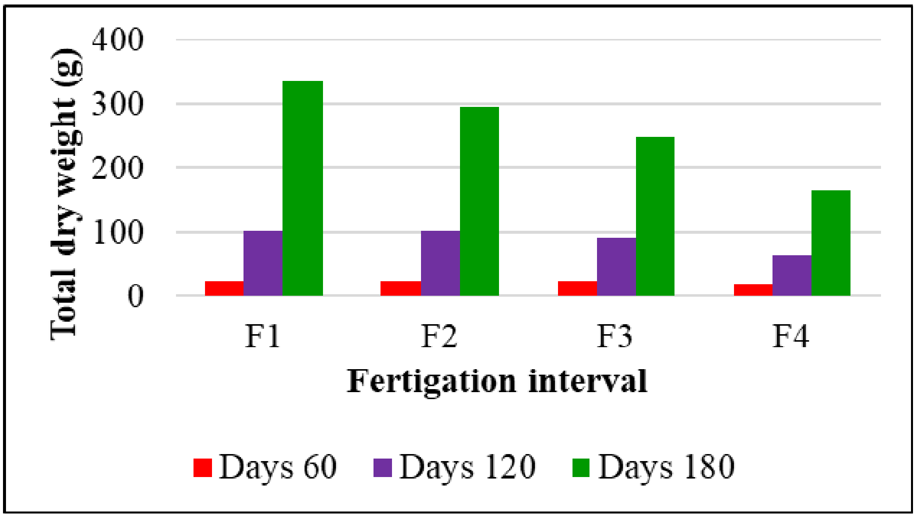


Fig 10. Effect of fertigation interval on total dry weight of *Tectona grandis* seedlings raised for stump production

F1- Fertigation at 7 days interval
F2- Fertigation at 14 days interval
F3- Fertigation at 21 days interval
F4- No Fertigation (control)

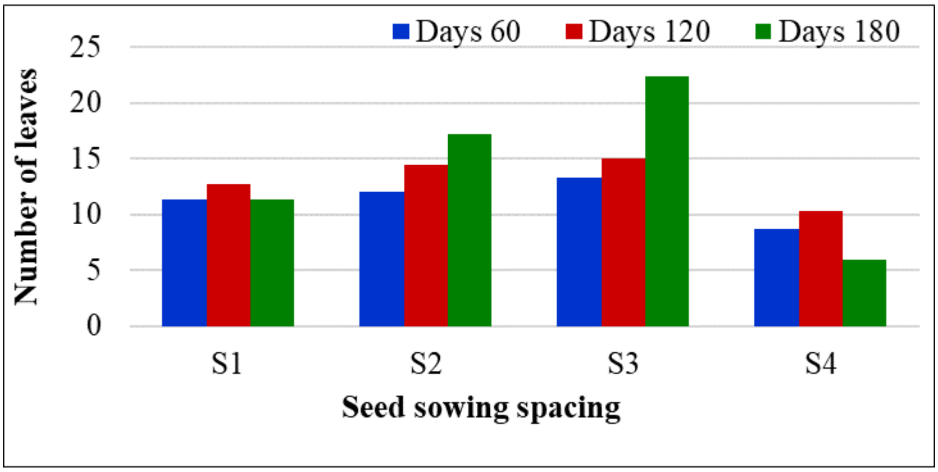


Fig 11. Effect of seed sowing spacing on number of leaves of *Tectona grandis* seedlings raised for stump production

S1-Spacing at 10cm x10cm
S2-Spacing at 15cm x15cm
S3-Spacing at 30cm x30cm
S4-Broadcasting (Control)

The increase in leaf dry weight in the wider spacing plot i.e. (30 x 30 cm) compared to broadcasting control were (S3 -134.43 g; S2-84.29 g; S1- 42.98 g) respectively at 180 days after seed sowing. The leaf dry weight noticed for the broadcasting control (S4) plot was 13.02 g corresponding to 180 days (Fig 12). Reduction in seedbed density also increased stem diameter and leaf dry weight of teak seedlings. Similar observations have been reported from other studies on red pine (Mullin and Bowdery, 1977).

The maximum collar diameter of teak seedling was observed in the wider spacing treatments S3 (Spacing at 30cm x 30cm) followed by S2 (Spacing at 15cm x 15cm) and S1 (Spacing at 10cm x 10cm). The collar diameter of teak seedling corresponding to various stages of growth period (60, 120 and 180 days) was highest in for the widest spacing S3 (12.46, 21.07 and 30.98 mm) followed by S2 (10.03, 17.33 and 24.83 mm) and S1 (8.90, 13.89 and 19.59 mm). The collar diameter growth in the broadcasting control (S4) was 5.90, 6.83 and 9.85 mm corresponding to 60, 120 and 180 days respectively (Fig 13).

The most notable fact is that the broadcasting control treatment, over the fertigation treatments, did not reached even 50% of the required diameter for preparation of stump even after 6 months of growth. The broadcasting practice was proved to be unsuitable for preparation of the teak stump, as this lead plant density increase, and greater competition among the plants resulting in plants with reduced stem diameter (Kruschewsky *et al.,* 2007; Leite *et al.,* 2006). The increase in collar diameter due to spacing may be ascribed to low plant population per unit area and subsequent reduced competition for soil moisture, nutrients and space. The positive effect of reduced seedbed density on field performance was likely the results of larger seedlings being produced at the lower densities. The increase in collar diameter and seedling dry weight with decreasing plant density was reported by many researchers like Simpson, (1989); Blok and vontol (1983); Kaushal (1983); Singh and Sharma (1984); Malik (1987); sofi (2005); Shoulders (1961).

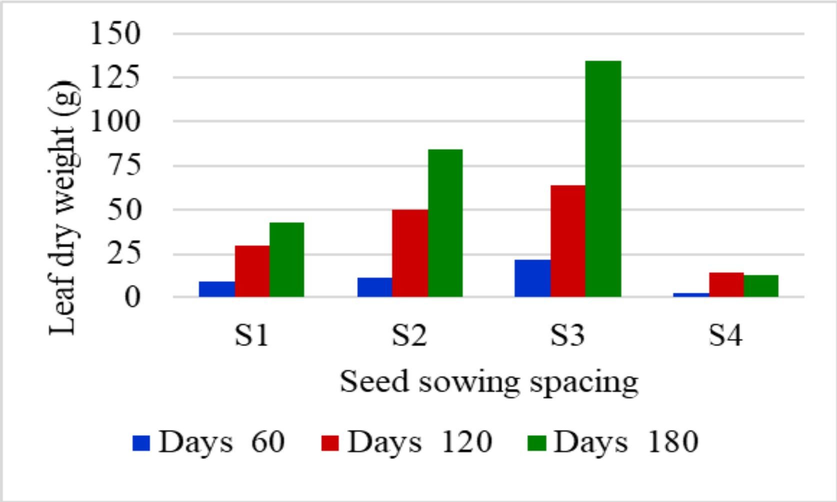


Fig 12. Effect of seed sowing spacing on leaf dry weight of *Tectona grandis* seedlings raised for stump production

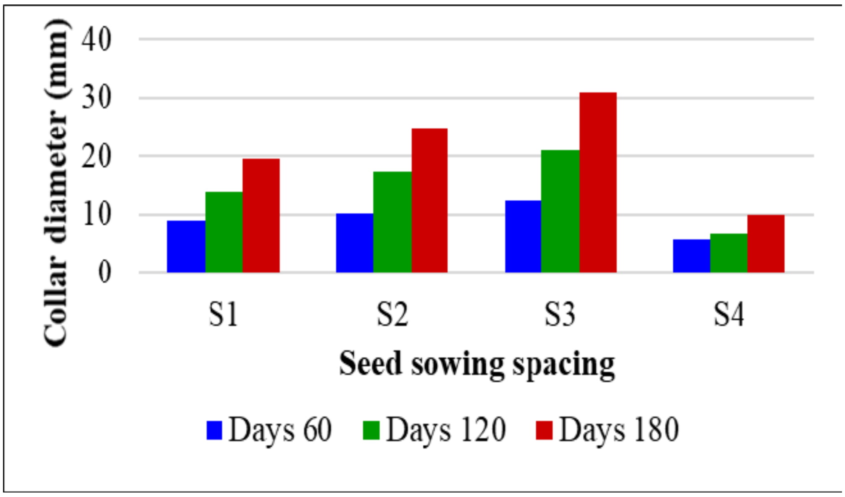


Fig 13. Effect of seed sowing spacing on collar diameter of *Tectona grandis* seedlings raised for stump production

S1-Spacing at 10cm x10cm

S2-Spacing at 15cm x15cm

S3-Spacing at 30cm x30cm

S4-Broadcasting (Control)

A significant result to be discussed is that dibbling treatment at 15 cm x 15 cm (S2) also reached required collar diameter for stump preparation (> 2cm) at 180 days of growth. That means, 600 numbers of utilisable seedlings are available from a standard nursery bed of 10 m x 1m at 180 days of seedling growth.

The shoot length was maximum for the wider spacing treatment (S3) followed by S2 and S1. The higher shoot length was recorded in seedlings plot subjected to wider spacing of seed sowing methods, at 60 days interval. The increase in shoot length in the wider spacing plot compared to broadcasting control was in the order S3>S2>S1 throughout the growth of seedlings. (Fig 14). The effect of spacing was more pronounced towards the later stages of growth. At the end of 180 days after seed sowing, the maximum shoot length was S3 (258.80 cm) followed by S2 (194.77 cm), S1 (173.54 cm) and the lowest value of 105.21 cm corresponding to broadcasting control (S4). This may because at maximum plant density in an area, seedlings will compete for light, moisture, space so growth will retard. Similar observations have been reported from other studies **(**Simpson, 1989; Switzer and Nelson, 1963**).**

Significantly high root length of teak seedlings (38.90, 50.02 and 90.24 cm respectively at 60, 120 and 180 days of growth) was observed in wider spacing treatments (S3-Spacing at 30cm x 30cm) followed by (S2-Spacing at 15cm x 15cm) and (S1-Spacing at 10cm x 10cm). Whereas the root length was 32.04, 39.41 and 54.15 cm in S2 and 28.60, 38.51 and 50.00 cm in S1. The lowest root length recorded for the broadcasting control treatments. However, there was no primary observable limitation for the decreased root length at this stage, the performance of the stumps prepared in the present study thrown light into significant differences between treatments.

The increase in total seedling length in S1, S2, S3 and S4 ranged from 91.63 to 223.53, 99.02 to 248.93, 108.92 to 348.76 and 62.46 to 141.56 cm for the time interval from 60 days to 180 days after the seed sowing (Fig 15). The total seedling length recorded were the lowest for broadcasting control treatment (62.76, 106.04 and 141.56 cm corresponding to 60, 120 and 180 days of growth). The results are supported by with the findings of (Mullin and Bowdery, 1977; Switzer and Nelson 1963; Kaushal, 1983).

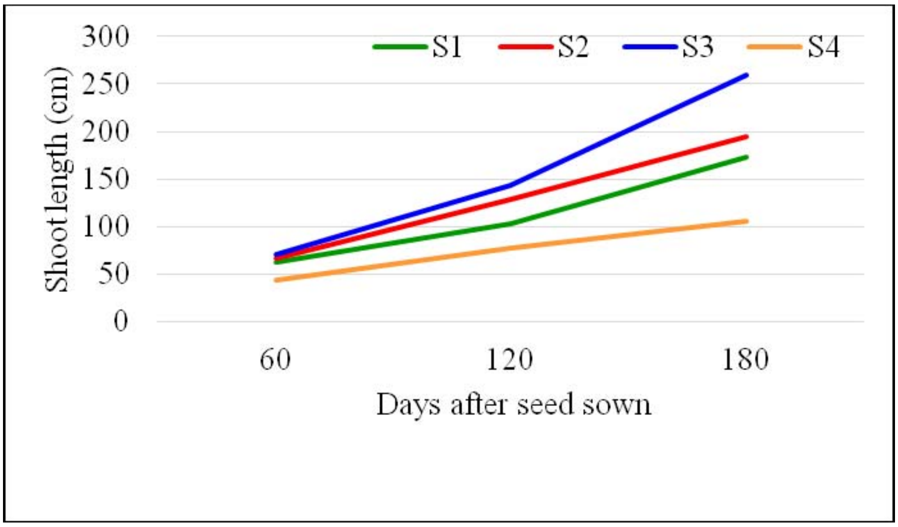


Fig 14. Effect of seed sowing spacing on shoot length of *Tectona grandis* seedlings raised for stump production

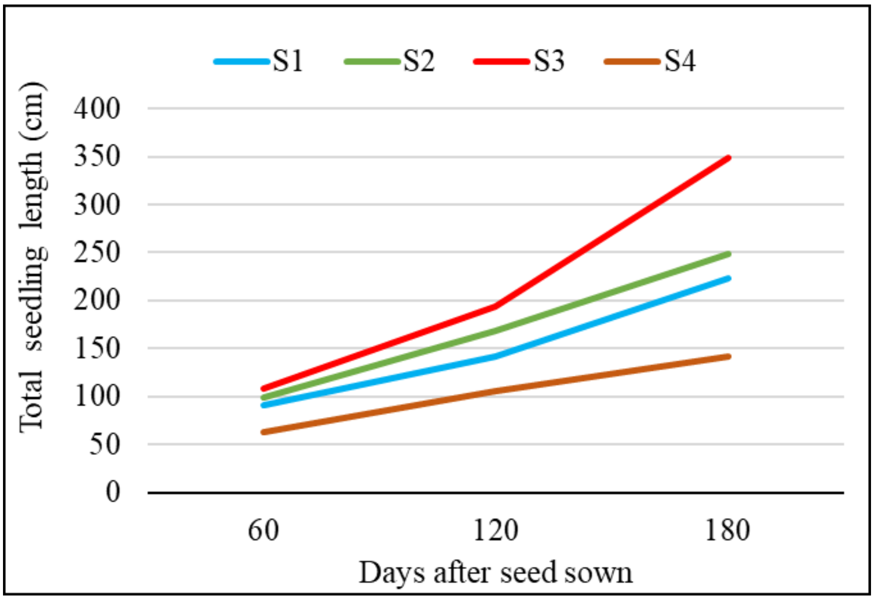


Fig 15. Effect of seed sowing spacing on total seedling length of *Tectona grandis* seedlings raised for stump production

S1-Spacing at 10cm x10cm

S2-Spacing at 15cm x15cm

S3-Spacing at 30cm x30cm

S4-Broadcasting (Control)

Total dry weight corresponding to various stages of growth periods (60, 120 and 180 days) were maximum for the wider spacing treatment (S3) which were 43.17, 144.31 and 510.01 g. The increase in biomass is evident as the individual component also registered an increased growth at the same spacing. At 180 days of growth, the maximum total dry weight was noticed in the widest spacing S3 (510.01 g) followed by S2 (307.11 g), S1 (175.00 g) and S4 (55.74 g) (Fig 16). Dry weight is a net result of photosynthesis activities. Sunlight is a major factor in the photosynthesis process, the more the sunlight it receives; the photosynthesis process can run well, resulting in more production of photosynthates. Larger photosynthetic production will form larger plant organs which those affecting the increase of dry weight of plants. The findings are in line with the studies of Driessche (1984) in Douglas fir and sitka spruce, Singh and Sharma (1984) in *Abies pindrow*, Mahajan (1990) in *Robinia pseudoacacia* and Lal (1993) in *Ulmus laevigata*, Masoodi (1990) in *Acer oblongum*, Sofi (2005) in *Cedrus deodara and* Thapa *et al.* (2019). Thus the better uptake of mineral nutrients from the soil and high biochemical and nutrient composition of the seedlings at wider spacing may be responsible for better growth and development of seedlings in the nursery (Sofi, 2005).

At the end of 180 days the root: shoot ratio for S1 and S2 (0.29), S3 (0.34) and S4 (0.35) which were on par. The lowest root: shoot ratio recorded in widest spacing (S3) this result results supported by, Simpson, 1989, Seedlings produced at lower bed densities had better morphological qualities (Greater dry weight, lower shoot: root ratio, larger collar diameter). It helps that improvements to both morphologic and physiological quality contributed to the superior performance of the seedlings raised at lower densities.

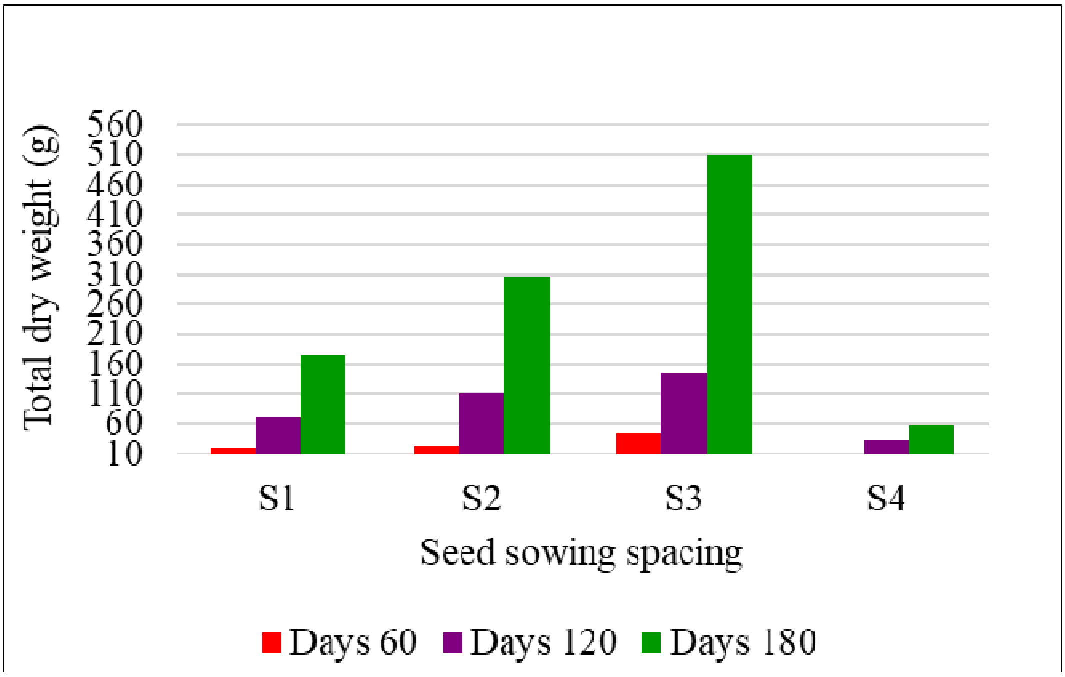


Fig 16. Effect of seed sowing spacing on total dry weight of *Tectona grandis* seedlings raised for stump production

S1-Spacing at 10cm x10cm

S2-Spacing at 15cm x15cm

S3-Spacing at 30cm x30cm

S4-Broadcasting (Control)

5.2.3 Interaction effect of fertigation interval and sowing methods on *Tectona grandis* seedlings raised for stump production at 180 days.

The combined effect of fertigation and seed sowing different spacing had a significant effect on seedling characteristics. With respect to number of leaves, the treatment combination F2 X S3 gave the maximum number of leaves (26.00) followed by F1 X S3 and F3 x S3 (23.00 and 22.67). The minimum number of leaves (3.67) was recorded by the combination of F4 x S4 followed by F2 X S4, F3 X S4 and F4 X S1 these four were on par with each other (Table 19). In the interaction across the fertigation treatments, the mean number of leaves for the broadcasting control treatment S4 was less (5.92), however all other spacing treatments gave number of leaves (ranging from 11.33, 17.17 and 22.42). Interaction effects indicated that more number of leaves at higher fertigation with wider spacing may be due to adequate availability of nutrients to induce more leaves, provided with ample space for more light interception and air movement. Sufficient number of leaves will harness the light energy and synthesis adequate photosynthates for biomass production (Thatikunta, 2016).

The mean leaf area per seedling will be a direct indicative of the total photosynthetic area of leaf and hence affects the growth and vigour of the seedling. For the mean leaf area per seedling, the treatment combination F1 X S3 gave the maximum leaf area (18,985.3 cm^2) followed by F2 X S3 and F3 x S3 (16,920.3 and 10,809.1 cm^2) (Fig 17). All treatment combinations with S2 and S1, across fertigation treatments, also gave reasonably good leaf area per seedling with mean values of 7467.0 sq cm and 3529.3 sq. cm respectively as against the lowest mean value of 551.0 sq. cm for the broadcasting control treatment (S4). From the point of view of mean leaf area per seedlings, wherever the seed bed is not scarce or not limited all the fertigated treatment combinations at 30 cm x 30 cm is gave best results. But while taking into account the number of seedlings produced in a standard bed of size 10 m x 1m the treatment combinations of S2 (600 seedlings per bed) and S1 (1000 seedlings per bed) also can be recommended provided fertigation can be given at 7 days interval. Leaf area, being the fundamental determinant of

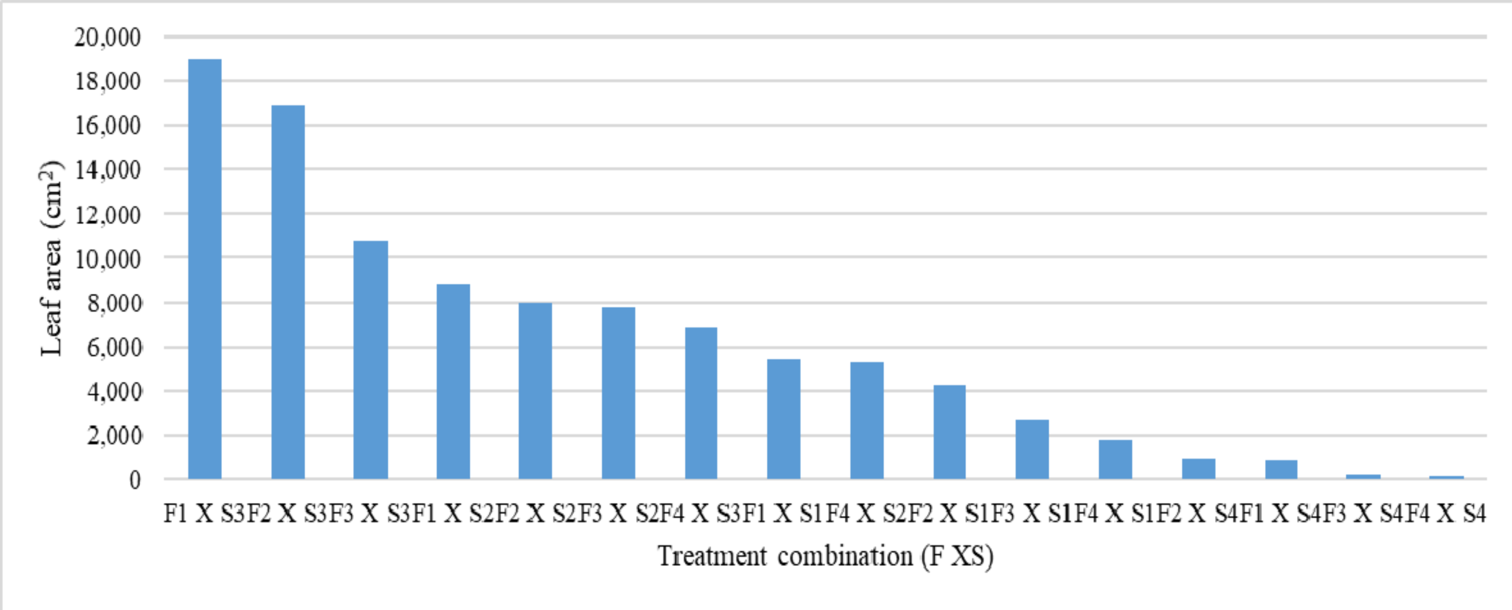


Fig 17. Interaction effect of fertigation interval and seed sowing spacing on leaf area of *Tectona grandis* seedlings raised for stump production at 180 days

F1- Fertigation at 7 days interval
F2- Fertigation at 14 days interval
F3- Fertigation at 21 days interval
F4- No Fertigation (control)

S1-Spacing at 10cm x10cm
S2-Spacing at 15cm x15cm
S3-Spacing at 30cm x30cm
S4-Broadcasting (Control)

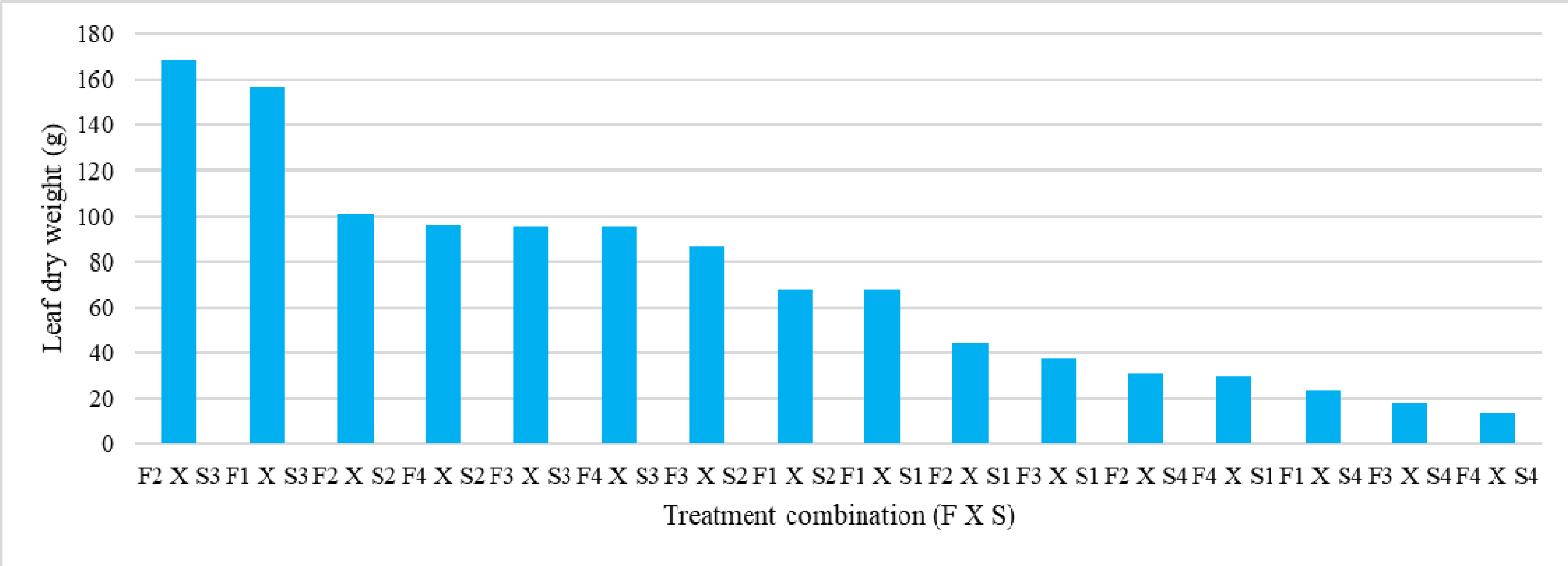


Fig 18. Interaction effect of fertigation interval and seed sowing spacing on leaf dry weight of Tectona grandis seedlings raised for stump production at 180 days

F1- Fertigation at 7 days interval
F2- Fertigation at 14 days interval
F3- Fertigation at 21 days interval
F4- No Fertigation (control)

S1-Spacing at 10cm x10cm
S2-Spacing at 15cm x15cm
S3-Spacing at 30cm x30cm
S4-Broadcasting (Control)

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photosynthesis, facilitates better biomass production of the crops through its effective interception of light energy and fixation of CO_2. The effective leaf area available for photosynthetic activity positively influences the growth and development of fruits and increased the total yield (Sindhupriya *et al.,* 2018; Apshara, 1997; Kumar and Nalina, 2001).

The treatment combination F1 X S3 gave the higher leaf dry weight (213.85 g) followed by F2 X S3 and F3 X S3, F4 X S3, F3 X S2 and F2 X S2 (110.90, 108.57,104.40, 82.97 and 82.78 g), which were on par with each other. The lowest leaf dry weight (10.46 g) was recorded by the combination of F4 X S4 followed by F3 X S4, F2 X S4, and F1 X S4 these were on par with each other (Fig 18). The seedlings of teak on application of fertigation (Fertigation at 7, 14 and 21 days interval) with widest spacing is found to be the most promising treatment combination for producing more leaf dry weight per plant and healthy nursery stock.

At 180 days, the treatment combination F1 X S3 recorded the maximum collar diameter (34.88 mm) followed by F2 X S3 and F3 X S3 (32.00 and 31.75 mm) these two were on par with each other. One significant result to be discussed here is that the combination of dibbling treatment at 10 cm x 10 cm with 14 days and 21 days intervals of fertigation with 0.2% NPK at 19:19:19 ratio (F2 X S1and F3 X S1) gave required collar diameter for stump preparation (> 2cm) at 180 days of growth (Fig 19).

Taking into account the number, the treatment combination S1 X F3 (10 cm X 10 cm with 21 days intervals of fertigation) is recommended as it produces 1000 numbers of utilisable seedlings fit for stump production from a standard nursery bed size of 10 m x 1m. Moreover, none of the treatment combinations with S4 (Broadcasting control) qualified to reach the required collar diameter for stump preparation even after 6 months of growth and hence the broadcasting treatment is not recommended for producing seedlings for preparation of teak stump. The findings are in line with the studies of Singh *et al.,* 2017 in Allepo pine. Thus the better uptake of mineral nutrients from the soil and high biochemical and nutrient composition of the seedlings at wider spacing may be responsible for better growth and development of seedlings in the nursery. Wider spacing in the seedbed resulted in seedling having

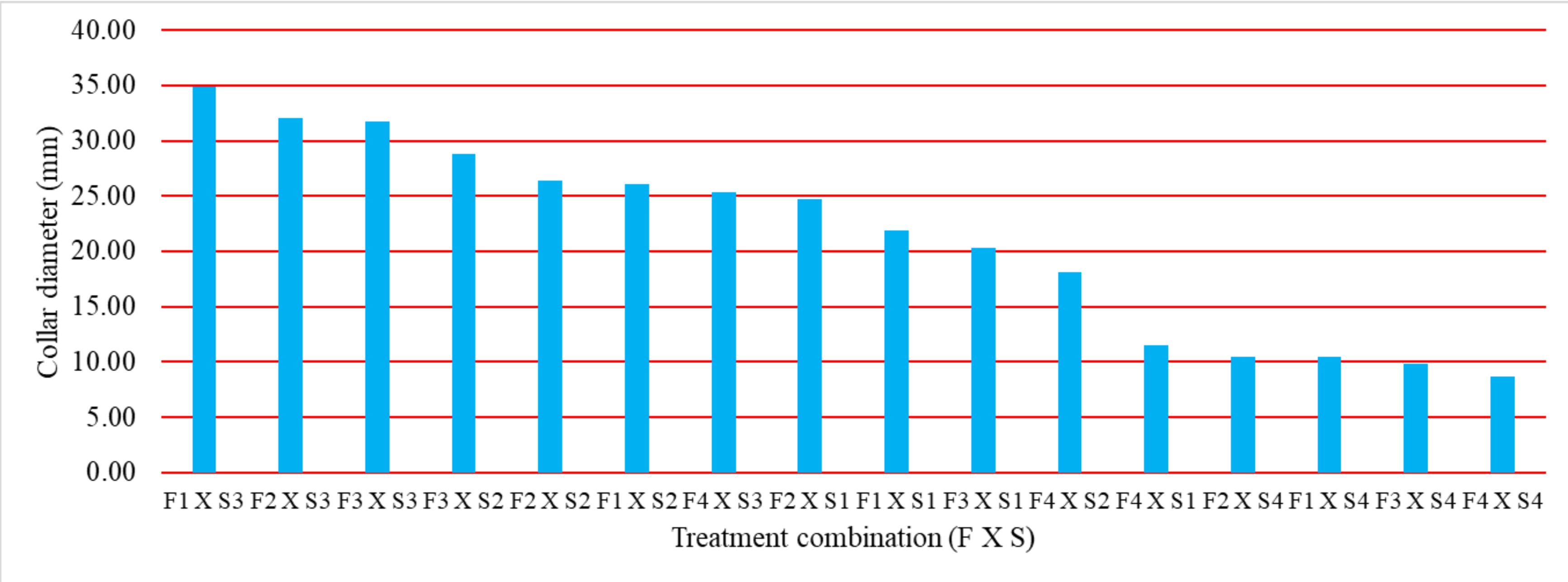

Fig 19. Interaction effect of fertigation interval and seed sowing spacing on collar diameter of *Tectona grandis* seedlings raised for stump production at 180 days

F1- Fertigation at 7 days interval

F2- Fertigation at 14 days interval

F3- Fertigation at 21 days interval

F4- No Fertigation (control)

S1-Spacing at 10cm x10cm

S2-Spacing at 15cm x15cm

S3-Spacing at 30cm x30cm

S4-Broadcasting (Control)

greater dry weight and collar diameter (Driessche, 1982; Shoulders, 1961; Mullin and Bowdery, 1977). The results are in line with Masoodi (1990) who reported that with the increase in spacing and level of nitrogen, there was a significant increase in the collar diameter of *Acer oblongum*. Lal (1993) observed almost similar results in *Ulmus laevigata*.

At 180 day, F1 X S3 has recorded highest shoot length (293.00 cm) followed by F2 X S3 (284.00 cm), which were on par with each other. The shortest shoot length was noticed in F4 X S4 (78.00 cm) followed by F2 X S4, F4 X S1 and F3 X S4, there were on par with each other (Table 25). At 180 days, the treatment combination F1 X S3 recorded the maximum root length (104.39 cm) followed by F2 X S3 and F3 X S3 (99.38 and 98.38 cm) these two were on two were on par with each other. The specific dominance of more sowing spacing is evident from the response of different treatment combinations. For instance, the widest sowing spacing treatments with highest values and the closest spacing with lowest values of root length. Generally, it is seen that the greater effect of wider spacing masked the slight differences in fertigation effects

At 180 days, the treatment combination F1 X S3 showed the maximum total seedling length (397.39 cm) followed by F2 X S3 and F3 X S3 (383.38 and 373.03 cm), these two were on par with each other (Table 27). This may be due to sufficient space, availability of light, nutrients, moisture and less competition. The lowest total seedling length (106.77 cm) was recorded by combination of F4 X S4. The retarded seedling growth may be due to less availability of space, moisture and nutrients. These results are in close agreement with the findings of Lal (1993) who observed that the seedlings grown at closer spacing (10 x 10 cm) and receiving nitrogen application at the rate of 80 kg ha^{-1} resulted in maximum height increment in *Ulmus laevigata*. Singh *et al.,* 2017; Switzer and Nelson, 1963 also reported height growth increase with increasing fertility and decreasing density.

The number of primary lateral roots showed significant interaction effect between fertigation interval and different spacing for seed sowing methods. The treatment combinations F1 X S3 and F2 x S3 gave the maximum number of primary lateral roots (74.80 and 73.37). The minimum number of primary lateral roots (28.83) was recorded by the combination of F4 x S4. The number of primary lateral roots being an index of growth of seedlings, the more the number of primary lateral roots, it is better. However, in practice, it is not possible to adopt a very wide spacing for seedlings in the nursery. Further, documented literature is scanty on this aspect with respect to the suitability for preparation of teak stump.

The interaction effect between fertigation intervals and different spacing for seed sowing methods was significant effect on root dry weight at all stages of growth period. The treatment combination F2 X S3 gave the maximum root dry weight (167.82 g) followed by F1 X S3, F3 X S3 (157.19 and 95.29 g). Lowest root dry (13.87 g) was recorded by the combination of F4 x SM4 followed by F3 X S4, F1 X S4 these all were on par with each other. The results are supported by many researchers (Driessche, 1984; Sofi, 2005).

These results indicated that the fertigation interval and seed sowing methods (spacing) desirable for the production of satisfactory planting stock must be considered concomitantly, since fertigation and spacing as the governing factor for the better growth of seedlings (Switzer and Nelson, 1963)

5.2.3 Root growth potential of the stumps prepared out of 180 days old seedlings

5.2.3.1 Effect fertigation interval on root growth potential of Tectona grandis seedlings raised for stump production

The results on important parameters of root growth potential that are indicative of quality of teak stumps such as number of sprouts per stump, length of sprouts, number of leaves per stumps, number of lateral and tertiary roots per stump, length of lateral roots and dry weight of lateral roots are discussed hereunder.

The maximum number of sprouts per stump produced by F2- Fertigation at 14 days interval (8.66) and F1 (8.00), both values being on par with each other. The minimum number of sprouts per stump was produced by F3 (21 days interval of fertigation) and control (Table 34). The most frequently fertigated treatments FI and F2 recorded significant differences. However, the fertigation at 21 days interval and no fertigation (control) treatments were on par, which indicates the number of spouts is not much affected and fertigation is not necessary from the point of view of number of sprouts of the teak stump. The length of sprouts also followed the same trend with maximum length of sprouts obtained in F1 (5.36 cm) followed by F2 (4.85 cm). The shortest length of sprouts produced by F4 (4.06 cm), the maximum number of leaves per stump observed in the most frequent fertigation interval treatment F1 (Fertigation at 7 days interval) and F2 (Fertigation at 14 days interval), which were (25.00 and 25.25) on par with each other, followed by F4 (23.08).

The fertigation intervals had significant effect on number of lateral roots per stump for the teak stump production after the 28 days of transplanting (p=0.05). The maximum number of lateral roots were obtained by F1 and F2 (21.50 and 20.75), which were on par with each other. The number of lateral roots also showed similar trend as with sprouts, leaves etc. Significantly higher number of tertiary roots per stump was recorded in the most frequent fertigation interval-F1 (72.34). The fertigation intervals F2 (68.29) showed next best for number of tertiary roots per stumps and lowest number of tertiary roots per stumps recorded by F4 (54.60). The fertigation intervals treatments showed marginal increase in the length of lateral roots, the maximum length of lateral roots recorded in F1, F2 and F3 (17.45, 17.49 and 17.25 cm), which were on par with each other. The lowest length of lateral roots (16.12 cm) recorded by the control treatment. The maximum dry weight of lateral roots was produced in F1 and F2 (6.51 and 6.25 g), which were significantly distinct from the treatments F3 and F4 (5.95 and 6.01) were on par with each other.

However, the fertigation at 7, 14 and 21 days interval, which indicates the root growth potential of *Tectona grandis* seedlings raised for stump production is affected and fertigation is necessary from the point of view of the teak stump production. In general, the performance indicators of stump viz. number of sprouts per stump, length of sprouts, number of leaves per stumps, number of lateral and tertiary roots per stump, length of lateral roots and dry weight of lateral roots was not much affected by the different intervals of fertigation. In some cases, non fertigated treatments were also on par with fertigation treatments. It may be because of the fact that, the stump prepared and evaluated after 28 days is insufficient to draw conclusive inferences at this stage. Rather it may be possible by a long term field evaluation of the stump so prepared.

5.2.3.2 Effect seed sowing spacing on Tectona grandis seedlings raised for stump production

The wider spacing S3 showed maximum number of sprouts followed by S2, S1 and S4 (9.58, 8.16, 7.91and 3.83 sprouts per stump). The interaction between fertigation interval and seed sowing methods at different spacing did not show significant effect on number of sprouts. Similar trend in length of sprouts, the maximum length of sprouts was recorded in S3 (spacing at 30 x 30 cm) after 28 days of stump planting. Whereas S1, S2 (4.82 and 5.07) showed almost similar values, which were on par with each other. The minimum length of sprouts (2.07 cm) was produced by broadcasting control (S4).

The highest number of leaves was produced by stump prepared from S3 (spacing at 30 x 30 cm) which was 33.33 followed by S2 (25.25) and S1 (21.50). The least number of leaves produced by S4 (14.00) broadcasting as control. Maximum number of lateral roots per stumps were produced by S3 (23.75), the widest spacing treatment adopted. The lowest numbers of lateral roots per stump after 28 days of stump planting was 16.83 in S4, the broadcasting-control treatment. The widest spacing (S3-spacing 30 x 30 cm) recorded maximum number of tertiary roots per stumps (56.75) followed by S2 and S1 (73.28 and 68.52) after 28 days of growth of stump. The lowest number of tertiary roots per stump (27.64) was observed in S4, the broadcasting control treatment. Highest length of lateral roots produced by S3 (21.29 cm) followed by S2 and S1 (18.75 and 18.45 cm) which were on par with each other and the control (9.83). The maximum dry weight of lateral roots produced (7.32 g) by S3 (spacing 30 x 30 cm) and S2 (7.06 g), which were on par with each other. The lowest value was for control as broadcasting (3.69 g).

Most of the above characters of stump seem to be influenced by the wider spacing treatments during the early seedling growth up to 180 days. Generally conforming to the general notion, all the stump characters were maximum in the widest spacing and decreased with decrease in space.

5.2.3.3. Correlation between seedling characters and root growth potential of teak stump

Root growth potential (RGP) is the ability of a tree seedling to initiate and elongate roots when placed into an environment favourable for root growth (Ritchie, 1984). The magnitude of RGP is often related with survival and even growth performance, of the seedling after out planting. Growth potential of the stumps is mostly used to test the seedling quality and which was started by Stone and his colleagues at Berkeley in 1950's. Traditionally, one-year-old seedlings are used to prepare the stumps in teak nurseries. Sometimes, deliberately or not, the inferior or immature teak seedlings are also included along with the healthy and mature seedlings during stump preparation. This may affect the quality of the stumps and thereby the establishment of them in the field.

The present study, correlation matrix drawn between important seedling characters and the RGP characters (Table 35) throws light on to the possible cumulative cause-effect relations of these characters, which may aid to predict the pattern of changes in one factor when the other factor is known /easily measurable. Collar diameter of the seedlings was highly correlated with length of sprouts, number of leaves per stump, tertiary roots per stump, length of lateral roots and root dry weight. Shoot length was significantly correlated with length of sprouts and tertiary roots per stump. Length of primary lateral roots was also significantly correlated with number and length of sprouts, number of leaves, lateral roots, tertiary roots per stump and length of lateral roots. The lower correlation of the root length with almost all of the RGP characters of the stump points to the general inference that the root length was not at all a limiting factor or a significant criterion in the performance features of teak stump. A very important fact is that the highest coefficient for root growth potentials were obtained for most of the desired characteristics needed for good quality teak stump with six months of seedling growth.

5.3 OPTIMIZATION OF POTTING MEDIA FOR PRODUCING QUALITY TEAK SEEDLINGS

To produce large scale teak plantations in forest and non-forest areas or private plantation, quality seedlings is the pre-requisite. In this context, best suited growing media is necessary for the production of high quality seedlings. The growing media in which seedlings are raised has an important bearing on the quality of nursery stock.

The present study reveal that the growing media treatment M3 (Soil+ Rice husk+ vermicompost in 2:1:1 ratio) was significantly superior throughout the seedling growth in almost all growth characteristics of the teak seedlings like shoot growth, collar diameter, number of leaves, leaf area and total seedling length (Plate 13, 14 and 15). At 90 days of seedling growth, the treatments M3 (90.87 cm) and M2 (85.43 cm) were showing significantly higher shoot length (Fig 20). The treatment M3 recorded significantly higher total seedling length (138.00 cm) followed by M2 (127.43 cm), however, M1 (99.87 cm) and Control (95.51 cm) were on par with each other. Overall, M3 combination growing media (Soil+ Rice husk+ vermicompost in 2:1:1 ratio) showed best seedling characteristics among all the other treatments. This may be due to rice husk created a lighter and friable growth medium which resulted in an almost loose root plug formation.

Plate 13. 30 days old seedling grown in different size of poly bags

Plate 14. 60 days old seedling grown in different size of poly bags

Plate 15. 90 days old seedling grown in different size of poly bags

A firm and cohesive root plug is very important for container seedlings because it facilities water and nutrient uptake by the roots as well as the seedling extraction. Composted rice husk is reported to serve as a practical soil substitute for plants grown in containers (Laiche and Nash 1990; Einert and Baker, 1973). Vermicompost is reported to have bioactive principles which are considered to be beneficial for root growth and this has been hypothesized to result in greater root initiation, increased biomass, enhanced growth and development and also balanced composition of nutrients. Vermicompost mixed with soil and rice husk affects the soil physical, chemistry and biology, since organic matter act as glue for soil aggregate and source of soil nutrient. Vermicompost granules may develop soil aggregate and its granulating. Soil aggregation will improve permeability and airflow in the polythene bags. The higher content of well-decomposed organic matter in vermicompost may preserve soil humidity, increase nutrient content and improve soil structure which increases water absorption and maintains the cell turgidity, cell elongation, and increase respiration at optimum level, leading to favourable condition for seedling growth (Bhardwaj, 2014).

With respect to the root length, M4 recorded maximum root length (24.81 cm) at 30 DAP, which was on par with treatment M2 (22.00 cm), M3 (21.47 cm), T5 (22.62 cm). The maximum root length at early stage recorded in coir pith compost, vermiculite and perlite (M4), the results are supported by Hartmann *et al.,* 2007. They observed that higher amount of vermiculite, perlite and peat moss in the media and these combinations of these materials aids anchorage of young roots and promotes faster root growth in early stage. At 60 and 90 days after transplanting the root length did not show statistically significant difference with respect to different potting media.

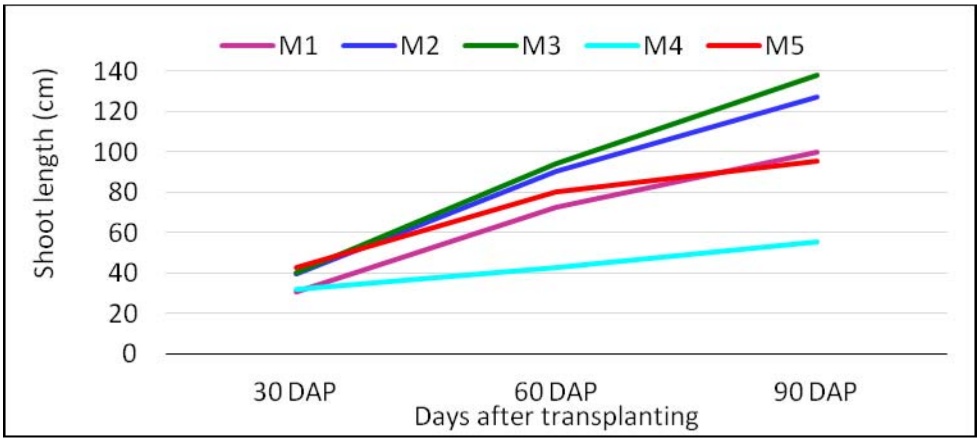

Fig 20. Effect of different potting media on shoot length of *Tectona grandis* seedlings

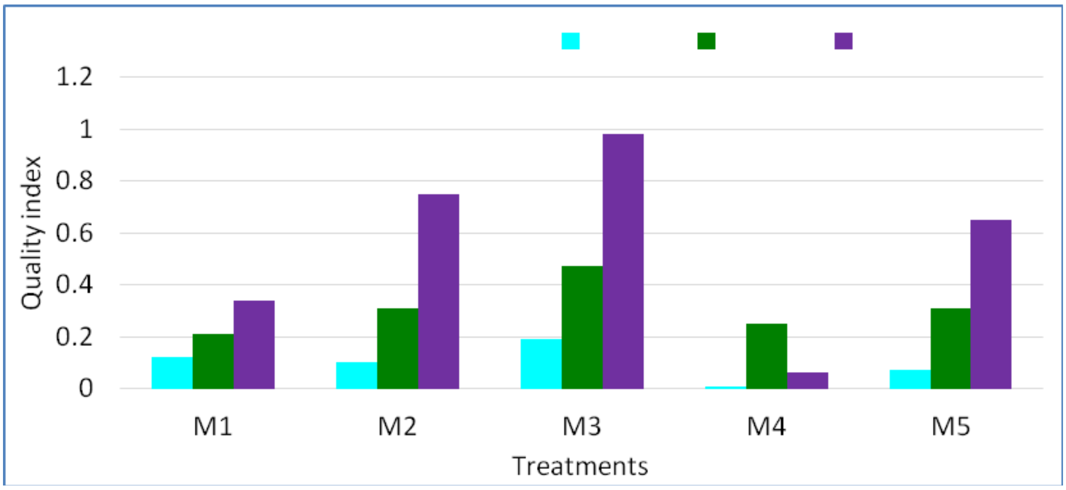

Fig 21. Effect of different potting media on quality index of *Tectona grandis* seedlings

M1-Soil+ coir pith compost+ FYM in 2:1:1 ratio

M2-Soil+ coir pith compost+ vermicompost in 2:1:1 ratio

M3-Soil+ Rice husk+ vermicompost in 2:1:1 ratio

M4-Soil+ vermiculite+ perlite in 2:1:1 ratio

M5-Soil+ Sand+ FYM in 2:1:1 ratio (Control)

The treatment M3 recorded the maximum root dry weight (3.14 g) root dry weight was recorded followed by M2 (2.93 g) which were on par with each other and the lowest root dry was recorded in M4 (0.52 g). M3 recorded maximum total dry weight (2.41 8.06 and 17.77 g) at 30, 60 and 90 days interval. While the treatment M4 (0.23, 0.47 and 1.40 g) recorded lowest total dry weight at all stages of growth. The results are supported by many researchers (Annapurna *et al.,* 2005; Rathore *et al.,* 2004; Dubie, 1982; Einert, 1973; Einert and Guidry 1975; Laiche and Nash 1990; Tsakaldimi, 2006). Aklibasinda *et al.* (2011) reported the effect of different growing media on scotch pine (*Pinus sylvestris*) seedling growth parameters such as collar diameter, seedling length, root length and number, dry root and shoot and dry biomass and the results revealed that the best growth attributes were shown by the media of 10% rice hulls to 90% peat material (Einert and Guidry, 1975).

Plant quality is a challenging parameter to characterize. Measurements of plant quality can be classified into three categories of plant attributes: morphological, physiological, and performance (Touhami *et al.,* 2017). Some of these are not regularly measured, and some performance attributes are time, labor and space-intensive. The use of simple, precise, and non-destructive measurements to characterize quality attributes using morphological and physiological measurements that are correlated to subsequent growth is of greater relevance (Kuan-Hung *et al.,* 2019).

In the present study, the quality index (Dickson quality index) differed significantly with respect to different potting media treatment at all stages of growth. At 90 days after transplanting, quality index showed significant difference with respect to different treatment, the highest quality index was (0.98) recorded in M3 followed by M2 (0.75) and M5 (0.65), both were on par with each other. The lowest quality index recorded in M4 (0.06) (Fig 21). DQI (Dickson quality index) incorporates three parameters (seedling dry mass, sturdiness quotient, and Shoot: Root ratio) and serves as a useful indicator for quality, and is often used during seedling selection. A larger DQI value indicates a more desirable phenotype and the greater the value of DQI, the better the seedling vigour, indicating robustness and balance in the distribution of biomass in the seedling (Scalon *et al.,* 2014). A smaller plant height/root collar diameter ratio indicates a sturdy plant of better quality. In addition, a small S: R ratio reveals a heavy dry mass for roots and is an indication of superior quality. DQI can also serve as a predictor for soil fertility, and poor seedling vigour may be due to limited root growth or poor soil fertility (Thompson and Troeh, 1978). Thus, the general trend observed for all tested plants is that larger seedlings had better DQI values.

Compared with Standard potting media used (M5-Soil+ Sand+ FYM), the maximum total seedling length (138.00 cm), collar diameter (8.77 mm), total dry weight (17.77 g) and quality index (0.98) recoded in M3-Soil+ Rice husk+ vermicompost in the ratio of 2:1:1 as against the standard potting media (Soil+ Sand+ FYM) normally practiced for raising seedlings. The control (the standard potting media adopted by the Forest department) recorded the total seedling length of 95.51 cm, collar diameter of 6.69 mm, total dry weight of 9.73 g and quality index of 0.65 with minimum seedling attributes and quality index than the treatment M3 (Soil+ Rice husk+ vermicompost).

Apart from the observed improvement in plant growth, the production cost of planting stock was found reasonable for M3- soil+ rice husk+ vermicompost, 2:1:1 mixture (9.09 ₹/ plant) as against the standard potting mixture (9.01 ₹/ plant) and the treatment M4-Coir pith+ vermiculite+ perlite was found as the costliest (13.02 ₹/plant). Both from the production /seedling quality and from the economic point of view, the treatment M3- Soil+ rice husk+ vermicompost was the best. The present study pointed out that the potting media of soil, rice husk and vermicompost in 2:1:1 ratio can be considered as a cheap alternative for production of quality planting stock of commercially important teak seedlings in humid tropics of Kerala and other areas of India, where the rice husk and vermicompost are readily available and less expensive than traditional substrates, thereby reducing dependence on costlier river sand and FYM. Further, converting these locally available organic waste materials into good quality manure can reduce the problems of environmental pollution and waste disposal and can also alleviate the problem of raw material scarcity in nurseries apart from mitigating the ecological hazards of sand mining. Rice husk is an abundantly available waste material in all the rice producing countries, and it contains about 30%–50% of organic carbon. The production of rice husks is about 100 million tons per year (Oosterkamp, 2014). Rice husk is a cellulose-based fiber and contains approximately 20% silica in amorphous form. In addition, it consists of 60–65% volatile matter, 10–15% fixed carbon, and 17–23% ash (Hu *et al.,* 2008). Rice husk can absorb water ranging from 5% to 16% of unit weights, and the unit weight of rice husk is 83–125 kg/m^3 (Phonphuak and Chindaprasirt, 2015).

5.4 EVALUATION OF CONTAINERS FOR PRODUCING QUALITY TEAK SEEDLINGS

In recent years' interest to produce robust, healthy and quality seedlings by using improved and modern nursery technique has increased. The new techniques mainly aim at producing sturdy seedlings by inducing morpho-physiological changes in the plants and prepare them to bear the shock on field planting. Although polythene bags are widely used for raising seedlings increasing importance is being accorded to the use of root trainers because of their wide acceptance due to its numerous advantages. Study was therefore undertaken to evaluate type and size of containers on growth and development of teak seedlings to recommend the best container type for large scale production of quality planting stock of this species over the conventional practices i.e. ploythene bag of 25 x 15 cm and root trainer of 150 cc for teak seedlings.

The present investigation on teak seedling indicated that type and size of container exert significant influence on germination and seedling growth parameters. Among the polythene bags, 30 cm x 25cm (T1) raised seedling exhibited maximum number of leaves (15.25), leaf area of 912.10 cm^2, 2361 cm^2 and 4025.95 cm^2 at 30, 60 and 90 DAP respectively, followed by T2 (663.24 cm^2, 1644.81 cm2 and 3817.52 cm^2).

The number of primary lateral roots (58.12), maximum length of primary lateral roots (29.58 cm, 35.12 cm and 38.96 cm) at 30, 60 and 90 days after transplanting, followed by T2 (20.19 cm, 21.06 cm and 24.73 cm), maximum root length (48.74 cm) the next best was T2 (37.62 cm) at 90 days. Biomass component viz. leaf dry weight, shoot dry weight, root dry weight and total dry weight. The maximum quality index was noticed for T1 and the quality index was decreased in the order T1>T2>T3>T4>T5 (Fig 22). Minimum root dry weight, total dry weight and quality index might be due to the development of root coiling and distortion which leads to stunned growth of seedlings (Gera and Ginwal, 2002).

Compared with Standard polythene bag (25 x 15 cm) as per Kerala Forest Department practice, the treatment T1 (Poly bag of 30cm x 25cm) and T2 (Poly bag of 30cm x 20cm) showed maximum seedling attributes and quality index.

Apart from the observed improvement in plant growth, the production cost of planting stock was found as 17.18 Rs and 11.12 Rs/ plant in T1 (Poly bag of 30cm x 25cm) and T2 (Poly bag of 30cm x 20cm) as against the low cost of Rs 9.09 /plant in the standard practice with polybag of size 25 x 15 cm. The choice of the poly bag is depended up on the total seedling height grow required at 90 days of interval. If seedlings of size >3 feet ie. 90 cm is expected, the treatment T2 (poly bag of 30 x 20 cm) will serve with an estimated cost of production of Rs 11.12 per seedling and if the target is to produce saplings of >1 meter, T1 production cost @Rs. 17.18 has to be adopted. The above advantages of taller teak saplings at 3 months of growth is to be viewed with a very low shoot length of 47.17 cm at the same period with only additional cost of production of Rs. 2.13 (11.12- 9.01) per sapling. Producing large-sized seedling stock prior to planting may also improve seedling growth and survival rates during the critical early period of seedling establishment and although this may increase initial costs, the increased likelihood of canopy closure may reduce the need for future expenditure on follow-up plantings and prolonged grass and weed control and also using large stock was advantageous when planting areas had excessive herbaceous competition. (Egnell and Leijon, 1999).

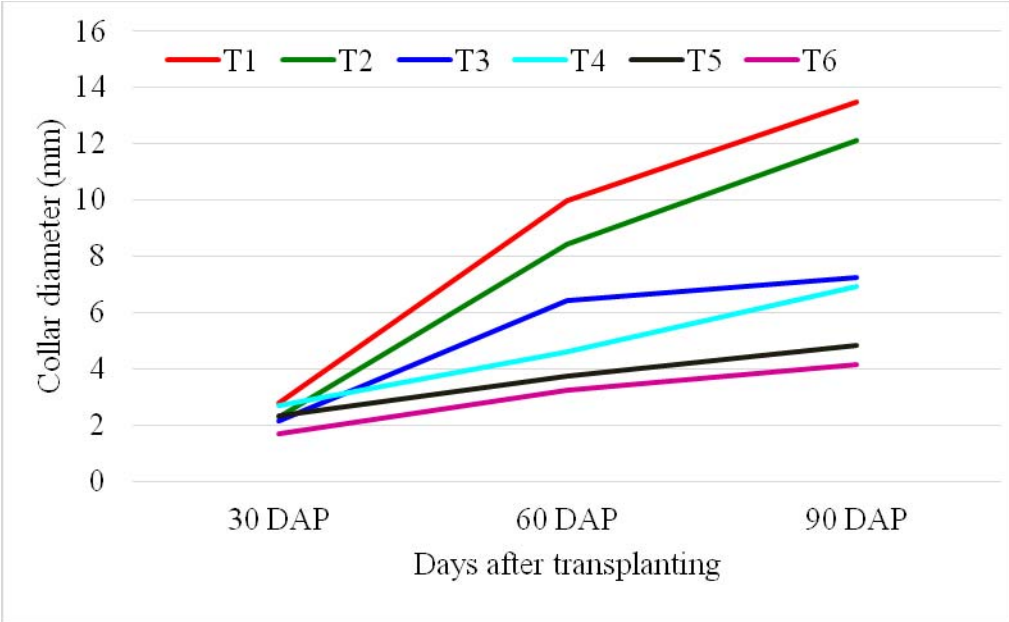

Fig 22. Effect of different type and size of containers on collar diameter of *Tectona grandis* seedlings

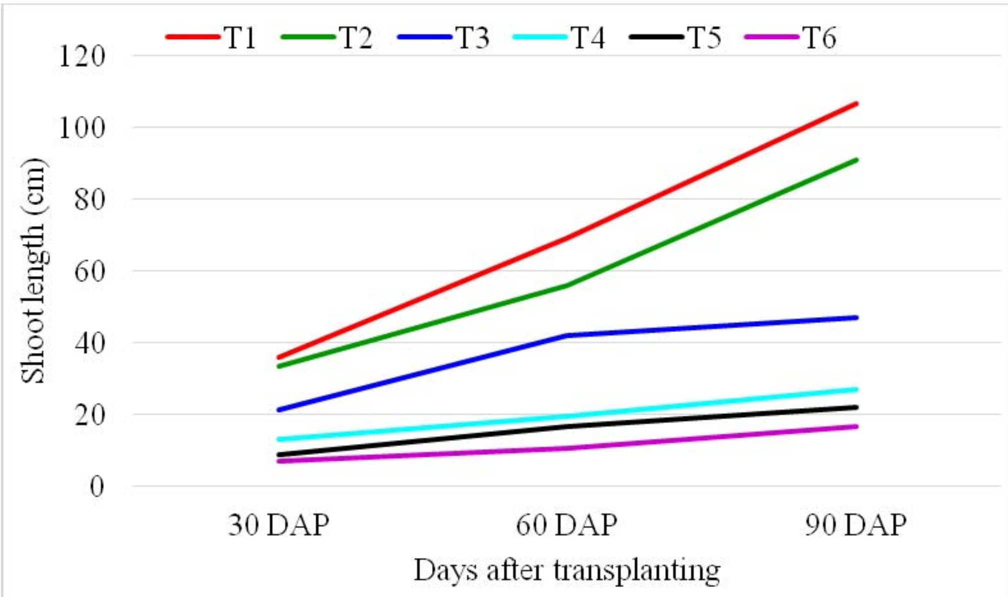

Fig 23. Effect of different type and size of containers on shoot length of *Tectona grandis* seedlings

T1-Poly bag of 30cm x25cm
T2- Poly bag of 30cm x20cm
T3-Poly bag of 25cm x 15cm (Control)
T4-Root trainer of 300 cc
T5-Root trainer of 200 cc
T6-Root trainer of 150 cc (Control)

Among the different toot trainers, 300 cc raised seedlings showed maximum number of leaves, leaf area, collar diameter (Fig 22), shoot length (Fig 23), root length, total seedling length, number of primary lateral roots, length of primary lateral roots (Plate 15), leaves dry weight, shoot dry weight, total dry weight and quality index (Fig 24). This might be attributed to the root trainer raised seedlings produces fibrous root system which enable to absorb water and nutrients from the soil more efficiently, ultimately leading to better growth and survival (Benson and Shephered, 1977). On the other hand, the fibrous root system produced might be due to the presence of ridges meant for guiding the roots to the drainage hole and ultimately lead to the development of lateral/adventitious root system thereby morphologically desirable, vigorous balanced root system is developed. Therefore, the higher container volume and presence of ridges and drainage hole in 300 cc root trainer recorded higher seedling growth and survival in the nursery. The results are supported by Carlson and Endean (1996) in *Picea glauca*, Sofi (2005) in *Cedrus deodara*, Hodgson (1977) in *Pinus patula* and Dominguez-Lerena *et al.,* (2006) in *Pinus pinea.* Ginwal *et al.* (2001) found *Acacia nilotica*. Khedkar (1999) also showed better establishment of teak plantation by using root trainer raised plants due to their multiple top root system Khedkar and Subramanian (1997) showed that root trainer raised teak plants are sturdier, healthier and are putting up better collar girth in comparison to stump original plants. The minimum values in all these parameters were observed in seedlings raised in root tardiness 150 cc.

In terms of quality index (DQI) T_4-Root trainer of 300 cc showed significantly highest index of 0.84 and T_5-Root trainer of 200 cc with 0.49 and the lowest by T_6-Root trainer of 150 cc (Standard size/control) (Fig 24). Apart from the observed improvement in seedling growth, the production cost of planting stock was found (₹ 9.09 and ₹ 7.89 / plant) for T_4-Root trainer of 300 cc and T_5-Root trainer of 200 cc and T_6-Root trainer of 150 cc - Standard size/control (6.99 ₹/ plant). From the results of the study, it is advisable to adopt root trainer of 300 cc only if the additional cost of ₹ 2.10 can be spent per seedling. Otherwise go for the standard size of 150 cc for there was no distinct advantage of adopting the next bigger size of 200 cc. With some of the advantages like well developed root system, uniformity in growth, cost of

Plate 16. Seedlings grown in different size of root trainers

A. 30 days old seedlings

B. 60 days old seedlings

C. 90 days old seedlings

production etc, the root trainer grown seedlings are less preferred wherever large saplings are needed for field planting. The container grown seedlings in general possess better environmental control of the growing regime, shorter production cycles, increased stock uniformity and assured superior field performance on poor quality sites also (Wilson *et al.,* 2007).

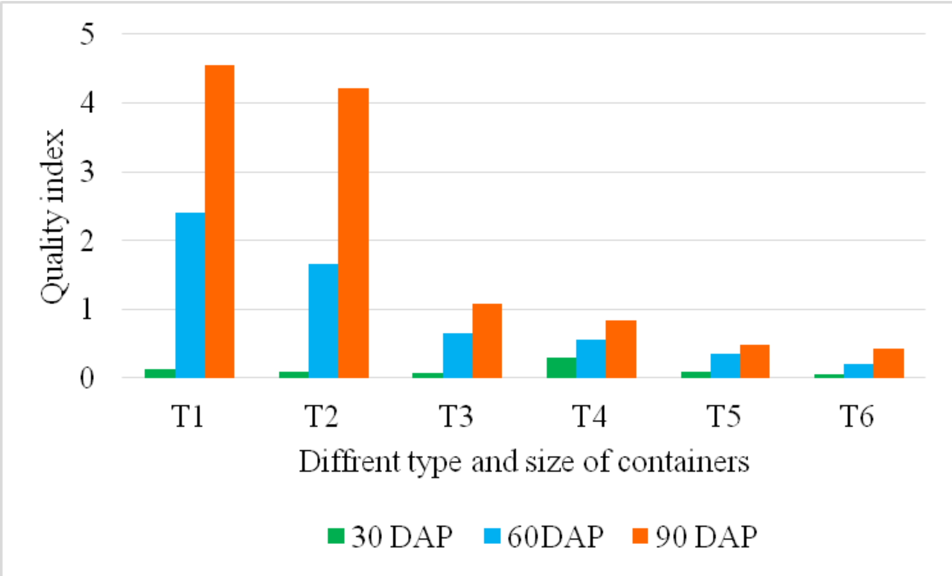

Fig 24. Effect of different type and size of containers on quality index of *Tectona grandis* seedlings

T1-Poly bag of 30cm x25cm

T2- Poly bag of 30cm x20cm

T3-Poly bag of 25cm x 15cm (Control)

T4-Root trainer of 300 cc

T5-Root trainer of 200 cc

T6-Root trainer of 150 cc (Control)

SUMMARY

6. SUMMARY

The results of the study on 'Standardisation of planting stock production techniques for teak (*Tectona grandis* Linn.f.) are presented and discussed in details in the previous chapters. The salient findings of the systematic investigations under the study are summarized hereunder.

Standardisation of pre-treatment methods for enhancing teak seed germination

1. Among the scarification methods, the highest germination percentage were recorded in Termite scarified seeds 63.04 %, followed by 54.29 % in mechanically scarified seeds as against the 40.79 % in untreated seeds. The highest mean daily germination, peak value and germination value (1.343, 2.76 and 3.71 respectively) were also recorded in termite scarified seeds.
2. Among the soaking treatments, AWD - 7days, the standard practice followed recorded highest germination per cent of 73.77 followed by ST4 ie. AWD for 3 days (71.66 %). All the acid soaking treatments showed significantly lower germination percentage. i.e the acid scarified seeds did not found to improve the germination at different durations tested with concentrated Sulphuric acid.
3. The soaking treatments exhibited significant differences with maximum mean daily germination of 1.49 (AWD 3 days) followed by AWD 7 days (1.42).
4. The treatment combination of termite scarified seeds + AWD-3 days gave the highest germination percentage (92.33 %). This resulted in 18.56 % increase in germination percent against the 73.77 % in the AWD 7 days alone (Standard Pre-treatment followed). However, the mechanical scarification resulted in a slight improvement of germination (77.00 %) i.e. an increase of just 2.23 % over the standard pre-treatment.
5. The dual advantages of the treatment combination of termite scarified seeds + AWD-3 days with respect to both high a germination percentage and the lesser number of days required for the pre treatment of teak seeds is an important highlight.
6. Termite scarified seeds gave the highest collar diameter of 1.46 mm as against the control treatment (0.81 mm) after 30 days of germination. The superiority of this treatment was evident, in most of the seedling growth characters in the

nursery also, as in shoot length (6.43 cm), root length (13.04 cm), total seedling length (19.48 cm), dry weight (0.20 g) and vigour index (14.91).

7. Mechanical scarification also has shown advantage over the untreated seeds as it followed as the next best treatment in most of the early seedling characteristics. Hence, in situations where the suitable subterranean termite can't be assured, mechanical scarification using the Mechanical Scarifier is recommended.

Optimization of fertigation levels and sowing methods for quality teak stump production

8. At the end of 180 days after fertigation, all the three fertigation treatments Fertigation at 7 days interval, Fertigation at 14 days interval and Fertigation at 21 days interval gave the higher number of leaves (15.83 and 15.66 and 14.08 respectively) which were on par with each other and the lowest number of leaves (11.25) was showed in the no fertilized control plots.
9. The maximum leaf area was in Fertigation at 7 days interval (8517.45 cm^2) followed by Fertigation at 14 days interval (7516.36 cm^2), Fertigation at 21 days interval (5371.38 cm^2) and the lowest leaf area of 3542.35 cm^2 corresponding to no fertigation control at six months of growth. All fertigation intervals were effective in improving the teak seedling leaf area as compared to the control.
10. At 180 days, the maximum collar diameter (23.31mm) showed by Fertigation at 7 days interval was significantly superior to all other treatments. Moreover, at 180 days, all the fertigation treatments reached the minimal collar diameter criteria of 1-2 cm were statistically distinct from the no fertigation (control) treatment.
11. All the fertigated treatments attained collar diameter of 2-3 cm criteria for better teak stump production. It is also proved that even the least frequent Fertigation at 21 days application resulted in the collar diameter of (22.66 mm) at 180 days of growth period. Hence, fertigation with 0.2 % N: P: K in equal proportion at 21 days interval can be recommended for producing utilisable seedlings for stump production.
12. It is noteworthy that all the fertigated treatments gave shoot length of more than one meter even at 120 days of growth. This is of greater relevance when it is

targeted to produce taller seedlings. At the end of observational period (180 days), the shoot length was 234.90, 189.39, 190.02 and 118.01 cm respectively for F1, F2, F3 and F4.

13. The maximum root length was observed in the Fertigation 7 days interval for all stages of growth (34.80, 48.38 and 72.03 cm respectively at 60, 120 and 180 days). During the period, the increase in root length noted in the F1 treatment compared to control was 8.58, 17.97 and 29.43 cm respectively.

14. With respect to seed sowing at different spacing, the maximum number of leaves recorded, in the widest spacing 30 cm x 30 cm, were 13.33, 15.08 and 22.41, while the corresponding number of leaves in the broadcasting control plot were 8.66, 10.33 and 5.91 at 60, 120 and 180 days respectively. Further a drastic reduction in the number of leaves was also noted (from10.33 at 120 days to 5.91 at 180 days) in the broadcasted control treatment.

15. At the end of 180 days after seed sowing, the maximum leaf area recorded in S3 (13,400 cm^2) followed by S2 (7467.04 cm^2), S1 (3529.33 cm^2) and the lowest value of 550.96 cm2 corresponding to broadcasting control (S4). In general, the leaf area showed tremendous increase with increase in the spacing for all the three intervals.

16. The collar diameter of teak seedling corresponding to 180 days was highest in for the widest spacing S3 (30.98) mm followed by S2 (24.83) mm and S1 (19.59) mm against lowest collar diameter of 9.85 mm in the broadcasting control (S4).

17. Dibbling treatment at 15 cm x 15 cm (S2) also reached required collar diameter for better stump production (> 2cm) at 180 days of growth. That means, 600 numbers of seedlings are available for good quality stump production from a standard nursery bed of 10 m x 1m at 180 days of seedling growth.

18. Significantly higher root length of teak seedlings (38.90, 50.02 and 90.24 cm respectively at 60, 120 and 180 days of growth) was observed in wider spacing treatments (S3-Spacing at 30cm x 30cm) followed by S2 (spacing at 15cm x 15cm) and S1 (spacing at 10cm x 10cm).

19. With respect to treatment combination (Fertigation intervals X seed sowing at different spacing), F2 X S3 (Fertigation at 14 days interval X Spacing at 30cm x

30cm) gave the maximum number of leaves (26.00) followed by F1 X S3 and F3 x S3 (23.00 and 22.67). The minimum number of leaves (3.67) was recorded by the combination of F4 x S4 (No fertigation X Broadcasting) followed by F2 X S4, F3 X S4 and F4 X S1, these four were on par with each other.

20. The treatment combination F1 X S3 (Fertigation at 7 days interval X Spacing at 30cm x 30cm) gave the maximum leaf area (18,985.3 cm^2) followed by F2 X S3 and F3 x S3 (16,920.3 and 10,809.1 cm^2).
21. From the point of view of mean leaf area per seedlings, wherever the seed bed is not scarce or not limited all the fertigated treatment combinations at 30 cm x 30 cm is gave best results. But while taking into account the number of seedlings produced in a standard bed of size 10 m x 1m the treatment combinations of S2 (600 seedlings per bed) and S1 (1000 seedlings per bed) also can be recommended provided fertigation can be given at 7 days interval.
22. The treatment combination F1 X S3 gave the higher leaf dry weight (213.85 g) followed by F2 X S3 and F3 x S3, F4 X S3, F3 X S2 and F2 x S2 (110.90, 108.57,104.40, 82.97 and 82.78 g), these were on par with each other. The lowest leaf dry weight (10.46 g) was recorded by the combination of F4 x S4. In the interaction across the fertigation treatments, the mean number of leaves for the broadcasting control treatment SM4 was very much less (5.92 g).
23. At 180 days, the treatment interaction F1 X S3 (Fertigation at 14 days interval X Spacing at 30cm X 30cm) showed the maximum collar diameter (34.88 mm) followed by F2 X S3 and F3 X S3 (32.00 and 31.75 mm), these two were on par with each other. One significant result to be highlighted here is that the combination of dibbling treatment at 10 cm X 10 cm with 14 days and 21 days intervals of fertigation with 0.2% NPK at 19:19:19 ratio (S1 X F2 and S1 X F3) gave required collar diameter (24.72 and 20.29 mm) for quality stump preparation at 180 days of growth.
24. Taking into account the number, the treatment combination S1 X F3 (10 cm X 10 cm with 21 days intervals of fertigation) is recommended as it produces 1000 numbers of seedlings fit for better stump production from a standard nursery bed size of 10 m X 1m.

25. The treatment S1 X F4 (10 cm X 10 cm) with no fertigation also reached the minimal collar diameter (11.51 mm) criteria of 1-2 cm.
26. As an important attribute of the Root growth potential, the maximum number of sprouts per stump was produced by F2- Fertigation at 14 days interval (8.66) and F1 (8.00), both values being on par with each other. The fertigation at 7, 14 and 21 days interval, which indicates the root growth potential of *Tectona grandis* seedlings raised for stump production, is affected and fertigation is beneficial from the point of view of the teak stump production.
27. In general, the performance indicators of stump viz. number of sprouts per stump, length of sprouts, number of leaves per stumps, number of lateral and tertiary roots per stump, length of lateral roots and dry weight of lateral roots was not much affected by the different intervals of fertigation or in some cases, non fertigated treatments were also doing good.
28. Characters of stump seem to be influenced by the wider spacing treatments during the early seedling growth up to 180 days. Generally conforming to the general notion, all the stump characters were maximum in the widest spacing and decreased with decrease in space for the seedling growth.
29. The number of leaves was not correlated with any of the RGR characteristics of the stump, it's ranged from 0.427 to 0.729, but in case of most of the seedling characteristics like length of sprouts (0.912), number of leaves per stump (0.837), tertiary roots per stump (0.926), length of lateral roots (0.896) and root dry weight (0.807) were found highly correlated with collar diameter.
30. Root length was not found correlated with any of the RGP characters and all were below 0.8 and maximum was 0.796 in length of sprouts.
31. Shoot length was highly correlated with length of sprouts (0.848) and tertiary roots per stump (0.862).
32. Length of primary lateral roots was also highly correlated with number and length of sprouts (0.810 and 0.886), number of leaves (0.841), lateral roots (0.820), tertiary roots per stump (0.899) and length of lateral roots (0.840).
33. A very notable fact is that the highest coefficient for root growth potentials were obtained for most of the desired characteristics needed for good quality teak stump with six months of seedling growth.

Optimization of potting media for producing quality teak seedlings

34. Maximum seedling length (138.00 cm), collar diameter (8.77 mm), total dry weight (17.77 g) and the highest quality index (0.98) recorded in M3-Soil+ Rice husk+ vermicompost in the ratio of 2:1:1 as against the standard potting media M5 (Soil+ Sand+ FYM) normally practiced for raising seedlings.
35. Apart from the observed improvement in plant growth, the production cost of planting stock was found reasonable for M3 (soil+ rice husk+ vermicompost) 2:1:1 mixture (Rs 9.09 / plant) as against the standard potting mixture (Rs 9.01 / plant) and the treatment M4-Coir pith+ vermiculite+ perlite was found as the costliest (Rs 13.02 / plant). Both from the seedling quality and from the economic point of view, the treatment M3- Soil+ rice husk+ vermicompost was emerged as the best.

Evaluation of containers for producing quality teak seedlings

36. Among the polythene bags 30 cm x 25cm (T1) raised seedling exhibited maximum number of leaves (15.25), leaf area (4025.95 cm^2), shoot length (106.89 cm), collar diameter (13.50 mm), the number of primary lateral roots (58.12), length of primary lateral roots (38.96 cm) maximum root length (48.74 cm), total dry weight (60.37 g) and quality index (4.56) at 90 days after transplanting.

37. Compared with Standard polythene bag as used by Kerala Forest Department (25cm x 15 cm), the treatment T1 (Poly bag of 30cm x 25cm) and T2 (Poly bag of 30cm x 20cm) showed maximum seedling attributes and quality index.

38. Apart from the observed improvement in plant growth, the production cost of planting stock was found higher as ₹ 17.18 and ₹ 11.12 / plant in T1 (Poly bag of 30cm x 25cm) and T2 (Poly bag of 30cm x 20cm) as against the low cost of ₹ 9.09 /plant in the standard practice with polybag of size 25 x 15 cm.
39. Benefit-cost ratio calculated for different containers the treatment, T1- Poly bag of 30cm x25cm recorded cost benefit ratio was 0.87, for T2 (poly bag of 30 x 20

cm) the benefit cost ratio was 1.35, as against 1.65 for control i.e. Standard poly bag of size of 25cm x 15cm.

40. The choice of the poly bag is depended up on the seedling height growth required at 90 days of interval. If only seedlings of size >3 feet ie. 90 cm is expected, the treatment T2 (poly bag of 30 x 20 cm) will serve with an estimated cost of production of ₹ 11.12 per seedling and if the target is to produce saplings of >1 meter, T1 with production cost @₹. 17.18 is to be adopted. The above advantages of taller teak saplings at 3 months of growth is to be viewed with a very low shoot length of 47.17 cm at the same period with only additional cost of production of ₹ 2.13 (11.12- 9.01) per sapling.

41. Among the different root trainers, 300 cc raised seedlings showed maximum number of leaves (11.12), leaf area (435.08 cm^2), collar diameter (6.91 mm), shoot length (27.09 cm), root length (23.80 cm), total seedling length (50.90 cm), number of primary lateral roots (51.25), length of primary lateral roots (19.80 cm), leaves dry weight (2.11 g), shoot dry weight (3.46 g), total dry weight (6.61 g) and quality index (0.84) as against the T6-Root trainer of 150 cc (Standard size/control).

42. Apart from the observed improvement in seedling growth, the production cost of planting stock was found (₹ 9.09 and ₹ 7.89 / plant) for T4-Root trainer of 300 cc and T5-Root trainer of 200 cc and T6-Root trainer of 150 cc - Standard size/control (₹ 6.99 / plant).

43. The benefit cost ratio was found (2.20 and 2.53) for T4-Root trainer of 300 cc and T5-Root trainer of 200 cc as against 2.86 for T6-Root trainer of 150 cc - Standard size/control.

44. From the results of the study, it is advisable to adopt root trainer of 300 cc only if the additional cost of ₹ 2.10 can be spent per seedling. Otherwise go for the standard size of 150 cc for there was no distinct advantage of adopting the next bigger size of 200 cc also.

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STANDARDISATION OF PLANTING STOCK PRODUCTION TECHNIQUES FOR TEAK (*Tectona grandis* Linn.f.)

by

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ABSTRACT OF THE THESIS

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ABSTRACT

The study was undertaken at Tree Nursery of College of Forestry to compare the effect of different pre-treatment methods on seed germination and optimization of fertigation intervals and seed sowing at different spacing for quality teak stump production. Attempt was also made to select ideal potting media and to standardize container type and size for producing quality teak seedlings.

The treatment combination of termite scarified seeds + Alternate wetting and drying (AWD)-3 days gave the highest germination percentage (92.33 %). This resulted in 18.56 % increase in germination percent against the 73.77 % in the AWD 7 days alone (Standard Pre-treatment followed). The dual advantages of the treatment combination of termite scarified seeds + AWD-3 days with respect to both high a germination percentage and the lesser number of days required for the pre- treatment of teak seeds is an important highlight. Termite scarified seeds gave the highest collar diameter of 1.46 mm as against the control treatment (0.81 mm) after 30 days of germination. The superiority of this treatment was evident, in most of the seedling growth characters in the nursery also, as in shoot length (6.43 cm), root length (13.04 cm), total seedling length (19.48 cm), dry weight (0.20 g) and vigour index (14.91). Mechanical scarification also has shown advantage over the untreated seeds as it followed as the next best treatment in germination percentage and in most of the early seedling growth characteristics. Hence, in situations where the suitable subterranean termite cannot be assured, mechanical scarification using the mechanical scarifier is recommended.

For quality teak stump production, at 180 days, the maximum collar diameter (23.31mm) showed by Fertigation at 7 days interval was significantly superior to all other treatments. Moreover, at 180 days, all the fertigation treatments reached the minimal collar diameter criteria of 1-2 cm were statistically distinct from the no fertigation (control) treatment. All the fertigated treatments attained collar diameter of 2-3 cm criteria for better teak stump production. It is also proved that even the least frequent fertigation at 21 days application resulted in the collar diameter of (22.66 mm) at 180 days of growth period. Hence, fertigation with 0.2 % N: P: K (19:19:19) in equal

proportion at 21 days interval can be recommended for producing seedlings for better stump production.

Seed sowing at 10 cm x 10 cm also reached required collar diameter for stump production. That means, 1000 numbers of utilisable seedlings are available for stump production from a standard nursery bed of 10 m x 1m at 180 days of seedling growth.

At 180 days, the treatment interaction F1 X S3 (Fertigation at 14 days interval X Spacing at 30cm X 30cm) showed the maximum collar diameter (34.88 mm) followed by F2 X S3 and F3 X S3 (32.00 and 31.75 mm), these two were on par with each other. Taking into account the number, the treatment combination S1 X F3 (10 cm X 10 cm with 21 days intervals of fertigation) is recommended as it produces 1000 numbers of seedlings fit for better stump production from a standard nursery bed size of 10 m X 1m. The treatment S1 X F4 (10 cm X 10 cm) with no fertigation also reached the minimal collar diameter (11.51 mm) criteria of 1-2 cm. Good correlation existed between root growth potentials and most of the seedling characteristics needed for good quality teak stump with six months of seedling growth.

Among the potting media the maximum seedling length (138.00 cm), collar diameter (8.77 mm), total dry weight (17.77 g) and the highest quality index (0.98) recorded in M3-Soil+ Rice husk+ Vermicompost in the ratio of 2:1:1 as against the standard potting media M5 (Soil+ Sand+ FYM) normally used for raising seedlings. Apart from the observed improvement in plant growth, the production cost of planting stock was found comparable for M3 (soil+ rice husk+ vermicompost) 2:1:1 mixture (₹ 9.09 / plant) as against the cost for standard potting mixture (₹ 9.01 / plant) and the treatment M4-Coir pith+ vermiculite+ perlite was found as the costliest (₹ 13.02 / plant). Both from the seedling quality and from the economic point of view, the treatment M3-Soil+ rice husk+ vermicompost was emerged as the best.

Among the polythene bags, 30 cm x 25cm (T1) raised seedling exhibited maximum number of leaves (15.25), leaf area (4025.95 cm^2), shoot length (106.89 cm), collar diameter (13.50 mm), the number of primary lateral roots (58.12), length of primary lateral roots (38.96 cm) maximum root length (48.74 cm), total dry weight (60.37 g) and quality index (4.56) at 90 days after transplanting. Among the different root trainers, 300 cc raised seedlings showed maximum number of leaves (11.12), leaf area (435.08 cm^2), collar diameter (6.91 mm), shoot length (27.09 cm), root length (23.80 cm), total seedling length (50.90 cm), number of primary lateral roots (51.25), length of primary lateral roots (19.80 cm), leaves dry weight (2.11 g), shoot dry weight (3.46 g), total dry weight (6.61 g) and quality index (0.84) as against the T6-Root trainer of 150 cc (Standard size/control).

The production cost of planting stock was found (₹ 9.09 and ₹ 7.89 / plant) for T4-Root trainer of 300 cc and T5-Root trainer of 200 cc and T6-Root trainer of 150 cc - Standard size/control (₹ 6.99 / plant). From the results of the study, it is advisable to adopt root trainer of 300 cc only if the additional cost of ₹ 2.10 can be spent per seedling, otherwise go for the standard size of 150 cc for there was no distinct advantage of adopting the next bigger size of 200 cc.

The prominent managerial inputs form this study for teak nursery production forestry include development of standard protocols for pre-treatment, seed sowing spacing, potting media, size of the polythene bags and root trainers. The package for quality teak stump production was also standardised.