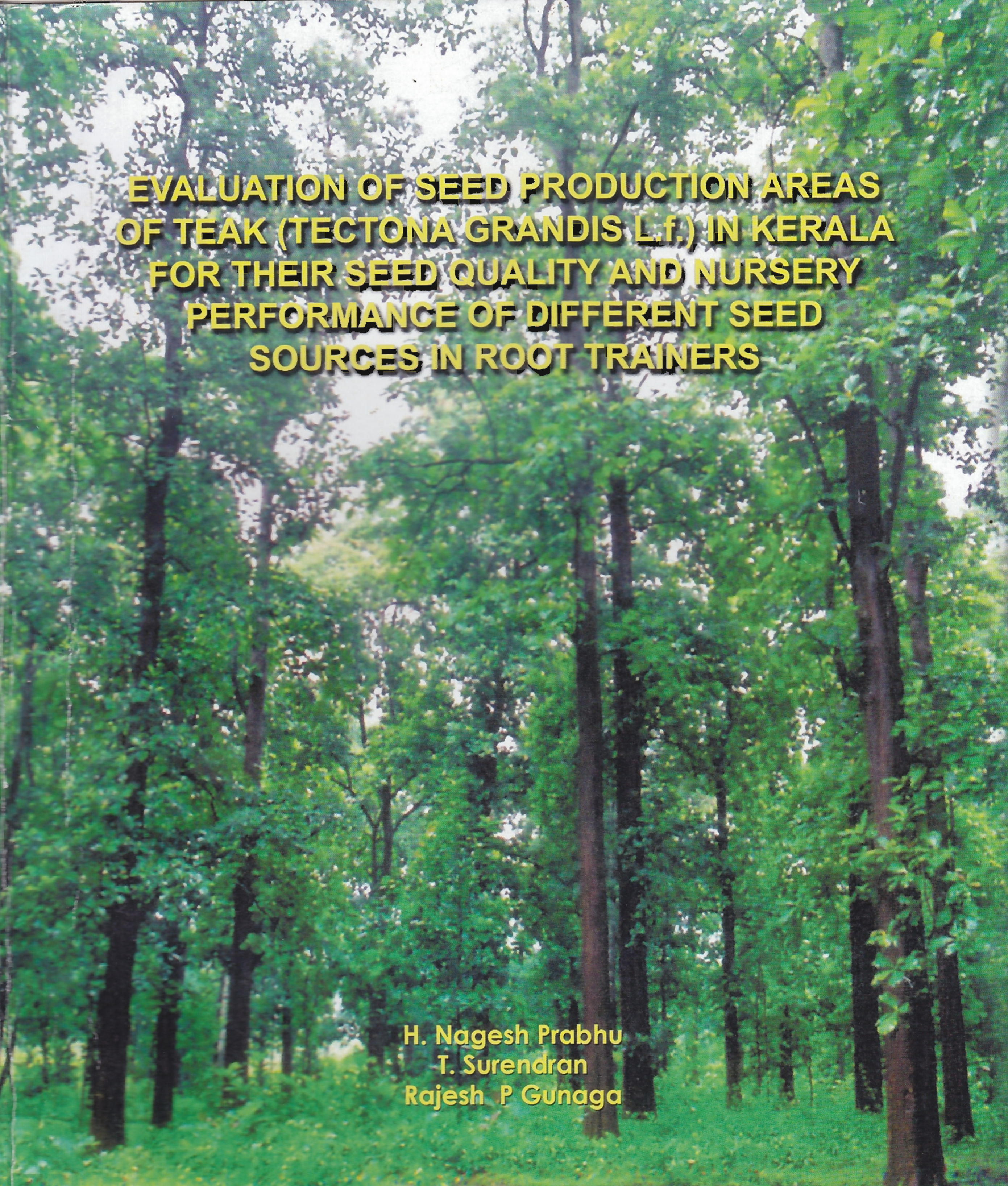

EVALUATION OF SEED PRODUCTION AREAS OF TEAK (TECTONA GRANDIS L.f.) IN KERALA FOR THEIR SEED QUALITY AND NURSERY PERFORMANCE OF DIFFERENT SEED SOURCES IN ROOT TRAINERS

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(Final Report of the Project KFRI/374/01)

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ABSTRACT OF THE PROJECT PROPOSAL

Project Number	: KFRI/374/01
Title	: Evaluation of Seed Production Areas of Teak (*Tectona grandis* L.f.) in Kerala for their Seed Quality and Nursery Performance of Different Seed Sources in Root Trainers
Objectives	: 1. To evaluate the variability and performance of seed production areas of teak in Kerala with respect to various fruit, seed, physiological and genetic parameters for the supply of the quality seeds. 2. To study the performance and variability of teak nursery stock raised in root trainers utilizing seeds collected from different seed production areas in terms of various growth parameters.
Practical utility	: The research information will be useful in planning seed collection, storage and raising quality nursery stock, leading to improvement in productivity to teak plantation raised.
Date of Commencement	: October, 2001
Scheduled date of completion	: June, 2005
Funding agency	: Kerala Forest Department
Investigator(s)	: H. Nagesh Prabhu (KFD) T. Surendran
Research Fellow	: Sri. Rajesh P Gunaga
Technical Assistant	: Sri. Sunil
Study area	: Teak seed production areas of KFD located in five teak seed zones of Kerala

CONTENTS

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We could carry out the study of this magnitude with the financial assistance given by Kerala Forest Department and the assistance of its field staff in collection of field data from seed production areas spread all over the State. We gratefully acknowledge the financial assistance from KFD and the assistance of its field staff.

ABSTRACT

There are 985 hectares of seed production areas of teak in Kerala. In this study an attempt is made for the first time to evaluate the performance of 38 seed production areas (SPAs) of Teak located in five teak seed zones of the state viz. Wynad, Nilambur, Parambikulam, Konni and Achencoil. The main objective of the study was to evaluate the performance of teak SPAs in Kerala with respect to various tree, fruit, seedling, soil and genetic parameters. To address this objective, tree growth parameters, phenological parameters, fruit and seed parameters, seedling parameters, soil and genetic parameters were studied. Considering the tree growth parameters like tree height, clear bole height, crop diameter, crown diameter, tree volume, site index and stem forms, Parambikulam and Nilambur seed zones emerge out to be superior in comparison to other seed zones. There are variations among different seed zones for different phenological phases indicating wide variability among seed zones.

Significant seed zone variation was observed for all the fruit and seed characters studied indicating wide variability. The fruit yield ranged from 3.74 to 36.97 kg. per hectare and the highest fruit yield was recorded in Parambikulam seed zone followed by Nilambur. The germination percentage of teak fruits varied from 0.44 to 18.92 percentage considering the germination data of two seasons. The germination percentage in Parambikulam and Wayanad seed zones was low comparing to other zones. Considering all the seedling parameters analysed, Parambikulam and Nilambur seed zones emerge out to be superior seed zones. All the analyzed soil parameters showed that Parambikulam seed zone was better than other seed zones. This is reflected in the highest fruit yield per hectare. The RAPD analysis shows that SPAs selected from Konni and Nilambur seed zones had comparatively higher gene diversity and percentage of polymorphic loci than those SPAs selected from other zones.

The ultimate aim of maintaining SPAs is to collect large quantity of quality seeds to raise quality nursery stock. As total fruit yield, germination percentage, quality and performance index have direct bearing on quality and quantity and performance index have direct bearing on quality and quantity of seeds produced and nursery stock raised, the 38 SPAs in the State have been ranked based on the rank index developed taking to consideration the above parameters giving equal weightage to all the parameters. As per ranking the top ten ranking SPAs in the State have been listed for collection of superior quality seeds. SPAs within the seed zones have also been ranked as a guideline for collection of seeds within the seed zone.

The seed zones have also been ranked based on the parameters considered for ranking SPAs. Parambikulam and Nilambur seed zones emerge out to be top ranking seed zones.

INTRODUCTION

Teak (*Tectona grandis* L.f.), belonging to family Verbenaceae, is a major plantation timber of Kerala. Teak is indigenous to India and Southeast Asian region, especially Myanmar, Thailand and Lao Peoples Democratic Republic. Although teak plantations account for only 5 to 8 per cent of the total forest area in the tropics (Ball *et al.*, 1999), the species accounts for about 90 per cent of the quality hardwood plantations for timber production (Granger, 1998).

Presently the total area under teak plantation in the country is 1.5 million ha and around 50,000 ha of teak plantations are raised annually (Subramanian *et al.*, 2000; Katwal, 2005). Currently, the area under teak plantations in Kerala is 75,300 ha amounting to 50 per cent of total forest plantations. Most of the teak plantations are distributed in Wayanad, Nilambur, Parambikulam, Achencoil, Konni, Ranni and Malayattoor regions (Rao *et al.*, 1997). In order to sustain the plantation programme, after completion of rotation cycle, the felled plantation areas are replanted with planting stock raised from seeds obtained from seed orchards and Seed Production Areas (SPAs). So far, over 5,000 ha of SPAs have been established in India (Mandal *et al.*, 1997) and of this about 1250 ha area is in Kerala (Prabhu, 2005).

In Kerala, about 1000 ha of teak plantations are being felled annually and replanted after their rotation age. The productivity of teak plantations in Kerala is about 50 per cent of the expected productivity (Nair *et al.*, 1996). One of the reasons for low productivity is the poor quality planting stock raised out of poor quality seeds. The nursery stock (stump/ root trainer seedlings) is raised using seeds collected from different SPAs. Considerable variations have been observed in various tree and fruit parameters of different SPAs. Information on teak seeds produced in different SPAs, which is largely a function of various tree parameters and site factors, is of great significance for proper planning of nursery operations and management practices to be followed in SPAs. It is well established that quality nursery stock raised from source identified improved seeds will result in increased productivity of teak plantations. Hence, one of the objectives of this study was to evaluate the performance of all seed production areas of teak in Kerala in terms of various tree/fruit/seed parameters to supply the quality seeds for afforestation programmes.

The traditional stump planting technique for teak planting was introduced way back in 1891 by T.F. Bourdillon. After a gap of almost 100 years, a new nursery technique for raising nursery stock of teak in root trainers was introduced in India by Maharashtra Forest Development Corporation in 1991 (Khedker and Subramanian, 1995). Kerala Forest Department introduced the root trainer nursery technology for teak in 1998 (Prabhu, 1998). Since then, more than 9.5 million teak seedlings have been raised in root trainers and utilized for raising teak plantations in different forest divisions of the State.

There has been no study on the performance of seedlings raised from seeds of different SPAs in root trainers. As this information is essential for planning root trainer nursery operations in the State, evaluation of performance of teak planting stock raised in root trainers using teak seeds from different SPAs was undertaken in this study.

The SPAs, located in different climatic regions of Kerala, show considerable variation in edaphic factors, which might be influencing the performance of SPAs to a great extent. Hitherto no attempt has been made to correlate edaphic factors influencing the performance of SPAs in the State. Hence, various soil parameters were studied to understand the influence of physical and chemical properties of soil on the performance of SPAs in terms of various fruit and tree parameters.

Most of the teak SPAs in Kerala were raised using seeds collected from presumably phenotypically superior mother trees either from the natural forests or plantations, which were, later, converted in to SPAs after culling inferior trees. Considering this, it is likely that there is considerable genetic variation among the teak SPAs located in different geographic areas. Since the nature and degree of variation existing in SPAs of Kerala, determine the strategies to be adopted for genetic conservation, management of SPAs and for producing superior quality seeds, genetic diversity of teak SPAs was studied using Randomly Amplified Polymorphic DNA (RAPD) analysis.

To address the above issues, a series of laboratory and field experiments were carried out during 2001- 2004. The broad objectives addressed in this study were:

1. To evaluate the variability and performance of seed production areas of teak in Kerala with respect to fruit, seed, physiological and genetic parameters for the supply of the quality seeds.
2. To study the performance and variability of teak nursery stock raised in root trainers utilizing seeds collected from different seed production areas in terms of various growth parameters.

2. REVIEW OF LITERATURE

Review of literature on tree growth parameters, phenological parameters, fruits and seed characteristics, seedling growth and other physiological parameters in root trainers, soil parameters and RAPD analysis to estimate the broad genetic variations of teak are presented in this chapter.

2.1. Tree growth parameters

Bedell (1989) in her preliminary observation on variability of teak in India has reported intra and inter- population variations in teak with respect to fruit production, morphological characters, floral biology, seed biology, *etc.* Rawat *et al.*, (1998) studied the leaf samples of teak from 21 different provenances including two from Africa. A total of seven leaf parameters, comprising shape, upper and lower surface texture, shape of the leaf tip, leaf margin, petiole length and pigmentation were studied. The study revealed that in teak, diverse races exist and the above characters are inheritable. Gunaga *et al.*, (2002) and Lyngdow *et al.*, (2006) have reported such morphological variations in leaf traits among teak clones of Kerala and Karnataka, respectively. Recently, Gunaga *et al.*, (2004) also reported variation in cotyledon number and phyllotaxy in seedlings of teak. Such abnormalities are also reported in teak by several authors.

Morphological variations in teak clones of Karnataka have been reported with respect to characters like floral traits (Hanumantha *et al.*, 2001a; Vasudeva *et al.*, 2001), vegetative and reproductive behaviors (Gunaga and Vasudeva, 2002a; 2002b;Gunaga and Vasudeva, 2003a), germination (Mathew and Vasudeva, 2005), early vigour (Mathew 2001), resistance to pest and disease (Lyngdow *et al.*,2006). Hanumantha *et al.*, (2001b) reported significant variation for qualitative fruit traits such as nature of calyx enclosing fruit, hairiness and splitting among teak clones. Kjaer *et al.*, (1996) while studying genetic variation in teak from South Asia and Africa observed that differentiation between populations was much larger for morphological traits like stem form, relative branch size, wood density and allozymes.

Bagchi (1999) measured five characteristics, *viz*, total height, total bole height, diameter, Girth at Breast Height (GBH) and crown length, in 80 sets of teak trees. Each set contained six phenotypicaly superior teak trees selected from different teak plantations of Tamil Nadu, Kerala and Karnataka. The results showed negligible differences in the magnitude of the correlation coefficient between different pairs of characters before and after partialling out age, indicating that age need not be considered for analytical purposes. Kumar *et al.*, (1997) studied height, diameter and basal area of different teak clones and indicated significant genetic variation at the family level. Height gave high heritability (84 per cent) and genetic gain (6.34 per cent).

Suri (1984) studied the quantitative and qualitative tree parameters in a provenance trial laid during 1931, involving five seed sources (Burma, Kerala, Madhya Pradesh, Maharashtra and Karnataka). He reported variation among the provenances with respect to tree growth parameters at the age of 47 years. The tree height ranged from 22.9 m (Burma) to 26.8m (Nilambur); DBH ranged from 27.3 (Maharashtra) to 31.5 cm (Karnataka); basal area ranged from 17.29 (Madhya Pradesh) to 18.38 m^2 per ha (Karnataka) and number of stems per ha ranged from 235 (Karnataka) to 300 (Maharashtra).

In India, very few progeny trials have been conducted in teak. Considerable genetic variations for economically important traits such as, height, diameter and basal area have been reported by several workers (Nagarajan *et al.*, 1996b; Swain *et al.*, 1996; Sharma, *et al.*, 1996; Kumar *et al.*, 1997; Gogate, *et al.*, 1997). Swain *et al.*, (1999) studied quantitative characters in teak clones. The results indicated the presence of considerable genetic variation for height, diameter and basal area. In an experiment involving progeny trials of different age groups, Sharma *et al.*, (1996) concluded that the estimates of genetic parameters obtained at the early age do not change much at later stage.

Gogate *et al.*, (1997) reported highly significant genetic correlation between DBH and basal area (r = 0.955), which enables one to achieve simultaneous improvement by selecting one or other character. DBH and/or basal areas have been recommended as primary parameters for teak improvement programme through selection. Gera *et al.*, (2001) assessed the variability for plant height, collar diameter and survival percentage in 40 clones of three and a half years of age.

2.2. Phenological parameters

Teak is an important deciduous tree species with defined phenological phases. Generally, it remains leafless in winter (November to January) when it becomes dormant in growth. In moist localities, trees may remain in leaf until March or even later. In abnormally dry seasons, the trees may remain leafless for longer time than the usual period of 2-3 months (Tewari, 1992).

Sudheendrakumar *et al.*,(1993) has reported that, in Nilambur provenance most of the leaf fall in teak occurred during December to February and leaf flushing began in late March and completed by April.

Understanding the floral biology of a species is important before attempting its genetic improvement, specially in lesser understood tropical species (Zobel and Talbert, 1984). Variations in floral characteristics and mode of pollination are also of great significance for tree breeding and further tree improvement programmes. Reproductive biology helps in estimating the genetic variation (Costich, 1995) and in estimation of quality and quantity of seeds produced by a species (Nagarajan *et al.*, 1996a`; Gunaga and Vasudeva, 2002a).

Teak flowers are small, white and sweet scented. Inflorescence of teak is (terminal and/or axillary) a large dichotomously branched terminal tomentose/ cymose panicle, which is 60-90 cm long and 10-30 cm across with decussate branching. Trichotomously branched inflorescences have also been observed occasionally (Tewari, 1992). The flowers of teak are perfect actinomorphic, which possess six whitish petals making up a corolla with a diameter range of 6.31mm (Tangmitcharoen and Owens, 1997a) to 8.06 mm (Nagarajan *et al.*, 1996a). Petal diameter of teak ranges between 6.0 (Palupi and Owens, 1997) to 10.03 (Hanumantha *et al.,* 2001b). Subramanian and Seethalaxmi (1984), have reported 2759 flowers per inflorescence. Whereas, Hanumantha and Vasudeva (2001) reported high variation in number of flowers (1917 to 5834) among teak clones of Karnataka.

In natural outcrossing, only 0.2 to 1.3 per cent flowers set fruits (Bryndum and Hedegart, 1969; Hedegart, 1973) depending upon the environment and genotype. Controlled cross-pollination resulted in 10 to 12 per cent (Hedegart, 1973) fruit set; (Indira and Mohandas, 2002).

Teak is a cross-pollinated species with self-incompatibility. It is mainly pollinated by insects such as *Heriades parvula, and Ceratina hieroglyphica,* which are most important pollinators. Bees, beetles and some other insects are also reported to be pollinating agents (Rawat, 1994). Gunaga and Vasudeva (2002b) reported that peak rains coinciding with peak flowering season in the seed orchard may affect pollination and hence low fruit set in teak. They have recommended to select medium rainfall zones for raising seed orchards.

Palupi and Owens (1998) have reported a fruit set of 10.4 to 35.6 per cent in teak clones. Tangmitcharoen and Owens (1997b) have reported lower average fruit set of 2.49 per cent in teak. Hanumantha (2000) also reported poor fruit set of 0.43-1.53 per cent in teak clones.

Egenti (1978) studied the pollen and stigma viability in teak. Pollination experiment revealed that the highest percent of fruit set was obtained with the pollens used on the day of anthesis, though some fertilization was obtained with pollen collected up to 2 days after anthesis.

Generally, flowering period in teak commences from July and extends upto December; in most cases it is from July to September (Gunaga and Vasudeva, 2002b). In early flowering races, the number and size of inflorescence is larger with buds numbering upto 10,000 and this was just opposite among late flowering sources (Rawat, 1994; Vasudeva *et al.,* 2005).

Corlett (1998) reported that phenological behaviors are most diverse and least understood in the tropics. Several scientists have studied vegetative behaviors of tropical, sub tropical and deciduous forest tree species (Beniwal, 1987; Ansari, 1989; Arjunan *et al.,* 1995).

Gunaga and Vasudeva (2002b) reported variation among teak clones of Karnataka for different phenological events. They found significant differences for different phenological events such as leaf flushing, expansion and shedding.

Teak flowering season varies from June to September according to locality and climate. Gunaga and Vasudeva (2002; 2002b) reported clonal variation for flowering and fruiting. Clones from central and southern regions of Karnataka flowered during late June, while clones from northern region flowered in the month of third week of July. In Southern part of Tamil Nadu, flowers are seen in December-January and fruits ripen in April-May, while in Nilambur and South Coimbatore, teak flowers from June-August (Singh, 1960).

Palupi and Owens (1998) conducted a study on reproductive behavior of teak in a Clonal Seed Orchard (CSO) in Indonesia. They found that low fruit production of clone 5 was related to early flowering, the intermediate fruit production of clone 12 was related to late flowering and the high fruit production of clone 17 coincided with the peak flowering of CSO. The higher fruit set in clone 17 (35.6 fruits/inflorescence) than in clones 12 and 5 (17.9 and 10.4 fruit/inflorescence respectively) may be due to a higher incidence of cross-pollination, as the flowering period of clone 17 coincided with the peak CSO flowering period. Tangmitcharoen and Owens (1997a) reported that self-pollination in teak was very high, which may lead to fruit abortion.

Enescu (1987) reported that the geographic location and overall climate influence the biorhythms and certain physiological processes in plants. Nagarajan *et al.,* (1996a) have also reported the influence of geographical factors on different pheno phases in teak.

Negative effects of air temperature (Weinstein, 1989), heavy rain (Bryndum and Hedegart, 1969; Rawat, 1994; Palupi and Owens 1998; Vasudeva *et al.,* 2005) on flowering and fruit set have also been reported.

Nagarajan *et al.*, (1996b) reported that the clones varied in flower production per inflorescence, fruit set, fruit diameter, fruit weight and number of seeds per fruit.

2.3. Fruit and seed characteristics

Teak fruit is a globose, hairy, drupe enclosed by an enlarged persistent calyx. The tree starts yielding fruits from 10 to 12 years after planting. On an average, a 40 year old tree produces about 3 kg fruits and the nuts vary in weight (Tewari, 1992).

Variation in quality and quantity of fruit produced in different seed sources have been reported by many authors. Nagarajan *et al.*, (1996b) studied variations for fruit characteristics of four teak clones planted in two different locations *i.e.*, Chandrapur and Walayar. Clones differed in fruit diameter and fruit weight. Clones from Chandrapur and Walayar varied significantly in fruit diameter and fruit weight. Munendrappa *et al.*, (1997) studied seed nut and seedling characteristics of different provenances in teak and recorded significant differences in seed nut size, dry matter distribution in fruits, number of seeds, test weight and emptiness among different provenances. On an average the 100 seed nut weight ranged from 45.63 g (Mettupalayam) to 63.10 g (Dharwad). The seed number also varied among the provenances, with Bangalore registering 45/100 seed nuts, while that from Dharwad had 103 seeds/100 seed nuts (102.8). Hanumantha (2000) reported variation among clones for fruit characters, *viz.*, fruit weight (43.07-70.56 g), fruit diameter (1.15-1.56 cm), fruit density (0.367-0.536 g/cc), mesocarp (2.69-4.27 mm) and endocarp thickness (1.74-2.45 mm).

Fruit production in an SPA depends on factors such as phenology, flowering pattern, pollination, soil nutrient status, age, climate, topography, edaphic and total reserve food present in the mother plant, insect-pest and diseases, *etc.* (Gunaga and Vasudeva, 2005b).

Bedell (1989) reported the variations in fruit size with varying locality factors in different seed sources of Andhra Pradesh, Karnataka, Kerala, Madhya Pradesh and Orissa. Considering all seed sources, number of fruits/ Kg was ranged from 1115 (Seed Zone – KL-III, Kerala) to 2686 (Seed Zone-MP-IX Madhya Pradesh).

Suri (1984) reported that the teak seeds from moist localities are comparatively heavier and bigger in dimension than those from the dry localities. Dabral (1976) reported that the emptiness was influenced significantly by site but not by age.

Gupta and Kumar (1976) have reported that out of sun-dried teak fruits collected from 23 sources, in 15 sources empty fruits were more in number, majority of fruits contained only one seed and three and four seeded fruits were less in number.

Indira *et al.*, (2000) reported that, most of the fruits belonged to 9 to 12 mm diameter and fruits of less than 9 mm diameter had low germination percentage.

Dharmalingam and Masilamani (1999) used radiography to test the quality of teak seed collected from India (Tamil Nadu) and Thailand. Radiograph showed the occurrences of four, three, two and one seed in the tetracarpellary ovary at the frequency of 1: 5:19 and 48 per cent respectively with 27 per cent empty drupe. When drupe size decreased, the percentage of single seeded and empty drupes increased correspondingly.

Several factors such as seed dormancy (Hodgson, 1900; Keiding,1985), size of fruits (Eidmann, 1934; Samapudhi, 1967; Banik, 1977; Banik, 1978; Indira *et al.*, 2000), age of plant (Hanumantha, 2000; Mathew, 2001; Vasudeva, *et al.*, 2001; Gunaga and Vasudeva, 2005a), effect of seed source/ provenance (Dabral, 1976; Prasad and Jalil, 1986; Jayasankar *et al.*, 1999b; Rajput and Tiwari, 2001; Mathew and Vasudeva, 2005) affect the fruit germination in teak.

Seed coat dormancy is an important factor that affects the germination behaviour of teak. Dormancy period in teak seeds varies from four weeks up to a maximum of 3 years within a seed lot (Keiding, 1985). Several methods to break dormancy of teak seeds have been reported by many authors.

Various pre-sowing treatments for improving the germination include, wetting fruits with water and drying under sun (Moss, 1892; Muttiah, 1975; Ngulube, 1988; Bedell, 1989 and Yadav, 1992) soaking in cow dung slurry (Osmaston, 1908; Gamble, 1921 and Ngulube, 1988), chemicals such as Sach's solution, acids, growth hormones (Hodgson, 1900; Unnikrishnan and Rajeeva, 1990; Vijaya *et al.,* 1996), mechanical treatments of fruits (Bryndum, 1968), sun scorching (Damale, 1901), pit method (Tuggresse, 1926), partial fermentation (Wunder, 1966) and exposing fruits to X-rays, gama rays, light rays in the red region of the spectrum and high frequency sound waves (Bhumibhamon, 1980).

Masilamani *et al.*, (2000) has reported that drupes collected from crown did not germinate at all without preconditioning but preconditioned drupes gave 2.75 per cent germination. Drupes collected from ground gave 7.5 per cent germination without pre conditioning and 32 per cent germination with preconditioning. Seedling emergence, time to emergence, seedling growth and vigor improved in preconditioned ground collected drupes.

Suri (1984) reported variation in germination percentage for fruits collected from different provenances ranging from 12 per cent (Betul, MP) to 46 per cent (Kakankote, Karnataka), average being 28 per cent.

Gupta and Pattanath (1975) reported that in a provenance trial, germination of seeds from seven sources of India did not germinate. Treatment with nutrient solution increased germination from 6 to 53 per cent. It was reported that nutrient imbalance, presence of water soluble inhibitors in the mesocarp and phenomenon of after ripening may be the causes for dormancy in teak.

Indira and Basha (1999) reported significant difference among the seeds collected from four seed sources (plus trees, plantation trees, trees from SPAs and trees from clonal seed orchards) with regard to germination percentage. Germination varied from 0.97 to 33 per cent.

Sivakumar *et al.,* (2002) reported an average viability percentage of 75.21, 86.68, 71.43 and 81.67 in the seed lots obtained from Konni, Nilambur, Wayanad and Parambikulam seed sources respectively. They have also reported an average germination percentage of 22.16, 48, 4.5 and 3.3 respectively for the Konni, Nilambur, Wayanad and Parambikulam seed sources.

Joshi and Kelkar (1975) in their study on teak fruits reported that only one seed was fully developed in each quadrilocular fruit and often two seeds did not develop at all. Of the developed seeds only 20 per cent gave deep uniform stain with tetrazolium and 40 per cent did not stain at all.

Keiding (1966) reported that the germination percentage could be increased considerably by removing the exocarp of the teak fruit. This was effectively done by exposing the fruit on the ground for one to two weeks, during which time the exocarp was consumed by white ants with negligible loss to seed. Chen and Yang (1969) have reported that teak seed treated with hot sand gave a mean germination of 44.5 per cent, after alternate soaking and drying, 29.5 per cent, after scarification of pericarp 20.8 per cent, after storage in the ground, 18.8 per cent and in control 9.4 per cent.

Chacko *et al.,* (1997) tested some pre- sowing techniques for germination of teak fruit. Results reveal that alternate wetting and drying for seven days and soaking in cow dung solution for 24 hours enhanced the germination of teak fruits. They have recommended cutting test as a quick test for assessment of seed viability as well as for prediction of germination percentage. When fruits with viability of 62-64 per cent were subjected to effective pre sowing treatment, 43-65 per cent of the viable seeds germinated, suggesting the multiplication factor of 0.43-0.65 for prediction of germination percentage from the viability percentage as determined by cutting test.

Masilamani and Dharmalingam (1999) tested different media for germination of teak fruits and it was reported that the best germination and seedling growth was recorded in the sand medium, followed by fly ash + red earth + farm yard manure mixture. Fly ash alone gave the poorest germination and seedling performance.

2.4. Seedling growth and physiological parameters in root trainers

Seedling selection and progeny testing are the two rigorous breeding methods being practiced for the improvement of forest trees (Kedharanath, 1986; Chaturvedi, 1986). Nursery selection of half-sib families has been recommended by many workers (Neinstadet, 1981; Sidhu, 1993; Li *et al.*, 1997). Progeny evaluation at seedling stage aims to derive preliminary information for developing juvenile-mature correlation of traits of economic importance. It is also useful in eliminating poor progenies from field-testing (Sidhu, 1993).

Early selection in tree improvement is an important aspect, which requires information on seedling growth parameters. Mathew (2001) observed that the performance of families did not differ significantly at any stage for plant height and collar diameter and suggested that the seedling may be too young to be fully expressing the genotype. To identify the genetic sources of high potential, field trials have to be continued for some more years. In contrast, Tewari *et al.*, (1994) demonstrated that the quality and genetic potential of the seedlings used to prepare stumps have a strong influence on the performance of stumps. An evaluation of recent teak provenance trial at seedling stage conducted by Jayasankar *et al.*, (1999a) indicated that height and collar diameter of plants raised from stumps had a positive correlation with height and collar diameter of the seedlings used for preparing stumps ($r = 0.807$ and $r = 0.613$, respectively) *i.e.* field performance of provenance followed growth patterns in the nursery.

Jayasankar *et al.*, (1999a) and Mathew (2001) have also reported significant influence of provenance/ clones on the root growth and their biomass in teak. Generally, plants with better root growth establish easily and perform well because of their ability to produce new roots faster after planting in the field. It is reported that the stumps with higher amount of reserve food materials perform well in subsequent evaluations (Davis *et al.*, 1990; Lebot, 1996). However, conclusive juvenile-mature correlation for economic traits up to rotation age is lacking and a thorough investigation in this regard is the need of the hour to accelerate teak improvement programme.

Seedling biomass, *viz.*, leaf, shoot and root, have influence on the growth, vigour, sturdiness and establishment of seedlings. As optimal leaf mass level increases, biomass production would substantially increase. Higher leaf area and biomass of seedlings are the good indicators of higher photosynthetic carbon fixation at seedling stage. Such variation has already been reported among teak clones for leaf area and biomass production at seedlings level (Mathew, 2001). Jayasankar *et al.* (1999a) have also reported that seed sources such as Parambikulam, Nilambur and Malayattur provenances of Kerala had higher leaf area and leaf biomass in comparison to other provenances tested.

Khedkar and Subramaniyan (1995) have reported the use of root trainer nursery technology for teak. Teak seedlings raised in root trainer have shown better root development with multiple tap roots in comparison to stump plants. Comparison of growth of 75-day-old root trainer stock and one-year-old stump planting stock revealed that root trainer plants were sturdier, healthier and had larger collar girth than stump origin plants.

Khedkar (1999) compared the performance of teak root trainer plants and teak stumps. Results revealed that the growth of root trainer plants was better and faster than the stump plants. The root trainer plants had shorter nursery period of 60 to 90 days in comparison to 12-13 months required for raising stumps.

Physiological characterization is an important factor in evaluation of quality of the nursery stock. There are many methods for physiological characterization and chlorophyll fluorescence is one among them. Vidaver *et al.*, (1989) opined that chlorophyll fluorescence is a useful physiological test due to its non-invasive, non-destructive and rapid nature.

The study on chlorophyll fluorescence parameters is very scanty in tropical tree species. Husein *et al.*, (2004a) reported diurnal variation in Fv, Fm and Fv/Fm in different *Ficus spp.* Maximum Fv/Fm of 0.736 and 0.758 was reported in *Ficus nemoralis* and *F. roxburgii*, respectively. Several authors have also reported such diurnal changes in chlorophyll fluorescence of different species (Ehleringer *et al.*, 1986; Joshi, 1995;Husein *et al.*, 2004b). Recently, Chacko (2005) reported variation in chlorophyll fluorescence of seedlings grown under different shade and irrigation regimes in teak and he has recorded variation in performance index (PI), which ranges from 4.6 to 35.0. So far no comparison has been made in teak seedlings with respect to variation for chlorophyll fluorescence parameters using seeds from different provenances, seed production areas or clonal seed orchards.

2.5. Soil analysis

Teak occurs on a variety of geological formations and usually grows on soils having pH range of 6.5 to 7.5. It can come up very well in laterite soil, which is highly disintegrated and mixed with other rocks (Tewari, 1992).

Good growth performance of the teak can be seen even under acidic soils of pH 4 to 4.1 (Puri, 1951; Banarjee *et al.*, 1986). Bhatia (1955) reported a positive correlation between the growth and distribution of teak with soil pH in Madhya Pradesh. However, on acid soils with low phosphate and low base content, regeneration suffers set back. Boonkird *et al.*, (1960) noticed no positive correlation between the growth of teak with pH. Tewari (1992) reported that the good teak occurs in soils where pH values ranged between 6.5 to 7.5. While discussing the optimum soil conditions, Tanaka *et al.*, (1998) indicated slightly acid to alkaline pH for the growth of teak.

Ezenwa (1988) observed a positive correlation between tree height and basal area with total exchangeable bases. Similarly, Singh *et al.*, (1990) also observed a strong relationship between tree height with cation exchange capacity in teak. Singh *et al.* (1988) noticed good growth of teak on the soil with higher cation exchange capacity. Tanaka *et al.*, (1998) reported that the abundance of bases provides an optimum soil condition for the growth of teak.

Bhatia (1955) obtained no significant correlation between the growth and distribution of teak with soil nitrogen. However, there exists a correlation between tree biomass and total nitrogen in A and B horizons (Pongsak and Sahunalu, 1970). Several scientists (Ezenwa, 1988; Singh *et al.*, 1990) have also reported positive correlation between total nitrogen with tree heights and basal area. (Drechsel *et al.,* 1989) noticed die-back in young plantation due to deficiency of nitrogen.

Soil phosphorus (P) has influence on the growth and distribution of teak. Good regeneration was observed in soils where P ranged between 0.022-0.108 per cent (Bhatia,1954). Total phosphorous content in various soils ranged between 19 to 135 mg/ 100 g of soil with available phosphorous from 2 to 21 mg/ 100 g. Bhatia (1955) observed positive correlation between the growth and distribution of teak and phosphates. Boonkird *et al.,* (1960) noticed no positive correlation between phosphorus content of the soil with growth measurements. Relationship between some soil properties and growth of 11-year-old teak was studied by Ezenwa (1988) who reported a negative correlation between tree growth and available phosphorous. (Drechsel *et al.,* 1989) related die back of teak to the phosphorous deficiency on sandy clay soils. On the other hand Tewari (1992) reported that performance of the teak depends not on the total phosphorus, but on the available phosphorus.

Total potassium in some teak soils were ranges from 0.54 -1.80 percent in the surface and 0.40-1.13 percent in the sub-surface. It depletes at the surface due to high leachability. Samapudhi (1967) reported that in Thailand, teak soil was found to contain more exchangeable potassium (29 ppm) in comparison to non teak soils, which ranges from 19 to 19.8 ppm. Ezenwa (1988) noticed positive correlation between soil potassium with tree height and basal area, while studying edaphic factors affecting the growth of *Tectona grandis* on basaltic soils in Nigeria.

Akinsanmi (1985) reported the influence of major site factors affecting the growth of teak in several areas of South West Nigeria. Multiple regression analysis of the growth data and soil analysis showed that teak volume growth was significantly correlated with rainfall, texture, organic matter content and soil pH.

Alexander *et al.,* (1987) studied the site quality based on the height attainable at 50 years. In a multiple linear regression analysis, soil variables accounted for 31 percent of the variation in top height, and age 63 per cent. Partial regression coefficients indicated the important effects of gravel, sand and pH.

Balagopalan and Jose (1991) carried out a study to examine the effect of monoculture of teak, eucalypt, and rubber along a transect in Trichur Forest Division in Kerala. Analyses were carried out for particle size separates, soil pH, bulk density, water holding capacity, organic carbon, cation exchange capacity, total N, P and S. In monoculture plantations, bulk density increased, while organic matter, N, P, S and most cation nutrients depleted in soils under monoculture plantations. The average values for three layers of teak soil analysed were sand (74.63%), silt (6.76%), clay (18.6%), pH (6.1), bulk density (1.37), water holding capacity (32.86%), organic carbon (1.01%), total N (654 ppm), total P (294 ppm) and total S (103 ppm). They have reported that soils under teak were less deteriorated than that under eucalypt.

Bhatia (1955) has studied pH, moisture content, exchangeable Ca, Mg, K, total available phosphates, N, organic matter and C/N in teak stands. He reported positive correlation between the growth and distribution of teak, soil pH, exchangeable Ca, Mg and phosphates.

Chandrasekhara (1996) noticed lesser biomass production of teak in site type A, which is characterized by soils containing higher potassium. Exchangeable potassium varied from 45 to 625 ppm in the surface and 113 to 647 ppm in subsurface. Aparanji (2000) reported that the major nutrients such as available nitrogen, phosphorus and potassium have a positive association with stand growth and volume of teak.

The necessity of Ca for good teak growth was emphasized by many workers (Kadambi, 1951; Bhatia, 1955; Totey and Bhawmik, 1990). According to Yadav and Sharma (1968) and Totey and Bhawmik , 1990), high exchangeable calcium favours the growth in teak plantation. Although, calcium is necessary for the growth of teak, high calcium content is often found on bad teak soils (Kadambi, 1951; Yadav, 1968). Bhatia (1955) noticed a positive correlation between the growth and distribution of teak on exchangeable calcium content in the soil. Ezenwa (1988) noticed a positive correlation between exchangeable calcium with tree height and basal area. Similarly, Singh *et al.,* (1990) reported significant correlation between exchangeable calcium and calcium oxide with height of teak.

Magnesium is the only mineral constituent of the chlorophyll molecule and is essential for photosynthesis. Bhatia (1955) observed a positive correlation between the growth and distribution of teak with exchangeable Magnesium. Singh *et al.,* (1990) recorded a strong association between tree heights with magnesium oxide content of surface soil in teak plantation of the Tarai region of West Bengal.

Organic matter content in some natural teak forest and plantations in Madhya Pradesh ranged from 1.87-5.5 per cent and it decreased to 0.17-1.90 per cent at a depth of 100cm (Bhatia, 1955). In the teak plantations of natural sal zone of West Bengal there is an increase in soil organic matter status (Banerjee *et al.*, 1986). However, there appears to be some positive correlation between measurements of mature teak trees with organic matter content (Boonkird *et al.,* 1960). Conversely, Singh *et al.,*(1988) noticed better growth of teak on soils with higher organic carbon. Manganese deficiency is one of the reasons to cause dieback in young teak plantation in sandy-loam soils (Drechsel *et al.*, 1989).

2.6. RAPD analysis to estimate the genetic variation

Determining nature and extent of genetic diversity in population of forest trees has been the focus of many studies over the past three decades (Wickneswary *et al*, 1996). RAPDs have been used as an efficient method to reveal the genetic structure and diversity pattern of trees in natural populations, reserve forests and plantations and the outcome could readily be used to select priority areas for conservation, to design and monitor management strategies in protected areas and to plan conservation strategies for genetic resources (Young *et al.*, 2000; Uma Shaanker *et al.*, 2001). RAPDs have been successfully used for estimation of genetic diversity/variation and relatedness in mahoganies (Chalmers *et al.*, 1994), *Populus* (Rajagopal *et al.*, 2000), *Grevillea* (Rossetto *et al.*, 1995), *Eucalyptus* (Nesbitt *et al.*, 1995), *Prunus* (Warburton and Bliss, 1996), *Quercus* (Kremer and Zenetto, 1997), plums (Shimada *et al.*, 1999), *Anacardium* (Mneney *et al.*, 2001), *Pinus* (Fazekas and Yeh, 2001) and sandal (Suma and Balasundaran, 2004)

2.6.1. Genetic diversity studies in teak

Isozyme studies in teak were carried out by Kertadikara and Prat (1995). In this study, enzyme activities were tested for fourteen different enzymes for reproducible patterns and for genetic analysis of these patterns from each individual. Changtragoon and Szmidt (2000) conducted isozyme and RAPD studies in teak in order to estimate the genetic diversity and outcrossing rates in selected populations from natural and cultivated range.

Nicodemus *et al.* (2005) studied the genetic variation in teak populations of the Western Ghats and Central India using RAPD markers selecting samples from natural populations and plantations. They observed that the Western Ghat population had more diversity than those from Central India. A negative relationship was observed between latitude and withinpopulation diversity. Parthibhan *et al.*, (2005) estimated the genetic distance between seed sources from 30 locations from India, Lao PDR and Bangla Desh using RAPD analysis. The seedlots from one of the Konni population and Uttaranchal population showed the highest genetic distance. High genetic diversity is expected among the teak populations of India considering their origin and wide distribution range in the country.

3. MATERIALS AND METHODS

The studies included in the report were undertaken in different SPAs of teak in Kerala during 2001-2003. The Laboratory experiments were carried out in Kerala Forest Research Institute (KFRI), Peechi, Thrissur, Kerala, while nursery trials were conducted in Central Forest Nursery, Chettikulam, Kerala Forest Department (KFD), Central Circle, Thrissur.

3.1 Study area

A total of 38 SPAs of teak located in five different seed zones, *viz*, Wayanad, Parambikulam, Nilambur, Konni and Achencoil of the State were selected for the study. Among the SPAs, nine each were from Wayanad and Parambikulam, seven Nilambur, ten from Konni and three were from Achencoil seed zones. The locations of SPAs are shown in Figure 3.1. Details of individual SPAs *viz.* SPA code, locality, forest research range, forest division and extent are presented in the Table 3.1.

3.2 Layout of sample plots

Sample plots of size of 40x40 m were laid out randomly during October – November 2001 with sampling intensity of approximately two per cent of the total area of each SPA. The number of total sample plots in each SPA varied from three to five depending upon the extent of the area. All the boundary trees around sample plots were ring marked with red paint. Sign board showing the SPA code and sample plot number was displayed in each sample plot. All the four corners of the sample plots were also demarcated by fixing boundary pegs.

To avoid the edge effect, a minimum distance of 100 m was maintained between the outer boundary of SPAs and boundaries of the sample plots. Between the two sample plots, a minimum distance of 100 m was also maintained depending upon the width and length of SPAs.

Table 3.1. Details of SPAs where the studies were undertaken during 2001-04

SPA Code	Year of establishment	Age in years	Location	Forest division	Extent (ha)
N1	1951	51	Kangirkadavu	Nilambur	13.12
N2	1943	59	Chathamparai	Nilambur	27.04
N3	1944	58	Chathamparai	Nilambur	37.12
N4	1945	57	Chathamparai	Nilambur	16.40
N5	1956	46	Erampadam	Nilambur	11.12
N6	1939	63	Edacode(North)	Nilambur	10.00
N7	1961	41	Sankarancode	Nilambur	79.57
W1	1948	54	Tholpetty	Wayanad North	28.94
W2	1949	53	Tholpetty	Wayanad North	23.56
W3	1953	49	Camp Road	Wayanad North	20.00
W4	1954	48	Camp Road	Wayanad North	20.00
W5	1955	47	Camp Road	Wayanad North	26.00
W6	1958	44	Thettu Road	Wayanad North	25.00
W7	1962	40	Tholpetty	Wayanad North	31.05
W8	1963	39	Tholpetty	Wayanad North	10.95
W9	1939	63	Thettu Road	Wayanad North	14.00
P1	1943	59	Thoonakadavu	Parambikulam WLD	30.00
P2	1944	58	Thoonakadavu	Parambikulam WLD	35.00
P3	1945	57	Thoonakadavu	Parambikulam WLD	40.00
P4	1945	57	Thoonakadavu	Parambikulam WLD	10.00
P5	1946	56	Thoonakadavu	Parambikulam WLD	40.00
P6	1947	55	Thoonakadavu	Parambikulam WLD	40.00
P7	1953	49	Peruvari	Parambikulam WLD	40.00
P8	1954	48	Peruvari	Parambikulam WLD	60.00
P9	1955	47	Anapady	Parambikulam WLD	27.00
K1	1947	55	Kummanoor	Konni	8.40
K2	1949	53	Kummanoor	Konni	12.60
K3	1950	52	Vattapara	Konni	12.54
K4	1955	47	Nadavathumoozhy	Konni	11.22
K5	1956	46	Nadavathumoozhy	Konni	10.82
K6	1960	42	Kadiyar	Konni	15.88
K7	1950	52	Nellidapara	Konni	10.72
K8	1959	43	Kondodi	Konni	4.24
K9	1965	37	Kondodi	Konni	16.72
K10	1963	39	Perunthumoozhy	Konni	10.00
A1	1943	59	Chempala	Achencoil	126.90
A2	1943	59	Achencoil	Achencoil	9.00
A3	1942	60	Achencoil	Achencoil	20.24
				Total	**985.15**

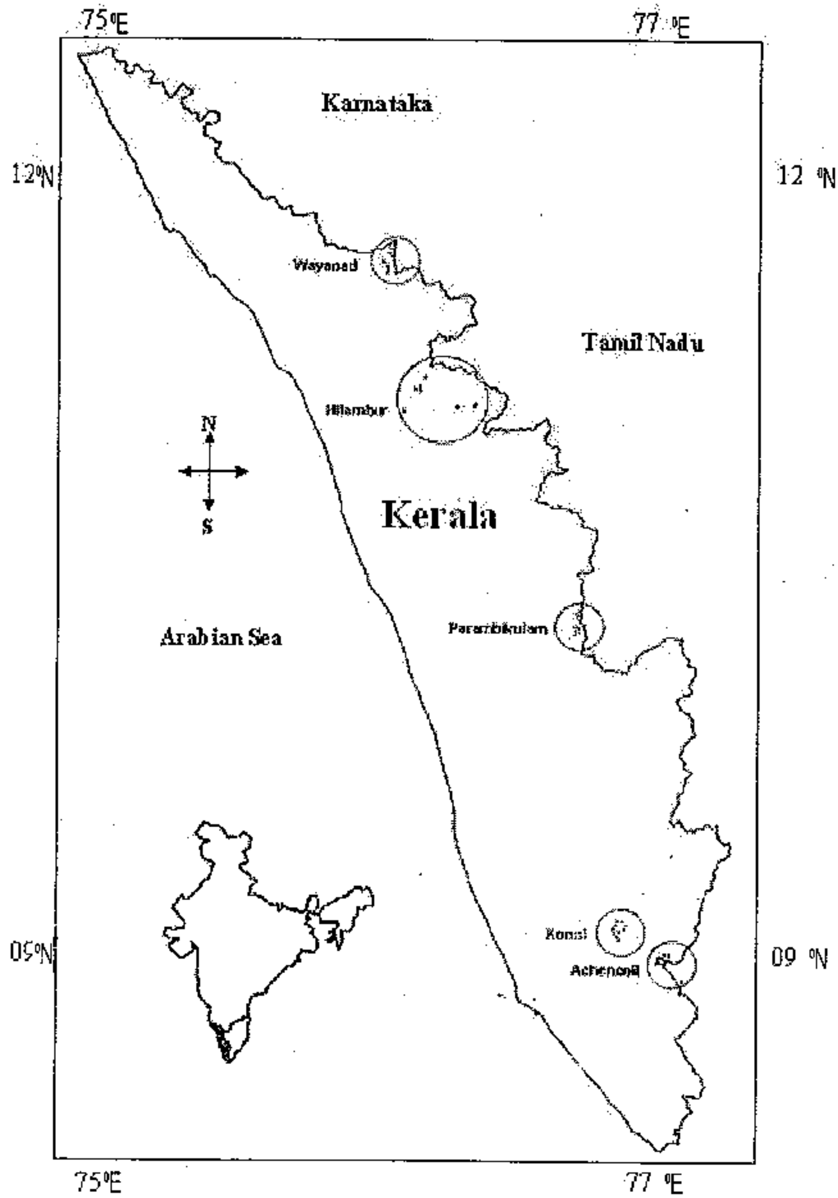


Figure 3.1. Locations of seed production areas of teak in Kerala

3.3 Topography and weather parameters

Geographic location of five seed zones (latitude, longitude, and altitude) were recorded using Global Positioning System is given in (Table 3.2). The rainfall data for the study period *i.e.* from March 2002 to February 2003 was collected from the nearest meteorological stations for all the seed zones and are presented in Figure 3.2.

Table 3.2. Geographic locations: Longitude, latitude and altitude of different teak seed zones

Seed zone	Latitude	Longitude	Altitude (m msl)
Nilambur	11° 17' N	76° 13' E	54-70
Wayanad	11° 58' N	76° 04' E	775-850
Parambikulam	10° 25' N	76° 46' E	544-546
Konni	09° 13' N	76° 51' E	150-170
Achencoil	09° 02' N	77° 07' E	240-252

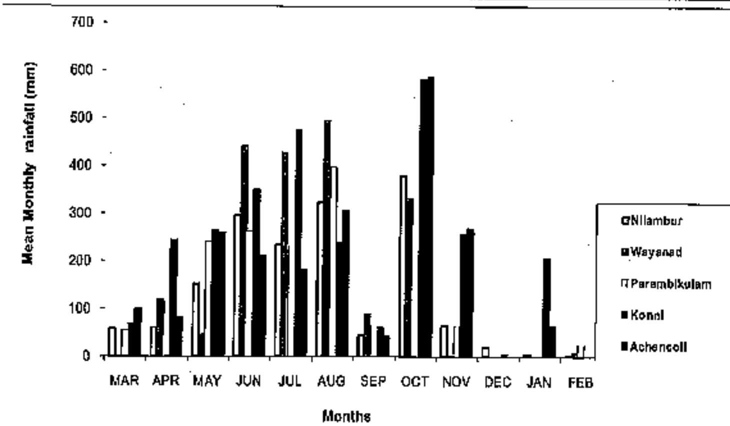


Figure 3.2. Mean Monthly rainfall recorded during study period (March 2002 - February 2003) in different seed zones of teak in Kerala

3.4 Tree growth parameters

The tree parameters such as total number of trees, tree height, clear bole height, GBH, crown diameter, straightness and roundness of stem and general health of each tree in a sample plot were recorded once during 2002. The data were utilized for calculating tree density, top height, tree volume and total volume. Methodology adopted for estimating each tree parameters is as follows:

3.4.1 Total height: Individual tree height was estimated by using Ravi's multimeter adopting prescribed procedure. Mean height of a SPA was calculated by dividing total height of all trees by the total number of trees in the sample plots.

3.4.2 Clear bole height: Defined as the tree height from the bottom of the tree to first developed live branch. This was recorded using Ravi's multimeter. Mean clear bole height (CBH) of a SPA was calculated by dividing total CBH of all trees by the total number of trees in the sample plots.

3.4.3 Girth at breast height: Girth at breast height (GBH) of individual tree was measured by tape of 3m length.

3.4.4 Crop diameter: Crop diameter was calculated taking quadratic mean diameter of the stand corresponding to mean basal area of trees in the plot as follows.

$$\text{Crop diameter} = \bar{d} = \frac{1}{\pi}\sqrt{\frac{\sum_{i=1}^{n} g_i^2}{n}}$$

Where, g_i is the girth at breast height of each tree n is the total number of trees in the plot

3.4.5 Crown diameter: It is the maximum spread of the crown along its two widest diameters. Crown diameter was estimated by taking the average of two perpendicular diameters of the crown by using 15 m tape. Mean crown diameter of a SPA was calculated by dividing total crown diameter of all trees by the total number of trees in sample plots.

3.4.6 Stem form: Physical tree characters such as straightness and roundness of stems were visually estimated and scored according to the criteria used by Rao *et al.* (2001). The scoring was restricted only to clear bole height of trees.

a. Straightness:
   i. Crooked = 1; ii. Wavering with 1 or 2 bends=5; iii Straight=9

b. Roundness:
   i. Heavy fluting=1; Medium fluting=5; Round=9

3.4.7 Stand density: Stand density of trees was recorded by counting all the trees in a sample plot and mean density per ha was calculated for each SPA.

3.4.8 Volume: Individual tree volume was computed according to Nair (1978).

$$V = a + bD + cD^2$$

Where, V = Volume in m^3

D = Diameter at breast height in cm

c= -0.720013

b= 2.808355

a= 1.684682

$r^2 = 0.700$; 'F' ratio = 319.3

3.4.9 Top height: It is defined as "the height corresponding to the mean diameter (calculated from basal area) of 250 biggest diameters (or about 125 trees) per ha as read from height diameter curve". For each sample plot, top height was calculated following Chaturvedi and Khanna (1994) and mean top height for each SPA calculated using top height of sample plots for each SPA.

.4.10 Site quality classes: The site quality classes were assessed referring ll India Site Qualities Table for teak using top height and age of SPAs. (FRI nd colleges, 1970)

.4.11 Site index: It is a measure of the productive capacity of a site. Site ndex curves were developed using the equation given in Sunanda (2004)

$$\ln S = \ln H + 7.41014\left(A^{-1} - A_0^{-1}\right)$$

Where A_0 = Base age which is taken as 50 years in the case of teak

H = Top height (m)

S = Site index (m) which is the expected top height at A_0 years.

A= Age in years

.5 Phenological parameters

For each seed production area, fifteen trees per sample plot were tagged t random for phenological study. Observations such as leaf shedding, leaf lushing, flower bud initiation, flowering, fruit set, fruit maturation and fruit all were recorded by visiting each SPA once in 15 days for one calendar year *i.e*, from March 2002 to February 2003). Views of leaf shedding and leaf lushing are shown in Figs.3.3 and 3.4.

.6 Fruit and seed characteristics

The mature fallen fruits were collected from December to May during 001-02 and 2002 - 03. The total fruit yield was estimated by pooling the ruits collected from each sample plot. From the total fruits collected, epresentative samples were taken for each SPA and transported to aboratory for studying the following fruit and seed parameters.

.6.1 Quantitative fruit characteristics

Mature fruits collected from each SPA were used for studying the ollowing fruit parameters.

- Fruit diameter (cm)
- Fruit weight (100 fruits weight in g)

Fig.3.3. A view of leaf shedding in Nilambur teak SPA (N3))

Fig.3.4. A view of leaf flushing in Nilambur teak SPA (N3)

- Fruit yield (kg ha^{-1})
- No. of locules per fruit
- No. of seeds per fruit

3.6.1.1. *Fruit diameter (cm):* Four replications of thirty fruits each were taken from each SPA and the largest diameter was measured to the nearest mm using Vernier caliper.

3.6.1.2. *Fruits weight (g):* Randomly selected eight samples of 100 fruit each for individual SPA were taken to measure 100 fruits weight in gram using a sensitive electronic balance.

3.6.1.3. *Fruit yield (kg/ha):* It was estimated by pooling and then weighing all the fruits collected from sample plots in an SPA and then extrapolating the same for the total area of the SPA.

3.6.1.4. *Number of locules per fruit:* Four replications of thirty fruits each were taken for each SPA and the number of locules per fruit were counted. The final value was calculated by taking average of four replications of thirty fruits each.

3.6.1.5. *Number of seeds per fruit:* Teak fruits generally contain four locules with one ovule per locule. Number of seeds per fruit was calculated by counting number of developed ovules (seeds) in each fruit, after cutting open the fruits by using locally made nut cutter. Four replications of thirty fruits each were taken for each SPA and the number of seeds per fruit was counted and the mean value was worked out by taking average of four replications of thirty fruits each.

3.6.2 Qualitative Fruit Characters

For studying all the qualitative fruit characters, such as nature of calyx, hairiness and splitting, three replications of 30 fruits (Hanumantha *et al.*, 2001a) each were used for each SPA and these characters were scored by visual observations.

3.6.2.1. Nature of calyx: Nature of calyx enclosing the fruit was scored visually as loose, medium and tight (Fig. 3.5). Loose calyx refers to the calyx, which is not closely attached to the fruit except at basal portion, whereas medium calyx refers to calyx that covers the fruit partially *i.e.,* from bottom to middle of the fruit. Calyx that encloses the fruits tightly is termed as tight calyx.

3.6.2.2. Hairiness: Based on the density of hair present on the fruit, visual scoring was done as high, medium and low (Fig. 3.6).

3.6.2.3. Splitting: Number of fruits showing splitting on the fruit wall were recorded and expressed as percentage (Fig. 3.7).

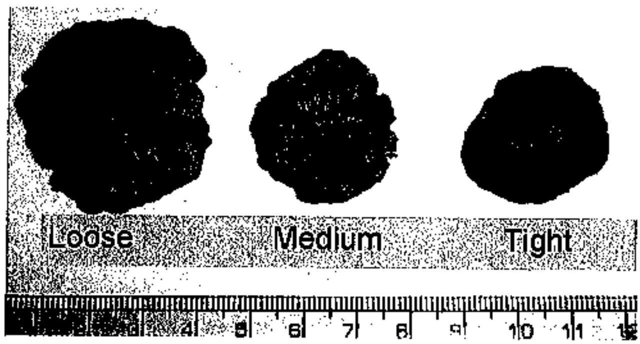


Fig. 3.5. Teak fruits showing different nature of calyx

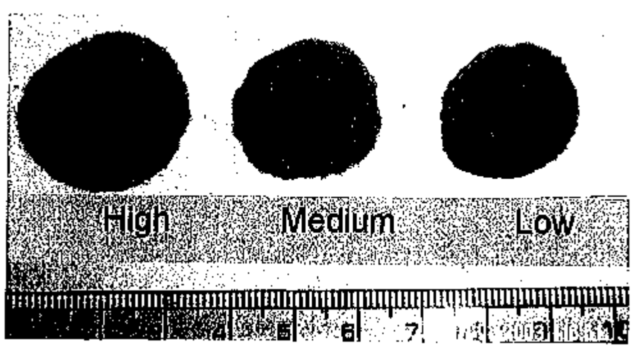


Fig. 3.6. Teak fruits showing different density of hairiness

Fig. 3.7. Teak fruits showing splitting of the fruit wall

3.7 Seed germination

Fruits collected from SPAs were dried and cleaned by removing calyx and other debris. Grading was done for each seed lot using 10 mm sieve. Fruits less than 10 mm were discarded.The graded fruits were subjected to pre-sowing treatment of alternate wetting and drying for seven days (Yadav, 1992; and Chacko *et al.*, 1997). Immediately after pre-sowing treatment;, fruits were sown in germination trays filled with vermiculite (Fig. 3.8). Germination trial was conducted according to the guidelines prescribed by ISTA (1974). There were four replications of 100 fruits each for each SPA. The experimental design followed was Randomized Block Design (RBD) under uniform laboratory conditions. Regular watering was provided once in two days. Daily germination count was recorded up to 45 days. Based on daily germination count, cumulative germination percentage was calculated. The experiment was repeated during the second season using fresh seeds.

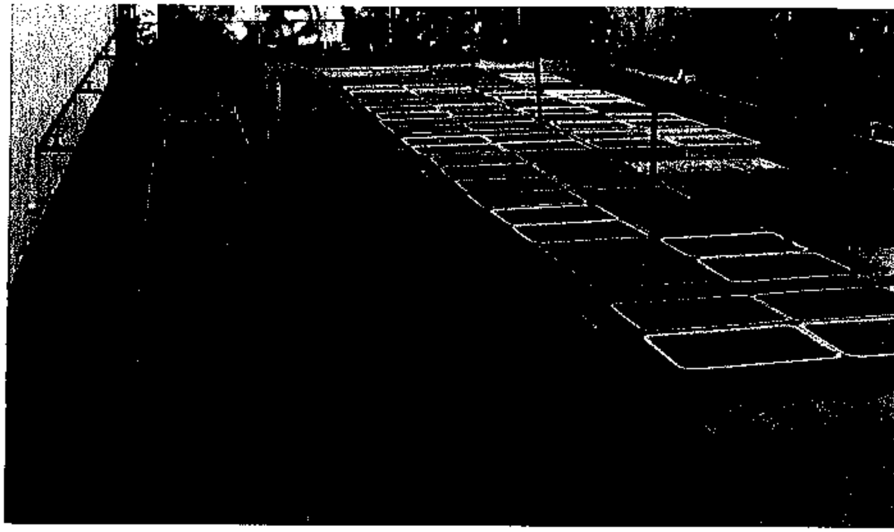


Fig. 3.8. A view of germination trial conducted in the Green house of KFRI

3.8 Seed viability

Since there are no earlier reports suggesting the exact concentration of 2,3,5- triphenyl tetrazolium chloride solution (TTC) for teak seeds, a protocol was standardized using three different concentrations *i.e.,* 0.1, 0.5 and 1.0 per cent for 24 hrs. All the concentrations showed good result. Deep staining was found in higher concentration of 1.0 per cent, while 0.1 and 0.5 per cent also showed light and medium staining, respectively. For teak seeds, even light staining with 0.1 per cent Tz solution was found to be adequate enough to check the seed viability (Fig. 3.9).

Seed viability was studied by carrying out tetrazolium test. For this, two replications of ten seeds each for each SPA were used. Seeds extracted by using locally made nut cutter were soaked in water for 12 hrs. The seed coats of soaked seeds were removed and treated with TTC and kept for 24 hr in dark room.

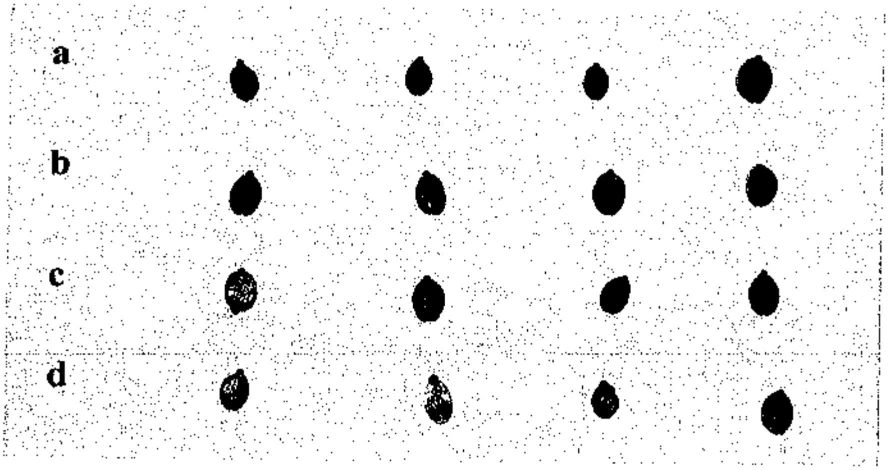


Fig.3.9. Teak seeds showing different degrees of staining (a-d) after subjecting to tetrazolium test
(a- 1.0 % conc., b- 0.5 % conc., c- 0.1 % conc. d- unstained seeds indicating non-viability)

3.9 Seedling growth and physiological parameters in root trainers

3.9.1 Study area

Nursery studies were carried out in the Central Nursery of Kerala Forest Department located at Chettikulam in Chalakudy Division. The area has a warm humid climate with mean annual rainfall of 2700 mm. The mean minimum and mean maximum temperatures of the nursery area during the study period were 21°C and 33 °C, respectively.

3.9.2 Raising experimental seedlings

Teak fruits were collected from the SPAs during December to May 2001-02. Dried and cleaned fruits were subjected to pre-sowing treatment of alternate wetting and drying for seven days as followed in germination trial (Fig. 3.10). Immediately after pre-sowing treatment, fruits were spread on sand bed and covered with wet gunny bags. The seed beds were irrigated daily. Pre-germinated seeds (Fig. 3.11) were handpicked and dibbled in root trainers filled with potting mixture. The block type root trainers of 24 cells with cell capacity of 150 cc were used. The potting mixture consisted of sieved compost, sieved sand, sieved soil and burnt rice husk mixed in the proportion of 65:20:10:5 by volume. De-oiled neem cake 10 kg, Phorate insecticide (0.25 kg), Dithane M 45 (0.2 kg) and single super phosphate (4.5 kg) were also added to the one cubic meter potting mixture (Prabhu, 1998) (Gunaga *et al.*, 2005).

For nursery trial, four replications of forty-eight seedlings (two root trainer blocks of 24 cells) were used following randomized block design (RBD). The root trainer cells dibbled with pre-germinated seeds were kept in shade house (50% shade) for thirty days (Fig.3.12). Later, they were shifted to hardening area and retained upto 90 days for recording observations.

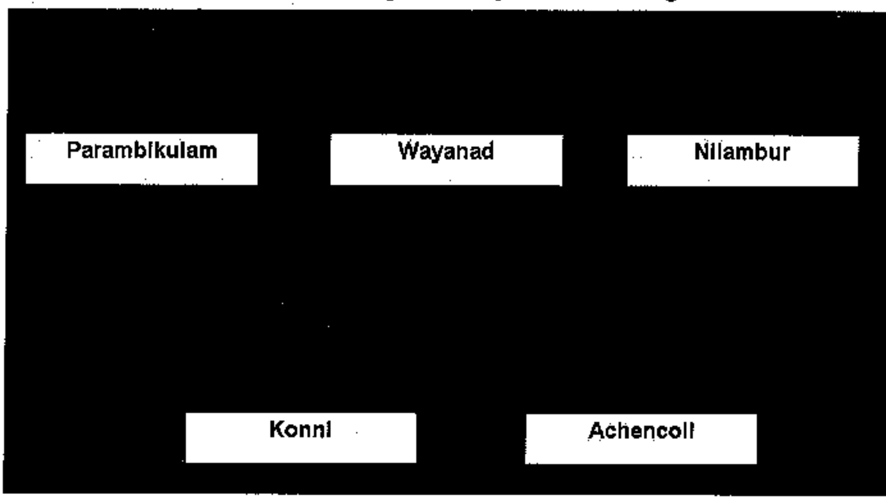


Fig. 3.10. Seeds after pre sowing treatment

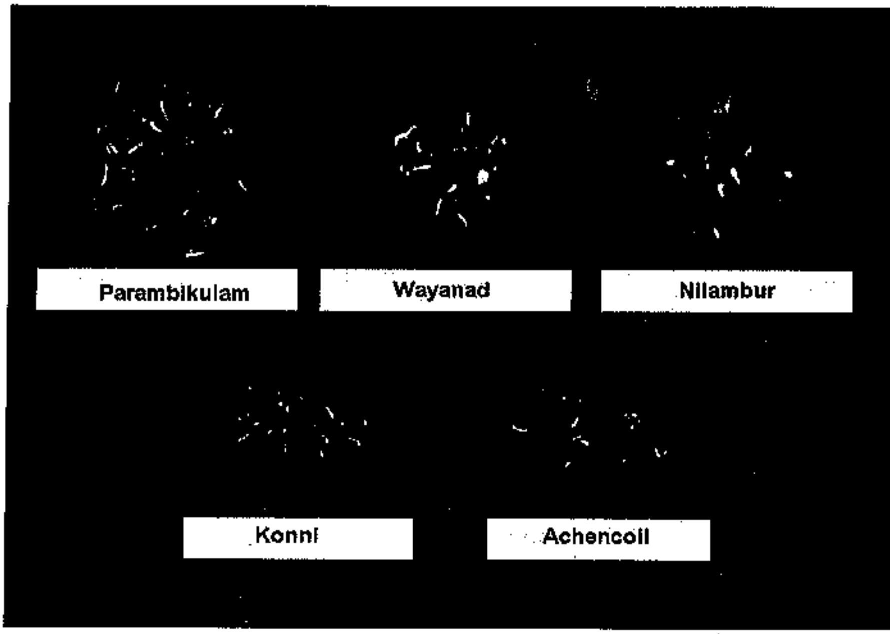


Fig. 3.11. Pre germinated seeds ready for dibbling

Fig. 3.12. Root trainers dibbled with pre-germinated teak seeds in Chettikulam nursery

3.9.3 Seedling growth parameters

The seedling growth parameters such as seedling height and basal diameter were recorded at 30, 60 and 90 days after dibbling. While the heights of all the seedlings were measured, only 20 percent of the total seedlings were used for recording basal diameter.

3.9.4 Leaf area and seedling biomass

Leaf area was measured at the age of 3 months and seedling biomass was estimated at 30, 60 and 90 days from date of dibbling.

Leaf area was estimated by dry weight method adopting the following equation.

$$Y = 31.605\,X + 13.805$$

Where, Y= leaf area (cm^2), X= dry leaf weight (g), R^2= 0.925

This equation was derived using randomly selected seedlings (n=25) from seed lots of all seed zones. Leaf area and dry weight of a seedling was measured using only mature leaves. Correlation between leaf area and dry weight of seedlings was estimated using their relationship curve for developing regression equation.

To find out average sized seedlings to be used in destructive sampling for biomass estimation, a seedling height and basal diameter curve was developed using seedlings randomly selected from the nursery stock. Seedlings for destructive sampling were drawn randomly using the average value from the curve. Destructive sampling from four replications of four seedlings each was done at monthly interval up to 90 days. Biomass measurements such as fresh and dry weight (oven dry weight at 85°C, till dry weight remains constant) of shoot and root of seedlings were recorded to the nearest 0.001 g using an electronic balance.

3.9.5 Seedling growth indices

3.9.5.1. Shoot to Root ratio: It is the ratio between seedling heights measured from collar region to tip of the shoot divided by the root length measured from the collar region to the tip of the tap root.

3.9.5.2. Sturdiness Quotient: It is the ratio between seedling height and the collar diameter measured at a given point of time. Here, final seedling height and collar diameter were measured at the age of three months.

SQ= H/D .... (Thompson, 1985)

Where, H= final shoot height (cm)

D= Final stem diameter (mm)

Lower SQ value indicates the sturdiness of seedling.

3.9.5.3 Dickson Quality index: It is calculated using the following formula for three month old seedlings.

$$DQI = \frac{\text{Total dry weight of seedling (g)}}{(SQ+[\text{Shoot dry weight (g)}/\text{Root dry weight (g)}])}$$ (Dickson *et al.*,1960)

3.9.6 Chlorophyll fluorescence parameters

To monitor and characterise photosynthetic events, which ultimately determine the vigour of seedlings, a chlorophyll fluorescence study was carried out.

A portable chlorophyll fluorometer (Plant Efficiency Analyser, Handy PEA, Hansatech, and King's Lynn, UK) was used to measure different chlorophyll fluorescence parameter such as Fv/Fm, Et_0/Rc, Di_0/Rc, Et_0/CS_0 and PI (ABS) and data were recorded in the computer using the software of chlorophyll fluorescence meter. The details of each parameter are presented in the Table 3.3.

Table 3.3. Details of the equation or index

Sl. No.	Equation/ Index	Details of the equation or index
1	Fv/Fm	This is a measure of the intrinsic (or maximum) efficiency of Photosystem II (PSII) (*i.e.* the quantum efficiency if all PSII centres were open. Fv = Fm-F0, where Fm is the maximum fluorescence and F0 is the minimal or initial level of fluorescence before excitation.
2	ET_0/RC	It is a specific flux and it estimates the electron transport capacity per reaction centre. In an efficient leaf this value should be high.
3	DI_0/RC	It is a specific flux and it is defined as 'the ratio of total dissipation to the amount of active reaction centres'. Its value increases due to the high dissipation of the inactive reaction centres.
4	ET_0/CS_0	It is a one of the phenomenological fluxs estimating electron transport capacity at the leaf cross section
5	PI_{ABS}	Another parameter, namely, the Performance Index (PI) is a synthesized parameter, taking into account several other parameters as can be seen from the following equation. $PI = \frac{ABS}{CS} \cdot \frac{RC}{ABS} \cdot \frac{TR}{DI} \cdot \frac{ET}{dQ_A/dt}$ (Strasser *et al.*, 1999) where, *ABS* = Photon flux absorbed by chlorophyll a *CS* = Cross-sectional area of the leaf *RC* = Number of reaction centres *TR* = Trapping flux of energy *DI* = Dissipated photon flux *ET* = Energy flux corresponding to electron transport dQ_A/dt = Flux of excitons trapped per reaction centre The PI is expected to be high for an efficiently functioning leaf.

Seedlings produced from all SPAs were utilized in this experiment. For each SPA, four replications of four seedlings each were selected randomly and one fully matured leaf from each seedling was selected to estimate the above-mentioned chlorophyll fluorescence parameters.

Before recording observations, all seedlings were transferred to a shade house to homogenise the condition for about one hour. This was mainly to reduce environmental changes in the yield of chlorophyll fluorescence (Strasser *et al.*, 1999).

3.10 Soil analysis

To study the effect of soil parameters on performance of SPAs, soil analyses were carried out. The soil samples were collected from standard pit of size 100 cm x 30 cm x 60 cm. There was one pit per sample plot. Soil samples were collected from each pit from three different depths *viz.*, 1-20 cm, 21-40 cm and 41-60 cm, considered as layer 1, layer 2 and layer 3, respectively. For each SPA, samples were pooled layer wise and one kg composite sample was drawn, labeled and used for physical and chemical analysis. The procedure followed for analysis is given below.

3.10.1 Physical properties

3.10.1.1 Particle size separates: (Hydrometer method) A dispersant solution was prepared by dissolving 20g Sodium carbonate in one litre of

distilled water. To 100g of soil, 100 ml dispersant was added and the mixture was kept overnight. The mixture was transferred to a stirring cup, and after adding water the mixture was stirred for two minutes at 4000 rpm. The suspension was transferred to a glass cylinder (380 mm height and 62 mm dia) and made up to one liter. The suspension was stirred with a plunger for 10 s. If frothing occurred at the top of the suspension, two drops of amyl alcohol were added after stirring. At the fourth minute, the density of the suspension was measured with a standardized hydrometer. Again the suspension was stirred and time noted. The density of the suspension was measured at 300th minute and the measurement noted. 100 ml dispersant was made to one liter and the reading was observed. This is the blank reading. The blank reading is subtracted from the observed reading.

Sand (%) = 100- 4th minute reading

Silt (%) = 4th minute reading – 300th minute reading

Clay (%) = 300th minute reading

3.10.1.2. Bulk density: The weight of the soil core of known volume is determined after air-drying and the bulk density was calculated by using the following formula of Sankaran (1966).

Bulk density (g/cm^3) = Soil wt. / Soil volume

3.10.1.3. Maximum water holding capacity (WHC): One hundred grams of soil was taken in plastic container of 8 cm diameter and 9.5 cm height, with holes drilled at the bottom being covered by a No. 1 filter paper. The container was taped 20 times from a height of 2 cm. It was then kept in a trough for 24 hr with sufficient water to saturate the soil column. After 24 hr the soil was drained and the weight of moist soil determined. (Sankaran , 1966)

Max. WHC (%) = [(weight of moist soil –100) x 100] /100

3.10.1.4. Soil pH: Twenty five ml of water was added to 10 g of soil and the suspension was stirred three times during the next 30 minutes. After allowing the suspension to settle for 30 minutes the pH was read with the glass electrode just touching the soil layer.

3.10.2 Chemical Properties

3.10.2.1. Organic carbon: Ten ml 1N potassium dichromate ($K_2Cr_2O_7$) and 20 ml of conc. Sulphuric acid were added instantly to 0.5 g of soil. After 30 minutes 150 ml water and Ortho Phenanthroline indicator were added. The mixture was titrated with 0.5 N Ferrous sulphate ($FeSO_4$). At the end point green flashed to red. A blank was also run (Walkley and Black, 1934). The organic carbon content was calculated as given below.

$$O.C\ (\%) = \frac{[(\text{ml of } FeSO_4 \text{ blank} - \text{ml} FeSO_4 \text{ sample}) \times N\ FeSO_4 \times 0.003 \times 100]}{\text{Sample wt.}}$$

3.10.2.2. Total N: 0.5 g soil was weighed and digested at high temperature with salicylic acid and sulphuric acid mixture. Potassium suplhate mixture acts as catalyst .Once the digestion mixture was clear, the contents were transferred to distillation apparatus and digested with excess alkali. The ammonia liberated was collected in excess of boric acid and estimated by titerating with standard solution of sulphuric acid. The total Nitrogen was calculated as below.

Total Nitrogen = (Titer value x14x 100)/ (1000x 0.05) ----Jackson (1958)

3.10.2.3. Available P: Fifty ml of Brays reagent (0.03N Ammonium fluoride (NH_4F) + 0.025 N Hydrochloric acid) was added to 5g of soil and shaken for 5 minutes and filtered through Whatman No. 42 filter paper. 5 ml aliquot of the extract was pipetted into a volumetric flask and carefully acidified with 5N sulphuric acid to pH 5. To avoid interference of fluorine, 7.5 ml of 0.8 m boric acid was added to the extract followed by 4 ml of coloring reagent (ascorbic acid in ammonium molybdate and antimony potassium tartarate). The solution was made up to the mark. After shaking colour was allowed to develop for 10 minutes. The intensity of blue colour was read in a spectrophotometer at 660 nm. Concentration of available P was determined by comparison with standard solutions

3.10.2.4. Available K, Ca, Na and Mg

Twenty-five ml of 1N ammonium acetate was added to 5 g of soil and shaken for 5 minutes and filtered through Whatman No.1 filter paper. The extract obtained was used for determination of available K, Ca, Mg and Na.

Available K: Available K in the extract was determined by a flame photometer by comparison with standard potassium chloride solution(Black 1965).

Available Na: Available Na in the extract was determined by a flame photometer by comparing with standard sodium chloride solution (Black, 1965).

Available Ca: Three ml of 5 percent Hydroxyl ammine, 5 ml of potassium ferrocynide and 4 ml 10 percent potassium hydroxide solution were added to 5ml of the sample solution. A few drops of murexide indicator was also added and titrated against 0.01N EDTA till a blue end point was obtained (Black, 1965). The available calcium content of soil was calculated as given below.

Available Ca = Titer value x 0.02

Available Ca and Mg: Five ml of K_4FeCN_6 and 10 ml of buffer solution (ammonium chloride- ammonium hydroxide buffer of pH 10) followed by a few drops of solochrome black T indicator was added to 5 ml of the sample solution and titrated against 0.01N EDTA solution until a pure blue color was obtained (Black ,1965) The available magnesium content of soil was calculated as given below.

Available Mg = (Titer value of Ca and Mg - Titer value of Ca) x 0.02

Variation between seed zones with respect to physical and chemical properties was studied using layer-wise data from SPAs within each seed zone. For examining the similarity among SPAs with respect to soil parameters, a cluster analysis was carried out taking SPA as entities and soil parameters as characters. Clustering was done using average linkage method and Euclidian distance as distance measure.

3. 11 RAPD analysis to estimate the genetic variation

3.11.1 Sample collection

To study the genetic variation among and within seed zones, two sets of studies were conducted using RAPD analysis. The first study comprised two SPAs from each of the four seed zones (excluding Achencoil seed zone) totaling 8 SPAs. These were 1944 and 1945 year SPAs (N3 and N4) from Nilambur seed zone, 1939 and 1948 year SPAs (W9 and W1) from Wayanad seed zone, 1943 and 1944 year SPAs (P1 and P2) from Parambikulam seed zone, 1950 and 1959 year SPAs(K3 and K8) from Konni seed zone. These plantations were selected based on seed germination and seedling vigour. The second study comprised of 26 SPAs (Table 3.4) distributed among all the seed zones *viz.*, N1, N5 and N7 SPAs from Nilambur seed zone, W2, W3, W4, W5, W6, W7 and W8 SPAs from Wayanad seed zone, P4, P5, P6, P7, P8 and P9 SPAs from Parambikulam seed zone, K1, K2, K3, K4, K5, K6, K9 and K10 SPAs from Konni seed zone and A1 and A2 SPAs from Achencoil seed zone. For the remaining four SPAs experimental material for RAPD analysis could not be collected.

3.11.2 DNA extraction and RAPD protocol

For the first set of study comprising 8 SPAs, DNA was extracted from juvenile leaf samples of 9 trees randomly selected from each SPA following the modified CTAB method of Doyle and Doyle (1990). For the second set of study, DNA was extracted as done for the first study; but equal quantities of purified DNA from 15 trees randomly selected from each SPA were mixed to form a composite DNA sample. Thus, there were 26 pooled DNA samples from 26 SPAs for the second set of RAPD analysis. Total quantity of DNA from each sample was estimated using U-V spectrophotometer (Genova, UK) at A_{260} (1OD=50 $\mu g\ ml^{-1}$).

Table 3.4. List of SPAs used for collection of DNA samples

Sl. No.	SPA code	Year of establishment	Location
1.	**N1**	1951	Kangirkadavu
2.	**N3**	1944	Chathamporai
3.	**N4**	1945	Chathamporai
4.	**N5**	1956	Erampadam
5.	**N7**	1961	Sankarncode
6.	**W1**	1948	Tholpetty
7.	**W2**	1949	Tholpetty
8.	**W3**	1953	Camp Road
9.	**W4**	1954	Camp Road
10.	**W5**	1955	Camp Road
11.	**W6**	1958	Thettu Road
12.	**W7**	1962	Tholpetty
13.	**W8**	1963	Tholpetty
14.	**W9**	1939	Thettu Road
15.	**P1**	1943	Thoonakadavu
16.	**P2**	1944	Thoonakadavu
17.	**P4**	1945	Thoonakadavu
18.	**P5**	1946	Thoonakadavu
19.	**P6**	1947	Thoonakadavu
20.	**P7**	1953	Peruvari
21.	**P8**	1954	Peruvari
22.	**P9**	1955	Anapady
23.	**K1**	1947	Kummanoor
24.	**K2**	1949	Kummanoor
25.	**K3**	1950	Vattapara
26.	**K4**	1955	Nadavathumoozhy
27.	**K5**	1956	Nadavathumoozhy
28.	**K6**	1960	Kadiyar
29.	**K7**	1950	Nellidapara
30.	**K8**	1959	Kondodi
31.	**K9**	1965	Kondodi
32.	**K10**	1963	Perunthumoozhy
33.	**A1**	1943	Chempala
34.	**A2**	1943	Achencoil

3.11.3 Polymerase chain reaction (PCR)

PCR-RAPD analysis was carried out using the following six primers.

Primer	Nucleotide sequence
OPB 01	5'-GTTTCGCTCC-3'
OPB 06	5'-TGCTCTGCCC-3'
OPB 07	5'-GGTGACGCAG-3'
OPB 08	5'-GTCCACACGG-3'
OPB 10	5'-CTGCTGGGAC-3'
OPE 04	5'-GTGACATGCC-3'

These six primers were selected from forty primers of OPB and OPE series (Operon Technologies, Alameda, CA), based on the number and reproducibility of amplification products. DNA was amplified in 25µl reaction mixtures containing 100-125 ng of template DNA, 100 µM each of dATP, dTTP, dCTP and dGTP, 1.5 units of Taq DNA polymerase, 1µl (250 ng) of each primer and 5µl Taq buffer with 1.5 mM $MgCl_2$ (Genei, Bangalore). The incubation mixture was overlaid with one or two drops of mineral oil (Genei, Bangalore) and subjected to 45 cycles of amplification in PTC-100 Thermal Cycler (MJ Research Inc., USA), each of 60 S denaturation (94° C), 60 S annealing (36° C) and 120 S extension (72° C). The last cycle was followed by incubation for 10 minutes at 72° C.

3.11.4 Separation and visualization of the amplification products

The PCR amplification products were electrophoresed on 1.5 % horizontal agarose gel (Sigma, USA) in TBE buffer (40 mM Tris-borate, 1 mM EDTA, pH 8.0). After the completion of electrophoresis, the gel was stained with ethidium bromide and bands were compared with a 100-bp DNA ladder (Genei). The gels were documented using Kodak Digital Science Electrophoresis Documentation and Analysis System 120 (Kodak, USA).

3. 12. Ranking of teak SPAs in Kerala

Ranking of SPAs was done using the result of four important parameters studied *viz.*, fruit production, germination percentage, Dickson quality index and Performance index, which have direct bearing on the quantity and quality of seeds produced in an SPA and quality of the nursery stock produced in nurseries, leading to enhancement of productivity of plantations. While ranking, equal weightage was given to all the above parameters. Ranking Index was developed using summation of proportion values of fruit production, germination percentage, Dickson quality index and Performance index. Ranking of SPAs within the seed zones was also done as a guideline to forest department for collecting seeds from the better performing SPAs within the seed zones. The seed zones in the state have also been ranked considering the mean values of above parameters for each seed zone.

3.13 Statistical analysis

All the data recorded on tree, fruit, seed, seedlings and soil characters were subjected to nested analysis of variance using SAS software so as to identify the variation between different seed zones and SPAs within the seed zones. The structure of nested ANOVA is given in the Table 3.5.

Table 3.5. Structure of Nested ANOVA

Source	df	Sum of squares	Mean sum of squares	F
Seed zone	a-1	SSR	MSR	MSR/MSSPA
SPA within Seed zone	$\sum_{i=1}^{a} b_i - a$	SS(SPA)	MS(SPA)	MSSPA/MSE
Error	$\sum_{i=1}^{a}\sum_{j=1}^{b_i} n_{ij} - \sum_{i=1}^{a} b_i$	SSE	MSE	
Total	$\sum_{i=1}^{a}\sum_{j=1}^{b_i} n_{ij} - 1$	SST		

Where Y_{ijk} be the measurement of kth plot in jth SPA in ith seed zone

$i = 1, 2, \ldots a,$
$j = 1, 2, \ldots b_i$
$k = 1, 2, \ldots n_{ij}$

$$\text{Where SST} = \sum_{i=1}^{a}\sum_{j=1}^{b_i}\sum_{k=1}^{n_{ij}} Y_{ijk}^2 - CF$$

$$\text{where } CF = \frac{\sum_{i=1}^{a}\sum_{j=1}^{b_i}\sum_{k=1}^{n_{ij}} Y_{ijk}}{\sum_{i=1}^{a}\sum_{j=1}^{b_i} n_{ij}}$$

$$\text{SSR} = \sum_{i=1}^{a}\frac{\left(\sum_{j=1}^{b_i}\sum_{k=1}^{n_{ij}} Y_{ijk}\right)^2}{\sum_{j=1}^{b_i} n_{ij}} - CF$$

$$\text{SS(SPA)} = \sum_{i=1}^{a}\sum_{j=1}^{b_i}\frac{\left(\sum_{k=1}^{n_{ij}} Y_{ijk}\right)^2}{n_{ij}} - \sum_{i=1}^{a}\frac{\left(\sum_{j=1}^{b_i}\sum_{k=1}^{n_{ij}} Y_{ijk}\right)^2}{\sum_{j=1}^{b_i} n_{ij}}$$

$$\text{SSE} = \sum_{i=1}^{a}\sum_{j=1}^{b_i}\sum_{k=1}^{n_{ij}} Y_{ijk}^2 - \sum_{i=1}^{a}\sum_{j=1}^{b_i}\frac{\left(\sum_{k=1}^{n_{ij}} Y_{ijk}\right)^2}{n_{ij}}$$

Mean sum of squares for each source is obtained by dividing the sum of squares by their corresponding degrees freedom.

$$MSR = SSR/(a-1)$$

$$MS(SPA) = SS(SPA)/\left(\sum_{i=1}^{a} b_i - a\right)$$

$$MSE = SSE/\left(\sum_{i=1}^{a}\sum_{j=1}^{b_i} n_{ij} - \sum_{i=1}^{a} b_i\right)$$

As per the assumptions of analysis of variance, data were transformed wherever necessary. In some cases logarithmic transformations were done for normalization. In the case of proportions, the observed proportions (p) were subjected to angular transformation to form a new variable $\theta = \sin^{-1}\sqrt{p}$. For converting the new variable to radian scale the new variable was multiplied by 59.27. These new variables were subjected to analysis of variance for finding out the variations among seed zones and also between SPAs.

The resemblance structure of the seed zones was examined on the basis of five seedling traits (seedling height, basal diameter, total dry weight, and leaf area and quality index) through cluster analysis using SYSTAT software packages (SYSTAT Inc., Evanston IL). The distance measure used was Eucleadean distance and the clustering algorithm was single linkage. Similar cluster analysis was carried out for soil analysis also.

For molecular study, the DNA fragment sizes were estimated comparing DNA size markers run on the same gel and the data scored for RAPD analysis. The bands were scored '1' for presence of locus and '0' for absence of the locus for each DNA sample in respect of each primer to create binary data matrices. The data matrices were entered into the population genetic analysis software Popgene version 1.32 package for estimating genetic diversity parameters, and pair-wise comparison of genetic similarity between seed production areas (Yeh *et al.*, 1999). Percentage of polymorphic loci (polymorphic bands per total bands) and gene diversity index (h) with respect to each SPA, and interpopulation differentiation (Gst) were determined. Nei's genetic distance (D) between SPAs was calculated and used to construct UPGMA dendrogram (Nei 1978). Data from pooled DNA samples of 26 SPAs were analyzed separately to get an overall picture of diversity within and between seed zones. Pair-wise genetic similarity coefficients between the 26 SPAs were calculated and the similarity/distance coefficients were used to construct UPGMA dendrogram.

4. RESULTS

4.1 Tree growth parameters

Although commercial teak plantations aim at production of high volume, better quality timber, the Mean Annual Increment (MAI) of teak plantations in Kerala at the rotation age of 60 years is 3.11m^3/ha whereas the potential MAI could be 8.38 m^3/ha (Nair *et al.,* 1996). This indicates that the productivity of teak plantations in Kerala is low in comparison to its potential yield. The overall productivity of teak depends upon the superior quality of planting stock in addition to management practices. The various tree parameters like tree height, clear bole, crop diameter, crown diameter, stem form and stand density have direct bearing on the productivity of teak plantations. Some of these parameters are reported to be inheritable (Nagarajan *et al.*, 1996b; Kumar *et al.*,1997). Ranking of SPAs based on these parameters and utilizing seeds from better SPAs for raising plantations will help to improve the productivity of teak plantations in Kerala.

Considering this, various tree parameters were studied as per the procedures laid down under Materials and Methods and the results are as follows.

4.1.1 Total height, clear bole height, crop diameter and crown diameter

Tree characteristics such as total height, clear bole height, crop diameter and crown diameter showed significant difference among different SPAs (Table 4.1). Overall mean height among SPAs was 22.53 m; SPA- N6 (29.95 m), N3 (29.64 m) and N4 (29.13 m) showed significantly higher tree height in comparison to the rest of the SPAs. Whereas, SPA- W6 (15.71 m), K3 (14.38 m), P7 (14.25 m) and P8 (13.88 m) recorded significantly lower tree height. Apart from other factors this difference could be due to age factor also.

Clear bole height ranged from 4.92 m (W6) to 16.65 m (N7) with overall mean of 9.74 m for all 38 SPAs. Significantly higher clear bole height was observed in SPA- N7 (16.65 m), K8 (16.47 m), K6 (14.69 m) and K5 (14.57 m) in comparison to other SPAs (Table 4.1).

Table 4.1. Tree growth parameters of different SPAs in Kerala

SPA code	Tree height (m)		Clear bole height (m)		Crop diameter (cm)		Crown diameter (m)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
N_1	23.46	0.59	6.61	0.35	38.91	1.21	7.43	0.39
N_2	28.96	0.24	12.86	0.47	44.28	3.12	8.08	0.23
N_3	29.64	0.13	12.89	1.90	41.55	1.99	6.95	0.50
N_4	29.13	0.87	12.14	1.21	44.45	4.04	7.98	0.39
N_5	26.26	0.64	13.19	0.64	34.55	0.47	5.70	0.27
N_6	29.95	0.10	13.10	0.14	49.94	3.46	8.61	0.20
N_7	24.64	0.60	16.65	0.45	39.09	1.74	8.81	0.10
W1	23.49	0.51	7.89	0.68	42.23	1.52	7.25	0.18
W2	21.44	0.53	7.00	0.25	32.45	1.45	6.85	0.16
W3	21.65	0.96	7.11	0.13	35.60	3.28	8.02	0.77
W4	23.02	0.63	7.88	0.51	34.66	1.23	8.65	0.17
W5	23.94	0.68	8.56	0.53	33.06	1.33	8.22	0.17
W6	15.71	1.59	4.92	0.80	31.88	1.26	7.41	0.29
W7	22.08	1.97	8.48	1.24	32.60	0.67	7.57	0.35
W8	22.83	0.28	9.32	0.14	30.44	1.24	7.71	0.17
W9	23.84	0.70	6.11	0.50	47.24	3.50	7.80	0.33
P1	25.98	0.33	8.19	0.52	52.43	2.43	6.96	0.20
P2	24.09	0.29	8.66	0.47	57.01	3.34	7.44	0.25
P3	22.04	0.99	7.12	0.65	51.84	3.31	6.64	0.11
P4	23.68	0.23	7.17	0.70	50.77	1.29	7.14	0.19
P5	24.03	0.35	6.07	0.88	52.94	0.64	7.25	0.08
P6	24.26	0.52	6.54	1.31	57.57	4.72	8.22	0.23
P7	14.25	0.22	5.88	0.85	37.96	1.02	5.78	0.25
P8	13.88	0.09	6.10	0.51	30.79	2.18	5.35	0.16
P9	17.15	1.12	7.62	0.18	42.65	3.60	6.60	0.26
K_1	18.37	0.30	10.06	0.28	48.28	2.41	6.75	0.10
K_2	18.91	0.19	9.58	0.95	43.88	1.22	6.74	0.13
K_3	14.38	0.85	7.90	0.91	40.09	1.43	6.19	0.19
K_4	22.58	1.50	14.10	1.04	37.57	3.41	5.13	0.55
K_5	22.21	1.63	14.57	1.30	38.84	5.35	4.51	0.10
K_6	23.72	0.18	14.69	0.41	40.15	0.24	5.18	0.35
K_7	19.46	1.70	9.57	0.83	50.30	5.33	7.09	0.28
K_8	24.03	0.22	16.47	0.13	43.21	3.48	6.50	0.32
K_9	21.02	0.95	11.13	0.88	42.60	0.32	6.71	0.11
K_{10}	20.41	0.59	10.23	0.17	45.28	1.11	6.87	0.22
A_1	25.19	1.39	11.23	0.82	49.46	4.02	7.46	0.48
A_2	22.21	0.37	10.61	0.72	49.51	3.49	5.76	0.48
A_3	24.20	1.02	11.82	0.12	50.54	4.22	5.52	0.14
Mean±SE	**22.53**	**0.39**	**9.74**	**0.31**	**42.81**	**0.79**	**6.97**	**0.11**
CD @ 5%	**12.53**		**8.26**		**23.42**		**3.34**	
CV (%)	**6.53**		**13.39**		**11.23**		**7.42**	

Overall mean crop diameter for all the SPAs was 42.81 cm, which ranged from 30.44 (W8) to 57.57 cm (P6). Crop diameter in SPAs of Parabikulam and Achencoil seed zone were higher in comparison SPAs of other zones.

The crown diameter ranged from 4.51 m (K5) to 8.81 m (N7) with a mean crown diameter of 6.97 m for all the SPAs (Table 4.1). The mean crown diameter was relatively higher in SPAs of Nilambur (7.65 m) and Wayanad (7.72 m) seed zones in comparison with the SPAs of other seed zones. This variation could be due to age factor along with other factors.

If we consider seed zone, co-efficient of variation was highest for clear bole height (23.75 %) and rest of the parameters showed moderate CV, which ranged between 13.35 (crown diameter) and 23.75 per-cent (Clear bole height; Table 4.2). Among all the seed zones, Nilambur seed zone found to be best, which recorded highest values for tree height (27.44 m), clear bole height (12.49) and crown diameter (7.65 m). Whereas Achencoil (49.84 cm) followed by Parambikulam (48.22 cm) seed zones have recorded highest crop diameter against the overall mean of 42.81 cm.

Table 4.2. Seed zone variation for tree growth parameters

Seed zones	**Tree height (m)**		**Clear bole height (m)**		**Crop diameter (cm)**		**Crown diameter (m)**	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Nilambur	27.44^{a}	0.57	12.49^{a}	0.68	41.83^{ab}	1.31	7.65^{a}	0.24
Wayanad	22.00^{b}	0.54	7.47^{b}	0.30	35.57^{b}	1.16	7.72^{a}	0.14
Parambikulam	21.04^{b}	0.88	7.04^{b}	0.28	48.22^{a}	1.86	6.82^{ab}	0.17
Konni	20.51^{b}	0.58	11.83^{a}	0.55	43.02^{ab}	1.07	6.17^{b}	0.17
Achencoil	23.87^{ab}	0.67	11.22^{a}	0.36	49.84^{a}	1.97	6.25^{ab}	0.36
Mean±SE	**22.53**	**0.39**	**9.74**	**0.31**	**42.81**	**0.79**	**6.97**	**0.11**
CV (%)	**14.74**		**23.75**		**16.42**		**13.35**	

Note: Values superscribed with same letter are not significantly different.

4.1.2 Stem form, stand density and tree volume

Tree stem form as judged from trunk straightness and roundness also showed significant differences among teak SPAs (Table 4.3). Significantly

Table 4.3. Stem form, tree density and tree volume of different SPAs in Kerala

SPA code	Stem form				Stand density (ha)		Tree volume (m^3) Re-transformed	
	Straightness		Roundness					
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
N_1	5.66	0.80	5.78	0.32	133.33	5.51	0.58	0.06
N_2	8.08	0.14	7.32	0.02	129.17	12.67	0.76	0.16
N_3	6.60	0.43	5.80	0.39	177.08	22.05	0.68	0.09
N_4	6.84	0.25	5.35	0.09	139.58	11.02	0.77	0.21
N_5	6.55	0.33	8.03	0.27	162.50	6.25	0.45	0.02
N_6	7.43	0.09	4.97	0.40	118.75	13.01	1.01	0.17
N_7	7.41	0.38	6.75	0.31	175.00	12.50	0.58	0.10
W1	5.58	0.58	7.03	0.15	183.33	9.08	0.69	0.08
W2	5.06	0.29	7.03	0.47	264.58	26.60	0.40	0.09
W3	5.62	0.70	5.84	0.72	250.00	90.64	0.48	0.17
W4	6.24	0.15	6.13	0.23	183.33	10.42	0.45	0.07
W5	5.03	0.32	5.43	0.21	216.67	27.32	0.41	0.08
W6	5.78	0.12	6.02	0.06	225.00	20.09	0.39	0.07
W7	4.27	0.32	6.04	0.35	168.75	16.54	0.40	0.04
W8	5.15	0.14	5.38	0.13	293.75	35.54	0.36	0.07
W9	5.47	0.09	6.09	0.05	143.75	21.95	0.89	0.17
P1	4.63	0.19	4.55	0.49	141.67	11.60	1.14	0.10
P2	6.37	0.46	5.23	0.46	106.25	15.73	1.38	0.14
P3	4.69	0.27	5.00	0.32	141.67	17.05	1.11	0.16
P4	5.00	0.39	4.95	0.20	104.17	7.51	1.06	0.06
P5	5.20	0.20	5.97	0.33	147.92	11.60	1.17	0.02
P6	5.07	0.31	4.49	0.42	95.83	12.67	1.40	0.20
P7	3.96	0.54	4.58	0.63	197.92	15.02	0.55	0.06
P8	5.49	0.28	6.86	0.27	229.17	5.51	0.46	0.18
P9	6.09	0.29	7.26	0.36	168.75	29.54	0.70	0.18
K_1	5.20	0.31	6.93	0.24	120.83	15.02	0.93	0.13
K_2	6.44	0.29	6.63	0.37	122.92	5.51	0.75	0.06
K_3	3.83	0.38	6.33	0.34	108.33	13.66	0.61	0.08
K_4	5.92	0.18	7.89	0.03	135.42	16.27	0.53	0.18
K_5	5.46	0.62	8.11	0.05	147.92	16.27	0.57	0.28
K_6	6.93	0.40	8.41	0.18	154.17	8.33	0.62	0.02
K_7	6.01	0.44	7.62	0.40	110.42	7.51	1.01	0.26
K_8	6.59	0.56	7.66	0.30	137.50	14.43	0.22	1.04
K_9	4.54	0.40	7.59	0.08	160.42	5.51	0.71	0.02
K_{10}	4.44	0.57	7.70	0.40	125.00	0.00	0.81	0.06
A_1	5.68	0.42	8.33	0.53	85.42	2.08	0.99	0.20
A_2	5.56	0.18	7.26	0.22	93.75	15.73	1.00	0.16
A_3	6.13	0.38	7.98	0.21	116.67	12.67	1.08	0.24
Mean±SE	**5.68**	**0.10**	**6.48**	**0.12**	**155.70**	**5.37**	**0.68**	**0.05**
CD @ 5%	**3.03**		**3.24**		**137.76**		**1.38**	
CV (%)	**11.75**		**8.78**		**23.41**		**28.76**	

higher straight trunks were observed in SPA N2 (8.08), followed by N6 (7.43), N7 (7.41) and K6 (6.93). The lowest score of 3.83 was in K3 with a mean of 5.68. In different SPAs stem roundness ranged between 4.49 (P6) and 8.41 (K6) with overall mean of 6.48. The higher score indicates perfect straightness and roundness of the stem, which yield maximum volume of timber.

There was significant difference among SPAs for stand density (No. of stems per ha) and tree volume (Table 4.3). Significantly higher number of stems per ha was observed in SPA- W8 (293.8), followed by W2 (264.6) and W3 (250.0) and lowest in A1 (85.42).

In the case of tree volume, highest value was observed in SPA-P6 (1.4 m^3/tree) and lowest in K8 (0.22 m^3/tree) and mean tree volume was 0.68 m^3/tree. This variation could be due to age factor also along with the other factors. In general, most of the SPAs in Parambikulam seed zone showed higher tree volume except P7 and P8, which are in site quality IV.

Among the seed zones, average stem straightness ranged from 5.16 (Parambikulam) to 6.94 (Nilambur) with overall mean score of 5.68. Whereas trees of Achencoil and Konni seed zones showed significantly higher stem roundness (7.86 and 7.49, respectively) in comparison with other seed zones. Statistically significant difference was also observed among various seed zones for stand density and tree volume (Table 4.4). Higher tree volume (1.02 m^3/tree) and lower tree density (98.61) was recorded in Achencoil seed zone, whereas Wayanad seed zone showed an opposite trend (lowest tree volume of 0.47 m^3 and highest stand density of 214.35/ha). Among all these traits, tree volume and stand density showed highest CV of 38.08 and 29.48, respectively and other traits showed moderate CV (Table 4.3).

Table 4.4. Seed zone variation for stem form, stand density and tree volume

Seed zones	Stem form (in points)				Stand density (ha)		Tree volume (m³)	
	Straightness		Roundness				Re-transformed mean	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Nilambur	6.94[a]	0.21	6.29[b]	0.25	147.92[b]	6.33	0.67	0.07
Wayanad	5.36[b]	0.14	6.11[b]	0.14	214.35[a]	13.68	0.47	0.06
Parambikulam	5.16[b]	0.17	5.43[b]	0.22	148.15[b]	9.31	0.93	0.08
Konni	5.54[b]	0.21	7.49[a]	0.14	132.29[b]	4.37	0.63	0.12
Achencoil	5.79[ab]	0.19	7.86[a]	0.24	98.61[b]	7.50	1.02	0.10
Mean ±SE	**5.68**	**0.10**	**6.48**	**0.12**	**155.7**	**5.37**	**0.68**	**0.05**
CV (%)	**16.40**		**14.39**		**29.48**		**38.08**	

Note: Values superscribed with same letter are not significantly different;
Values superscribed with different letters are significantly different

4.1.3 Top height, site quality and site index

Top height of different SPAs (Table 4.5) ranged from 15.2 (P8) to 33.5 m (N3). Such variation could be due to variation in age, soil and climatic factors of the site. Using top height and age of the SPA, site quality was assessed using all India site quality Table (FRI & Colleges, 1970). Out of the 38 SPAs only 13 SPAs fall in site quality II, 20 SPAs in site quality III and 5 SPAs in site quality IV (Table 4.5) except one SPA (N1) rest of the SPAs in Nilambur seed zone were in site quality II.

Site index, which is a measure of productivity of site, ranged from 19.33 (P8) to 39.81 (N3). Considering top height and site index, Nilambur seed zone recorded maximum values (mean top height of 91.66 m and mean site index of 37.05), followed by Achencoil (mean top height of 79.03 m and mean site index of 31.47).

Table 4.5. Top height, site quality and site index of different SPAs in Kerala

SPA code	Top height (ft)	Site Quality	Site index (m)
N_1	77.96	III	31.68
N_2	96.12	II	38.30
N_3	99.69	II	39.81
N_4	96.88	II	38.77
N_5	88.96	II	36.73
N_6	99.16	II	39.20
N_7	82.83	II	34.88
W1	79.00	III	31.85
W2	74.96	III	30.30
W3	73.68	III	30.12
W4	77.56	III	31.81
W5	81.55	II	33.55
W6	54.52	IV	22.67
W7	75.12	II	31.77
W8	79.06	II	33.60
W9	79.70	III	31.50
P1	86.27	II	34.38
P2	79.85	III	31.89
P3	74.03	III	29.63
P4	78.41	III	31.38
P5	79.93	III	32.07
P6	80.02	II	32.18
P7	47.84	IV	19.56
P8	47.14	IV	19.33
P9	57.71	III	23.75
K_1	60.73	IV	24.42
K_2	62.52	III	25.27
K_3	48.22	IV	19.54
K_4	76.15	III	31.33
K_5	75.76	III	31.28
K_6	79.41	II	33.29
K_7	69.58	III	28.20
K_8	80.33	II	33.54
K_9	70.89	III	30.44
K_{10}	67.42	III	28.65
A_1	84.09	III	33.51
A_2	73.36	III	29.23
A_3	79.63	III	31.66

4.2 Phenological parameters

Information on different phenological phases in teak such as leaf shedding, leaf flushing, flower bud initiation, flowering, fruiting and fruit fall is essential for forest resource managers for planning silvicultural operations, genetic thinning and cultural operations like weeding and soil working. This information is also important to take up timely measures for fire control and prophylactic measures against pest and diseases. Information on fruit maturity and fruit fall are highly essential for timely collection of fruits as well as for planning large-scale commercial nursery operations.

Observations recorded on different phenological phases in teak SPAs are as follows.

4.2.1 Nilambur seed zone

Flowering in Nilambur seed zone started during first week of July, which extended up to last week of August, peak flowering occurred during August. Fruit set started in the third week of July and fruit maturation completed during second week of November. Fruit fall started during the following January and it took about four months for complete fruit fall. Leaf shedding started during the last week of December and continued up to third week of February. Total duration of leaflessness was around 50 days. Leaf flushing started during second week of March and completed in second week of June. There were some variations between SPAs of Nilambur seed zone for different phenological phases. The diagrammatic representation of phenological cycles of teak in Nilambur seed zone is shown in Figure 4.1.

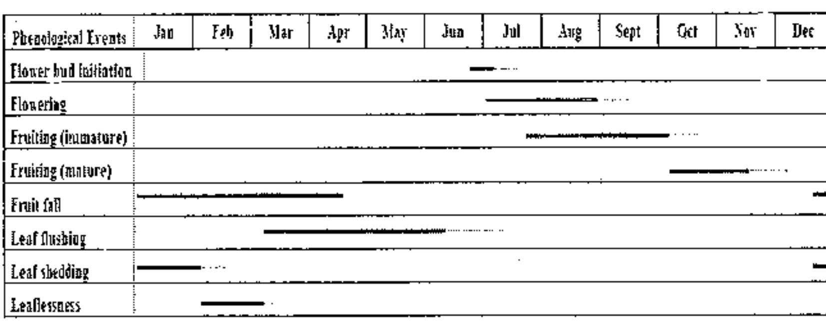


Figure 4.1. Phenology of teak in different SPAs of Nilambur seed zone

4.2.2 Wayanad seed zone

Flower bud initiation in most of the SPAs in Wayanad seed zone started during the second week of May and continued till second week of June. Duration of flowering was about two months from second week of June to third week of August. Peak flowering occurred during July. Duration of fruit maturation was about five months from middle of June to middle of November. Leaf shedding started from the middle of December and continued up to middle of February, with 40 days leaflessness period between February and March. Leaf flushing started during end of March and completed within two months. The diagrammatic representation of phenological cycles of teak in Wayanad seed zone is shown in Figure 4.2.

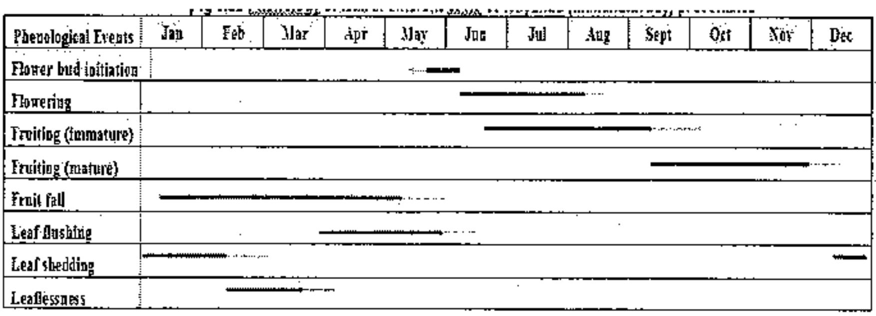


Figure 4.2. Phenology of teak in different SPAs of Wayanad seed zone

4.2.3 Parambikulam seed zone

Trees of Parambikulam seed zone started flowering during the last week of June and it continued till August end with peak flowering recorded between second week of July and first week of August. About 5 months duration was taken to complete fruit development, *i.e.*, from fruit set (second week of July) to fruit maturity. A view of profuse flowering of teak SPA (P2) in Parambikulam seed zone is shown in Figure 4.5. Peak fruit fall occurred during February and March. Leaf shedding started from third week of November and extended up to January. The total period of leaflessness was about thirty days. Leaf flushing began in the third week of February and took around 80 days to complete leaf expansion. The diagrammatic representation of phenological cycles of teak in Parabikulam seed zones is shown in Figure 4.3.

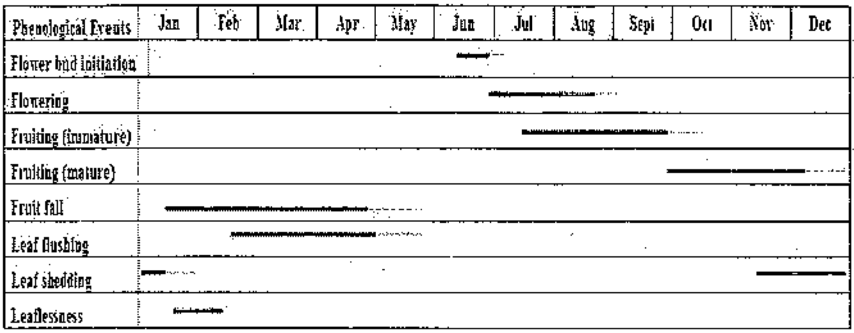


Figure 4.3. Phenology of teak in different SPAs of Parambikulam seed zone

4.2.4 Konni and Achencoil seed zones

Since these two seed zones are located closely they were studied together for different phenological phases. In Konni and Achencoil seed zones flower bud initiation started in May and flowering occurred during third week of May to second week of July. Total duration of fruit maturation was about three months from fourth week of August till third week of November. Leaf flushing started from January and continued till first week April. Duration of leaflessness was less in Konni and Achencoil seed zones, which was only for 10 days. The diagrammatic representation of phenological cycles of teak in Konni and Achencoil seed zones is shown in Figure 4.4. A general view of flowering, fruiting and maturity of fruits in Konnii seed zone (K3) is shown in Figure 4.6.

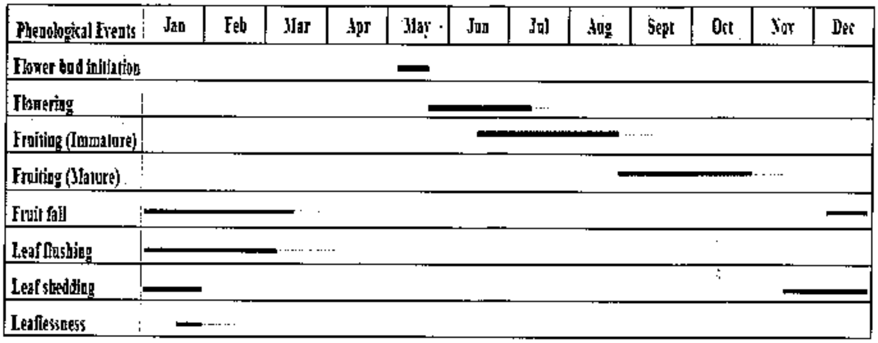


Figure 4.4. Phenology of teak in different SPAs of Konni and Achencoil seed zone

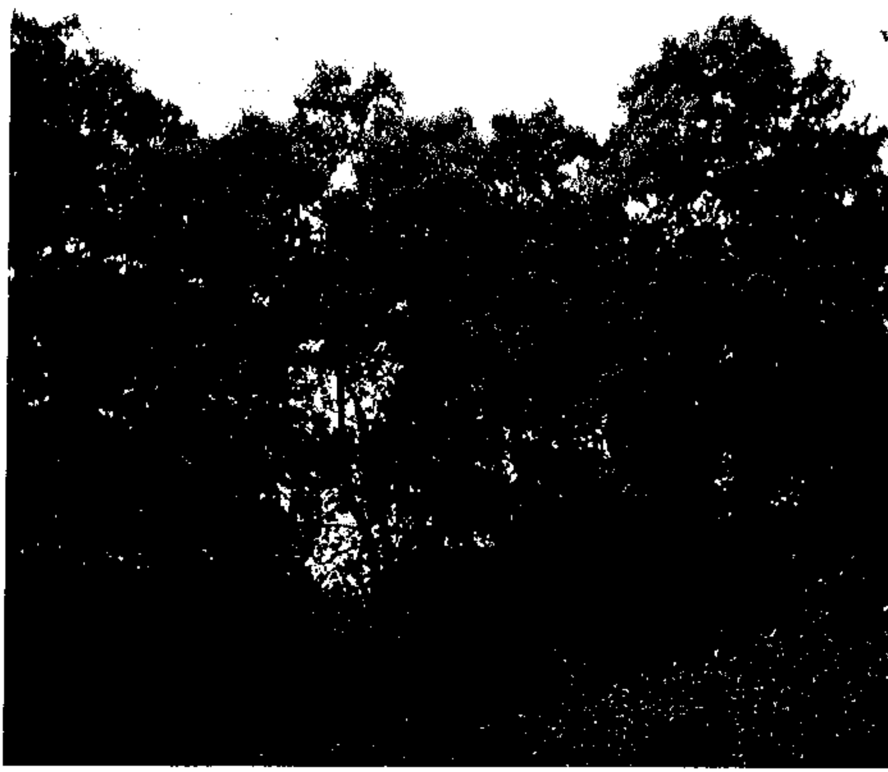
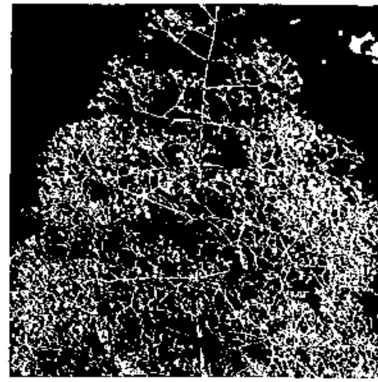


Fig. 4.5. Profuse flowering of Teak trees in Parambikulam seed zone (P2)

a.Flower bud initiation



b. Flowering

c. Immature/green fruits

d. Matured fruits

Fig. 4.6. Stages of teak seed production in a SPA (K3) located at Konni

4.3 Fruit and seed characteristics

The major purpose of raising and maintaining seed production areas is to collect and supply source identified quality seeds for raising genetically improved plantations for higher productivity. The quantity of seed produced, viability and their germination percentage determine the quality of seed production areas. This information is vital for adequate supply of seeds for planning large-scale nursery and planting operations. The results of studies conducted on fruit and seed characteristics of various seed zones are given below.

4.3.1 Quantitative fruit characteristics

There were significant differences among teak SPAs for quantitative fruit characteristics such as fruit diameter, fruits weight and total fruit yield; there was no significant difference for number of locules per fruit as well as for number of seeds per fruit (Table 4.6). SPA-W1 recorded significantly higher fruit diameter of 1.88cm than other SPAs. Whereas W9 recorded lowest fruit diameter of 1.42 cm, average being 1.57 cm. Fruit weight was significantly higher in SPA- W3 (118.93 g/100 fruits) in comparison to other SPAs. N1 recorded lowest fruit weight of 63.76 g/100 fruits, average being 82.91/100 fruits.

In general, the fruit yield was higher for Parambikulam SPAs and lower for SPAs of Konni and Achencoil seed zones. SPA-P2 recorded significantly higher average fruit yield of 53.52 kg per ha among all the SPAs (Figure 4.7). Fruit yield was lowest of 2.34 kg/ha in K2 with an average of 13.07 kg/ha (Table 4.6). Number of locules per fruit ranged from 3.79 (N1) to 4.06 (N6), average being 3.98.

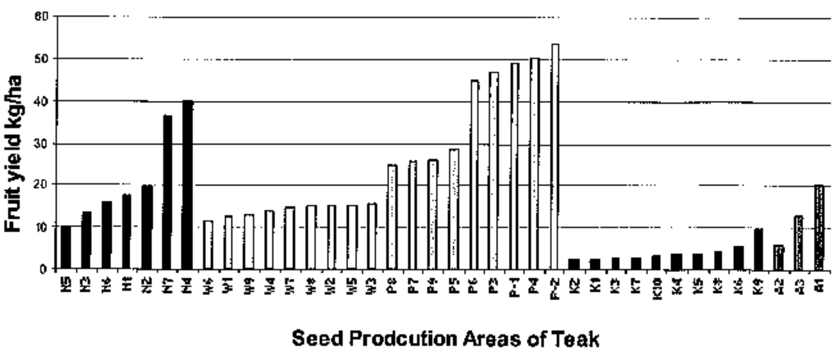


Fig. 4.7. Variation in fruit yield among different teak SPAs of Kerala

Fig. 4.8. Variation in numbers of locules (3, 4, 6) in teak fruit

Table 4.6. Fruit and seed characteristics of different SPAs in Kerala

SPA code	No. locules per fruit		Fruit diameter (cm)		100 fruit weight (g)		No. of seeds per fruit		Fruit yield per ha		
									On log scale		Re-trans formed
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean
N_1	3.79	0.12	1.49	0.01	64.76	1.37	1.08	0.08	2.87	0.08	17.64
N_2	3.92	0.04	1.50	0.02	64.88	0.41	0.83	0.14	2.99	0.08	19.89
N_3	3.98	0.01	1.52	0.03	67.69	2.24	0.88	0.20	2.59	0.08	13.33
N_4	3.85	0.12	1.60	0.03	71.40	2.12	1.30	0.07	3.69	0.08	40.04
N_5	3.93	0.08	1.56	0.01	79.19	1.25	1.01	0.08	2.31	0.08	10.07
N_6	4.06	0.07	1.56	0.02	71.12	2.53	1.15	0.23	2.76	0.08	15.80
N_7	3.79	0.18	1.60	0.04	75.10	1.21	1.02	0.04	3.60	0.08	36.60
W_1	4.02	0.02	1.88	0.05	103.24	2.33	1.19	0.05	2.54	0.08	12.68
W_2	3.99	0.01	1.72	0.01	101.16	1.77	0.99	0.05	2.72	0.08	15.18
W_3	3.98	0.01	1.75	0.03	118.93	2.76	0.91	0.13	2.74	0.08	15.49
W_4	3.90	0.03	1.67	0.01	107.95	1.31	0.84	0.08	2.62	0.08	13.74
W_5	4.05	0.02	1.49	0.05	81.75	2.86	1.41	0.07	2.72	0.08	15.18
W_6	3.98	0.01	1.44	0.05	74.93	1.22	1.17	0.14	2.41	0.08	11.13
W_7	4.01	0.03	1.49	0.06	81.05	4.03	1.12	0.13	2.68	0.08	14.59
W_8	3.98	0.01	1.62	0.06	90.61	3.55	1.00	0.09	2.71	0.08	15.03
W_9	4.05	0.04	1.42	0.02	72.94	1.17	1.29	0.11	2.57	0.08	13.07
P_1	4.00	0.00	1.63	0.02	90.46	3.30	0.94	0.11	3.89	0.08	48.91
P_2	4.00	0.00	1.60	0.03	83.86	3.62	1.06	0.05	3.98	0.08	53.52
P_3	4.00	0.00	1.62	0.03	94.19	1.98	0.98	0.11	3.85	0.08	46.99
P_4	4.00	0.00	1.58	0.02	90.29	1.25	1.03	0.07	3.92	0.08	50.40
P_5	3.87	0.08	1.60	0.02	86.66	1.56	1.03	0.08	3.35	0.08	28.50
P_6	3.99	0.01	1.60	0.02	91.59	0.32	1.11	0.05	3.80	0.08	44.70
P_7	4.05	0.02	1.57	0.02	86.79	2.12	1.18	0.05	3.25	0.08	25.79
P_8	4.00	0.00	1.59	0.04	88.25	3.21	0.98	0.02	3.21	0.08	24.78
P_9	4.00	0.00	1.50	0.02	80.07	2.53	1.02	0.04	3.26	0.08	26.05
K_1	3.91	0.02	1.55	0.03	78.84	3.52	1.03	0.10	0.98	0.08	2.66
K_2	3.93	0.05	1.56	0.03	78.93	1.85	1.01	0.10	0.85	0.08	2.34
K_3	4.05	0.04	1.56	0.03	79.83	2.04	1.16	0.07	1.05	0.08	2.86
K_4	4.01	0.03	1.54	0.01	81.42	2.30	1.17	0.07	1.30	0.08	3.67
K_5	4.02	0.02	1.57	0.02	80.69	1.40	1.27	0.14	1.32	0.08	3.74
K_6	4.05	0.02	1.58	0.02	83.19	0.93	1.07	0.14	1.66	0.08	5.26
K_7	4.01	0.03	1.54	0.02	79.38	1.60	1.29	0.09	1.13	0.08	3.10
K_8	4.00	0.00	1.56	0.02	82.50	0.95	0.93	0.11	1.47	0.08	4.35
K_9	4.05	0.02	1.52	0.01	81.71	0.93	1.08	0.05	2.26	0.08	9.58
K_{10}	4.00	0.00	1.51	0.00	75.52	2.39	0.98	0.07	1.22	0.08	3.39
A_1	3.99	0.01	1.50	0.02	80.90	1.51	1.00	0.11	3.00	0.08	20.09
A_2	4.00	0.00	1.51	0.01	76.29	1.23	0.78	0.05	1.77	0.08	5.87
A_3	3.99	0.01	1.52	0.03	75.78	1.59	1.12	0.09	2.55	0.08	12.81
Mean±SE	**3.98**	**0.01**	**1.57**	**0.01**	**82.99**	**0.96**	**1.06**	**0.02**	**2.57**	**0.09**	**13.07**
CD @ 5%	**NS**		**0.10**		**4.62**		**NS**		**0.28**		
CV (%)	**2.04**		**3.36**		**3.97**		**15.90**		**10.88**		

Generally, there are 4 locules in a teak fruit. But in the present nvestigation, one to six locules were found, four being the most common Figure 4.8). Number of matured ovules ranged from one to four and number of seedlings germinated from single fruit was also from one to four.

Average number of seeds per fruit among teak SPAs ranged from 0.78 A2) to 1.41 (W5) with mean of 1.06 seeds per fruit (Table 4.6). Generally, otal number of seeds per fruit ranged between nil to four, usually at least one matured seed was noticed per fruit.

There were significant variations among seed zones for all the quantitative fruit characters studied except for fruit diameter (Table 4.7). The

Table 4.7. Seed zones variation for various fruit and seed characteristics

Seed Zones	No. locules per unit		Fruit diameter		100 Fruit wt.		No. of seeds per fruit		Fruit yield per ha		
									On log scale	SD	Re-trans formed
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean
Nilambur	3.90^{b}	0.04	1.55^{a}	0.01	70.59^{a}	1.11	1.04^{a}	0.05	2.97^{b}	0.11	19.49
Waynad	4.00^{a}	0.01	1.61^{a}	0.03	92.51^{c}	0.17	1.10^{a}	0.04	2.64^{b}	0.03	14.01
Parambikulam	3.99^{a}	0.01	1.59^{a}	0.01	88.02^{c}	0.62	1.04^{a}	0.02	3.61^{a}	0.07	36.97
Konni	4.00^{a}	0.01	1.55^{a}	0.01	80.20^{b}	1.77	1.10^{a}	0.03	1.32^{c}	0.07	3.74
Achencoil	3.99^{a}	0.00	1.51^{a}	0.01	77.66^{a}	2.77	0.95^{b}	0.06	2.44^{b}	0.18	11.47
Mean±SE	**3.98**	**0.01**	**1.57**	**0.01**	**82.99**	**0.97**	**1.06**	**0.02**	**2.57**	**0.09**	**19.49**
CV (%)	**2.28**		**5.91**		**10.84**		**20.60**		**43.78**		

Note: Values super scribed with same letter are not significantly different.

mean number of locules per fruit ranged from 3.90 (Nilambur) to 4.00 (Konni and Wayanad) mean being 3.98. Fruit diameter did not vary much among the seed zones. It ranged from 1.51cm Achencoil to 1.61 Wayanad seed zone, average being 1.57 cm. Fruits weight ranged from 70.59 g per 100 fruits (Nilambur) to 92.51g per 100 fruits (Wayanad seed zone), average being 82.99g per 100 fruits. Number of seeds per fruits ranged from 0.95 (Achencoil) to 1.10 (Konni and Wayanad) average being 1.06. Seed zones showed significantly higher variation for fruit yield. During the seed collection period from December 2001 to March 2002, highest fruit yield of 36.97kg/ha was recorded in Parambikulam seed zone. While Konni seed zone registered very low fruit yield of 3.74 kg/ha in comparison to overall mean fruit yield of 19.49 kg/ha (Table 4.7).

4.3.2 Qualitative characteristics

Relatively high variation was observed for qualitative fruit characteristics such as nature of calyx (extent of coverage of calyx over fruit) hairiness and splitting (Figure 3.5, 3.6, & 3.7). Nature of calyx enclosing the fruits was classified into three groups namely loose, medium and tight and degree of hairiness on fruits was classified in to 3 categories namely high, medium and low. For splitting of fruit, only presence or absence of splitting was recorded. Seed zone variation for qualitative fruit characteristics is presented in the (Table 4.8).

All the three types of nature of calyx (loose, medium and tight) were seen in almost all SPAs (Figure 4.9). Out of thirty-eight SPAs, 12 could be grouped into tight calyx category, 14 into medium category and remaining 12 into loose calyx category (Table 4.9). Hairiness on fruit also showed variation among SPAs. Majority of SPAs (24) showed low hairiness on the fruits, where as, only 7 SPAs recorded high and another 7 SPAs recorded medium hairiness. However, fruits from all SPAs of Konni and Achencoil seed zones showed low hairiness (Figure 4.10).

There was significant variation with in the SPAs of different teak seed zones of Kerala for splitting behavior of teak seeds (fruits). All the SPAs of southern parts of Kerala namely, Konni and Achencoil did not show splitting (Table 4.9). However, SPAs of northern seed zones *viz.* Nilambur, Wayanad and Parambikulam have shown splitting.

Fruits from 15 SPAs showed splitting and rest of SPAs did not show any splitting. Highest percentage of splitting was observed in SPA- W1 (46%) and W2 (37%) (Table 4.9).

Table 4.8. Qualitative fruit traits of different teak SPAs in Kerala

Seed Zone	SPA code	Fruit parameter		
		Nature of calyx enclosed	Hairiness	Nature of splitting
Nilambur	N1	Loose	Low	Absent
	N2	Medium	Low	Absent
	N3	Medium	Low	Absent
	N4	Tight	Low	1.0 %
	N5	Tight	Medium	1.0 %
	N6	Medium	Medium	1.0 %
	N7	Medium	Medium	Absent
Wayanad	W1	Tight	Low	46.0 %
	W2	Tight	Low	37.0 %
	W3	Loose	Low	11.0 %
	W4	Loose	High	Absent
	W5	Medium	High	2.0 %
	W6	Medium	High	1.0 %
	W7	Medium	High	1.0 %
	W8	Loose	Low	1.0 %
	W9	Loose	Low	3.0 %
Parambikulam	P1	Loose	High	3.0 %
	P2	Loose	High	Absent
	P3	Medium	Medium	1.0 %
	P4	Loose	High	1.0 %
	P5	Loose	Medium	Absent
	P6	Tight	Medium	Absent
	P7	Tight	Low	Absent
	P8	Tight	Medium	11.0 %
	P9	Loose	Low	Absent
Konni	K1	Tight	Low	Absent
	K2	Tight	Low	Absent
	K3	Tight	Low	Absent
	K4	Medium	Low	Absent
	K5	Medium	Low	Absent
	K6	Medium	Low	Absent
	K7	Tight	Low	Absent
	K8	Tight	Low	Absent
	K9	Medium	Low	Absent
	K10	Loose	Low	Absent
Achencoil	A1	Loose	Low	Absent
	A2	Medium	Low	Absent
	A3	Medium	Low	Absent

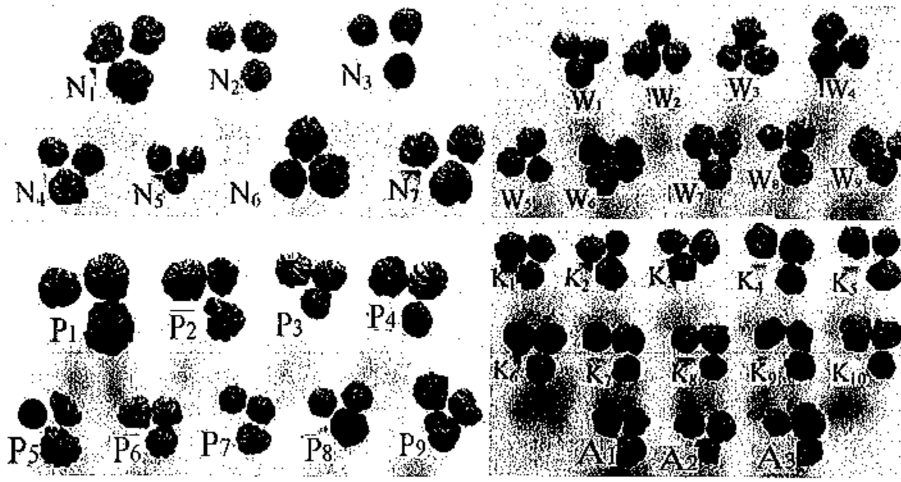


Fig.4.9. Variation in nature of calyx enclosing fruit among SPAs

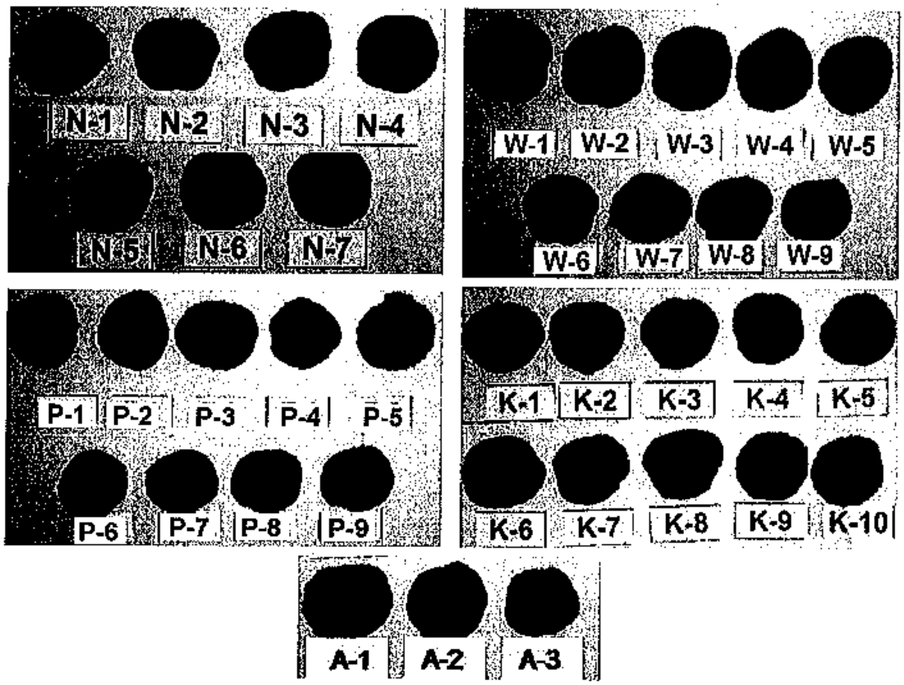


Fig. 4.10. Variation in hairiness of fruit among SPAs

Table 4.9. Summary qualitative fruit characteristics of different SPAs in Kerala

Seed zones	Total SPA	Calyx enclosing fruit			Hairiness of fruit			Splitting	
		Tight	Medium	Loose	High	Medium	Low	Present	Absent
Nilambur	7	2	4	1	-	3	4	3	4
Wayanad	9	2	3	4	4	-	5	8	1
Parambikulam	9	3	1	5	3	4	2	4	5
Konni	10	5	4	1	-	-	10	-	10
Achencoil	3	-	2	1	-	-	3	-	3
Total	**38**	**12**	**14**	**12**	**7**	**7**	**24**	**15**	**23**

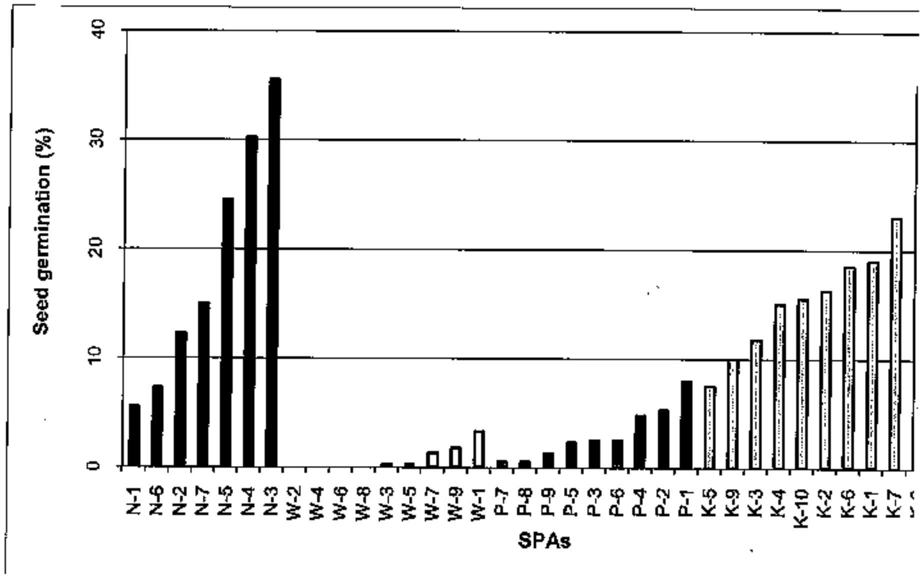
4.4 Seed germination

Germination in teak mainly depends upon the viability of the seeds, exogenous and endogenous dormancy, type of pre-seed treatment given, *etc.* Though teak produces plenty of fruits, at times during poor seed years, low germination becomes a problem for planning large-scale commercial nursery operations. Information on germination of teak fruits collected from a known source is essential for economizing the cost of collection and pre-treatment practices to be followed. The results of germination studies carried out in this investigation are as follows.

Year-to-year variation with respect to seed germination have been observed in the present study. In the first season (2002), the overall germination percentage from freshly collected fruits was 9.37 (Table 4.10) and it was slightly better (10.14%) in the freshly collected fruits during second season 2003 (Table 4.11). A view of teak germination is shown in (Figure 4.11)

During first year (2002), germination percentage showed significant differences among teak SPAs (Table 4.10 and Figure 4.11). In the germination study carried out during 2002, the germination percentage ranged from 0 to 35, depending upon SPAs/seed zones. (Figure 4.11) shows the germination of teak seedlings. In Wayanad seed zone germination percentage was very poor. It ranged from zero (W2, W4, W5, W6, and W8) to

5 % (W7). Five SPAs from Wayanad seed zone *viz.*, W2, W4, W5, W6 and W8 showed no germination up to 45 days after sowing (Table 4.10). Even though, the observations were recorded up to six months, three was no germination. Hence, the germination trial was repeated during second year using freshly collected seeds.



During second year (2003) germination percentage slightly improved, which ranged from 0.75(W2) to 35.5(N3) (Table 4.11). Teak SPA- N3, K8, N4, N5 and K7 recorded slightly higher germination percentage of 35.5, 33.75, 27.5, 24.25 and 22.75, respectively compared to other SPAs (Figure 4.12 & 4.13). There was no significant improvement in the germination of SPAs of Wayanad and Parambikulam seed zones during second year season (2003). In the case of Wayanad seed zone the germination ranged from 0.75 % (W2) to 4.25 % (W7). Whereas, in Parambikulam seed zone it ranged from 0.25 % (P8) to 4.75 % (P6). Three SPAs from Wayanad provenance *viz.*, W1, W2, and W6 showed delay in germination for about 20 days as compared with others. This could be due to presence of seed dormancy in the fruits of these SPAs.

Table 4.10. Details of seed germination of different SPAs of Kerala in first season (Year 2002)

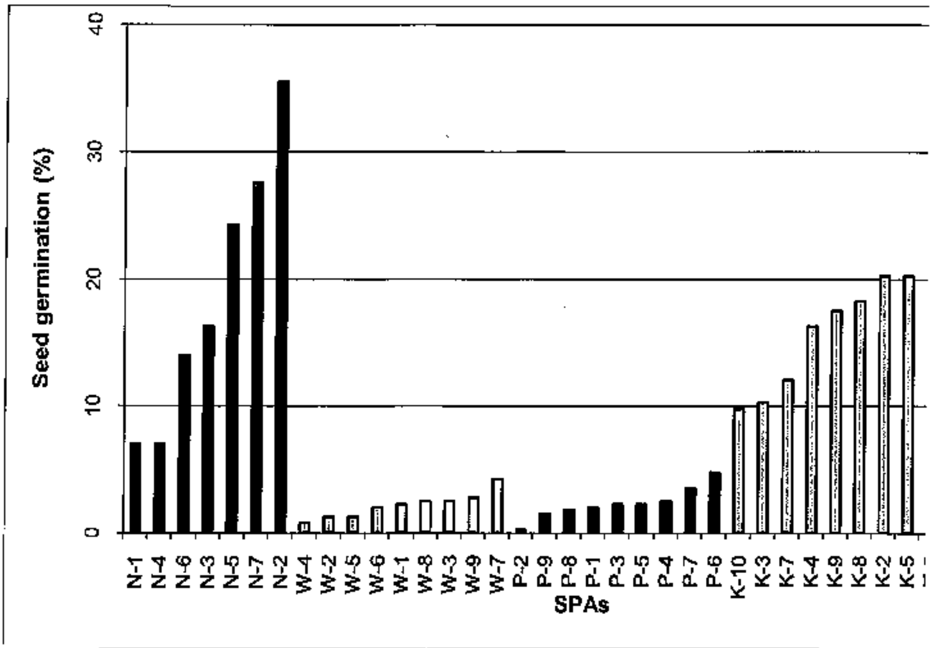
SPA code	Seed germination (%)			
	Mean	**SE**	**Mean**	**SE**
N_1	5.25	2.75	(10.66)	(4.64)
N_2	12.25	4.59	(19.20)	(4.46)
N_3	35.00	9.34	(35.23)	(6.44)
N_4	29.50	8.05	(32.22)	(5.24)
N_5	24.25	6.12	(28.61)	(4.82)
N_6	07.00	2.35	(14.41)	(3.15)
N_7	14.75	5.15	(21.84)	(3.88)
W1	02.25	1.03	(07.29)	(2.68)
W2	00.00	0.00	(00.00)	(0.00)
W3	00.25	0.25	(01.44)	(1.44)
W4	00.00	0.00	(00.00)	(0.00)
W5	00.00	0.00	(00.00)	(0.00)
W6	00.00	0.00	(00.00)	(0.00)
W7	05.00	0.29	(02.87)	(1.66)
W8	00.00	0.00	(00.00)	(0.00)
W9	01.00	0.41	(04.90)	(1.73)
P1	08.00	3.08	(15.27)	(3.67)
P2	05.25	2.63	(12.23)	(3.07)
P3	02.50	0.29	(09.06)	(0.53)
P4	04.75	2.25	(11.32)	(3.28)
P5	02.25	0.25	(08.59)	(0.46)
P6	02.25	1.19	(07.55)	(2.96)
P7	00.50	0.50	(02.03)	(2.03)
P8	00.50	0.50	(02.23)	(2.03)
P9	01.25	0.75	(04.53)	(2.64)
K_1	18.75	5.22	(24.80)	(4.30)
K_2	16.00	4.43	(22.97)	(3.52)
K_3	11.75	3.94	(19.12)	(3.77)
K_4	14.75	2.46	(22.37)	(2.01)
K_5	07.50	3.40	(14.57)	(3.86)
K_6	18.25	7.39	(23.64)	(5.94)
K_7	22.75	7.03	(27.68)	(4.87)
K_8	34.50	2.72	(35.93)	(1.63)
K_9	09.50	3.01	(17.22)	(3.13)
K_{10}	15.50	5.30	(22.01)	(4.67)
A_1	03.00	0.58	(09.84)	(0.98)
A_2	13.25	6.45	(18.95)	(6.17)
A_3	11.00	4.80	(17.81)	(4.74)
Mean ±SE	**9.37**	**0.96**	**(13.90)**	**(0.97)**
CD @ 5%	**10.93**			
CV (%)	**47.39**			

Note: Figures in the parenthesis are arc-sign transformed values

Table 4.11. Details of seed germination of different SPAs of Kerala in second season (Year 2003)

SPA code	Seed germination (%)			
	Mean	SE	Mean	SE
N_1	7.0	2.4	(14.7)	(2.7)
N_2	14.0	3.2	(21.5)	(2.8)
N_3	35.5	5.8	(36.3)	(3.5)
N_4	27.5	5.1	(31.3)	(3.5)
N_5	24.3	2.3	(29.4)	(1.5)
N_6	7.0	2.6	(14.0)	(3.8)
N_7	16.3	1.8	(23.7)	(1.4)
W1	1.3	0.3	(06.3)	(0.6)
W2	0.8	0.8	(04.6)	(1.8)
W3	2.0	0.7	(07.7)	(1.7)
W4	2.5	0.3	(09.1)	(0.50
W5	2.5	0.3	(09.1)	(0.5)
W6	1.3	0.3	(06.3)	(0.6)
W7	4.3	0.9	(11.7)	(1.3)
W8	2.8	0.3	(09.5)	(0.5)
W9	2.3	1.3	(07.7)	(2.4)
P1	3.5	1.3	(10.3)	(2.0)
P2	1.8	0.5	(07.4)	(1.0)
P3	1.5	0.7	(06.7)	(1.5)
P4	2.3	0.6	(08.4)	(1.2)
P5	2.3	0.9	(08.1)	(1.9)
P6	4.8	1.0	(12.4)	(1.4)
P7	2.5	0.7	(08.8)	(1.2)
P8	0.3	0.3	(03.6)	(0.7)
P9	2.0	0.7	(07.7)	(1.7)
K_1	20.3	2.2	(26.7)	(1.5)
K_2	17.5	2.4	(24.6)	(1.8)
K_3	10.3	2.1	(18.4)	(2.1)
K_4	16.3	1.3	(23.7)	(1.0)
K_5	14.8	1.9	(22.5)	(1.6)
K_6	20.3	3.1	(26.6)	(2.2)
K_7	22.8	1.9	(28.4)	(1.3)
K_8	33.8	5.9	(35.3)	(3.6)
K_9	12.0	2.6	(19.9)	(2.3)
K_{10}	18.3	1.3	(25.2)	(1.0)
A_1	7.3	1.8	(15.3)	(2.0)
A_2	8.8	0.9	(17.1)	(0.9)
A_3	16.5	1.5	(23.9)	(1.2)
Mean ± SE	**10.3**	**0.8**	**(16.4)**	**(0.8)**
CD @ 5%	**10.93**			
CV (%)	**47.39**			

Note: Figures in the parenthesis are arc-sign transformed values



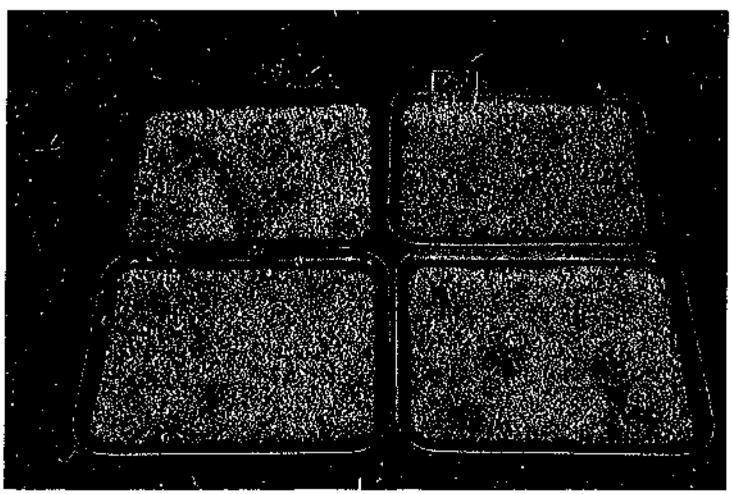


Fig. 4.13. General view of teak germination (K2)

Highly significant variation among different seed zones was observed for seed germination in the first season trial (Table 4.12). Among all, Nilambur and Konni seed zones recorded highest germination percentage of 18.29 and 16.93, respectively. While Wayanad (0.44 per cent) and Parambikulam (3.06 per cent) seed zones recorded very low germination percentage. Co-efficient of variation was high (58.70 per cent) among all the seed zones. The similar trend was also observed during second season (2003) with slightly better fruit germination among seed zones. Here also Nilambur (18.92 per cent) and Konni (18.02 per cent) seed zones performed better than those of others (Table 4.13).

Table 4.12. Seed zone variation for seed germination during first season (2002)

Seed Zones	**Seed germination (%)**			
	Mean	SE	Mean	SE
Nilambur	18.29	2.85	(23.17^{a})	(2.28)
Wayanad	00.44	0.17	(01.83^{b})	(0.57)
Parambikulam	03.06	0.62	(08.09^{b})	(1.04)
Konni	16.93	1.76	(23.03^{a})	(1.42)
Achencoil	09.08	2.77	(15.5^{ab})	(2.66)
Mean ±SE	**09.37**	**0.96**	**(13.90)**	**(0.98)**
CV (%)	**58.70**			

Table 4.13. Seed zone variation for seed germination during second season (2003)

Seed Zones	**Seed germination (%)**			
	Mean	SE	Mean	SE
Nilambur	18.92	2.29	(24.35^{a})	(1.87)
Wayanad	2.17	0.25	(7.61^{b})	(0.63)
Parambikulam	2.31	0.30	(7.68^{b})	(0.71)
Konni	18.02	1.30	(24.79^{a})	(0.94)
Achencoil	10.83	1.43	(18.78^{ab})	(1.33)
Mean ±SE	**10.14**	**0.84**	**(16.12)**	**(0.82)**
CV (%)	**37.37**			

Note: Figures in the parenthesis are arc-sign transformed values
Values superscribed with same letter are not significantly different;
Values superscribed with different letters are significantly different

4.5 Seed viability

Seed viability indicates the potential germination capacity of a seed lot. The seeds used in nursery stock production should have good viability and germination potential in order to obtain a large number of uniform seedlings from the seeds sown and to reduce the cost of seedling productions. The viability of teak seed depends upon the seed size, seed source, seed year and climatic conditions during flowering and fruiting period. The details of viability test conducted are as follows.

Seed viability tested using 0.1 per cent TTC salt solution (2, 3, 5 triphenyl tetrazolium salt) did not show significant difference among teak SPAs and it ranged from 31.65 (W7) to 62.30 per cent (P5 and K1) with overall mean of 50.29 per cent (Table 4.14). There were significant differences among different seed zones. Konni, Nilambur and Achencoil seed zones recorded maximum seed viability in comparison to Parambikulam and Wayanad (Table 4.15).

Table 4.14. Details of seed viability of different teak SPAs in Kerala

SPA code	Seed viability (%)			
	Mean	SE	Mean	SE
N_1	52.75	5.13	(46.59)	(2.95)
N_2	50.60	5.45	(45.35)	(3.13)
N_3	47.75	1.59	(43.71)	(0.96)
N_4	51.35	4.92	(45.78)	(2.83)
N_5	58.35	5.91	(49.88)	(3.45)
N_6	67.50	2.76	(55.28)	(1.69)
N_7	54.15	2.94	(47.39)	(1.69)
W1	36.10	9.83	(36.55)	(5.97)
W2	41.65	5.91	(38.62)	(4.51)
W3	42.30	8.70	(40.43)	(5.10)
W4	42.20	1.56	(40.50)	(0.90)
W5	59.25	14.67	(50.89)	(8.87)
W6	35.40	3.26	(36.47)	(1.95)
W7	31.65	1.17	(34.22)	(0.72)
W8	40.95	3.22	(39.76)	(1.88)
W9	46.65	9.44	(43.00)	(5.49)
P1	52.75	5.13	(46.60)	(2.95)
P2	37.75	5.48	(37.81)	(3.26)
P3	50.00	0.00	(45.00)	(0.00)

Table 4.14. Contd...

SPA code	Seed viability (%)			
	Mean	SE	Mean	SE
P4	52.30	1.63	(46.32)	(0.94)
P5	62.30	5.45	(52.21)	(3.24)
P6	51.90	4.53	(46.10)	(2.60)
P7	45.00	3.54	(42.11)	(2.04)
P8	39.30	7.57	(38.66)	(4.48)
P9	53.10	4.88	(46.79)	(2.81)
K_1	62.30	5.45	(52.22)	(3.24)
K_2	57.75	8.66	(49.61)	(5.08)
K_3	58.35	5.91	(49.67)	(3.30)
K_4	61.90	5.16	(51.97)	(3.06)
K_5	49.10	9.48	(44.47)	(5.50)
K_6	50.00	0.00	(45.00)	(0.00)
K_7	54.55	6.40	(47.66)	(3.70)
K_8	52.50	4.10	(46.45)	(2.36)
K_9	51.65	1.17	(45.94)	(0.67)
K_{10}	49.20	3.82	(44.54)	(2.19)
A_1	53.10	4.88	(46.79)	(2.81)
A_2	50.00	5.87	(45.00)	(3.38)
A_3	57.70	2.69	(49.44)	(1.56)
Mean±SE	**50.29**	**0.94**	**(45.13)**	**(0.56)**
CD @ 5%	**NS**			
CV (%)	**15.20**			

Note: Figures in the parenthesis are arc-sign transformed values

Table 4.15. Variation for seed viability in different seed zones in Kerala

Seed zones	Seed viability (%)			
	Mean	SE	Mean	SE
Nilambur	54.63	1.70	(47.71)	(0.99)
Wayanad	41.79	2.27	(40.05)	(1.39)
Parambikulam	49.38	1.69	(44.62)	(0.99)
Konni	54.73	1.53	(47.75)	(0.89)
Achencoil	53.60	2.32	(47.08)	(1.34)
Mean±SE1	**50.29**	**0.94**	**(45.12)**	**(0.56)**
CD @ 5 %	**NS**			
CV %	**14.10**			

Note: Figures in the parenthesis are arc-sign transformed values; NS= Non significant

4.6 Seedling growth and physiological parameters in root trainers

Quality nursery stock raised from improved teak sources will play a major role in raising successful commercial teak plantations of high productivity. The study aimed at evaluating the growth performance of seedlings raised from different SPAs in root trainers are given below.

4.6.1 Seedling height and basal diameter

Significant differences were observed among teak SPAs for seedling growth parameters *viz.* seedling height and basal diameter recorded at one, two and three months intervals after dibbling of pre-germinated seeds in root trainers (Table 4.16). One month after dibbling, maximum seedling height was recorded in SPA-K5 (7.33 cm), whereas W8 recorded lowest seedling height of 3.88 cm (Figure 4.14. and 4.15). The overall mean height for all the SPAs was 5.91cm. SPA- K7 recorded highest basal diameter of 2.58 mm and SPA W5 minimum basal diameter of 1.86 mm with overall mean basal diameter of 2.28 mm for all the SPAs.

Seedling height at two months after dibbling ranged from 6.85 (W3) to 13.61 cm (N1) with overall mean height of 10.59 cm (Figure 4.16 & 4.17). Basal diameter of seedlings among SPAs ranged between 2.81 (W3) and 4.19 mm (N3) with overall mean of 3.71 mm.

Three months after dibbling, highest seedling height was recorded in SPA- K5 (16.77 cm). Whereas SPA W3 recorded lowest seedling height of 9.55 cm (Table 4.16, Figure 4.18 & 4.19). For basal diameter, highest and lowest values were observed in SPAs- P3 (6.01mm) and N3 (4.20 mm), respectively.

If we consider the growth at 90 days, the time at which the root trainer seedlings are generally transplanted in the field, there was significant difference in seedling height between seed zones. Wayanad seed zone recorded lowest mean height of 11.54 cm whereas Nilambur seed zone recorded the highest mean height of 15.13 cm. There was significant difference among the seed zones for basal diameter also. The mean minimum basal diameter of 4.78 mm was recorded in Wayanad seed zone and the maximum basal diameter of 5.53 mm was recorded in Nilambur seed zone (Table 4.17).

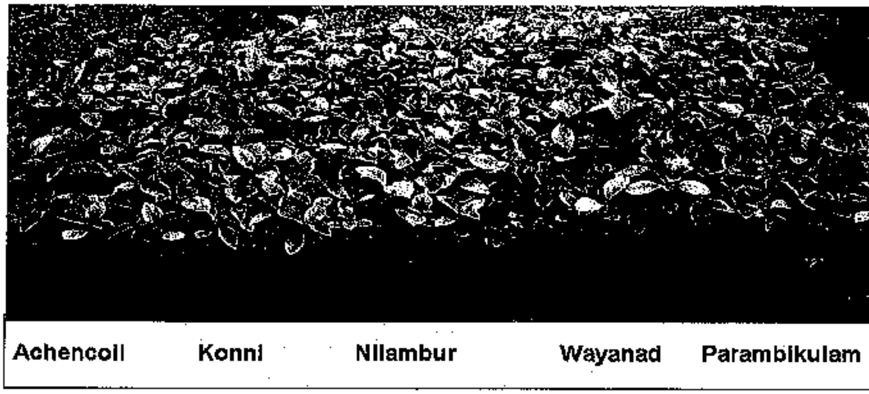


Fig. 4.14. Thirty days old teak seedlings of different seed zone in root trainers

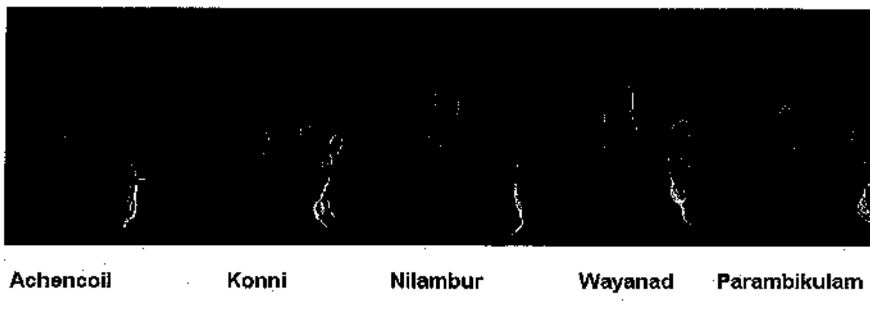


Fig. 4.15. Thirty days old root trainer seedlings of different seed zones with root plugs and exposed root systems

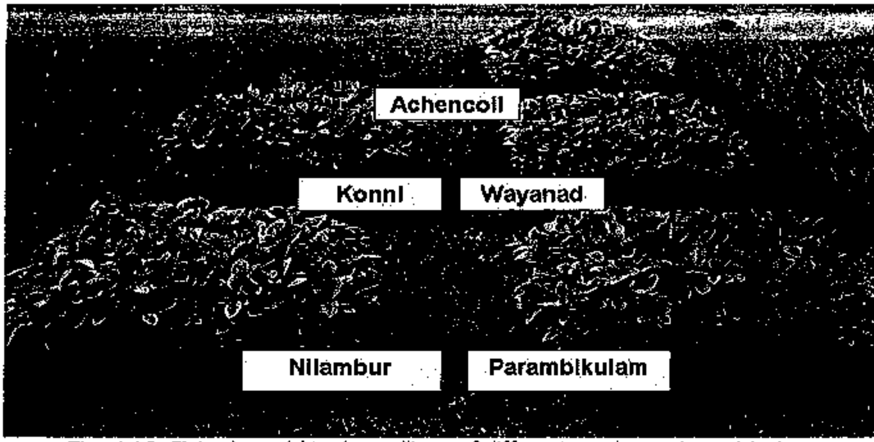


Fig. 4.16. Sixty days old teak seedlings of different seed zone in root trainers

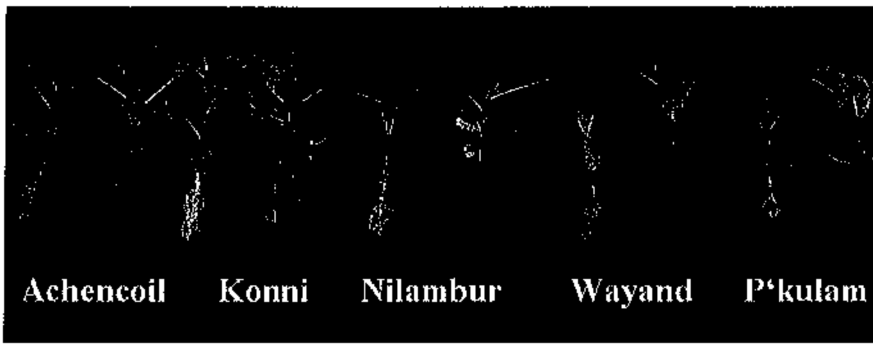


Fig. 4.17. Sixty days old root trainer seedlings of different seed zones with root plugs and exposed root systems

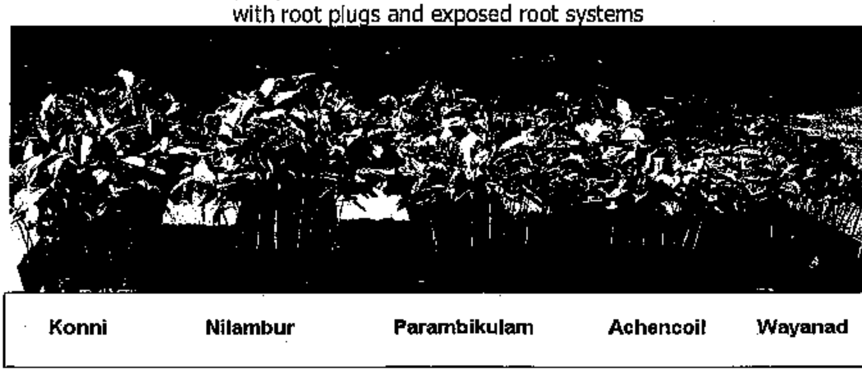


Fig. 4.18. Ninety days old teak seedlings of different seed zone in root trainers

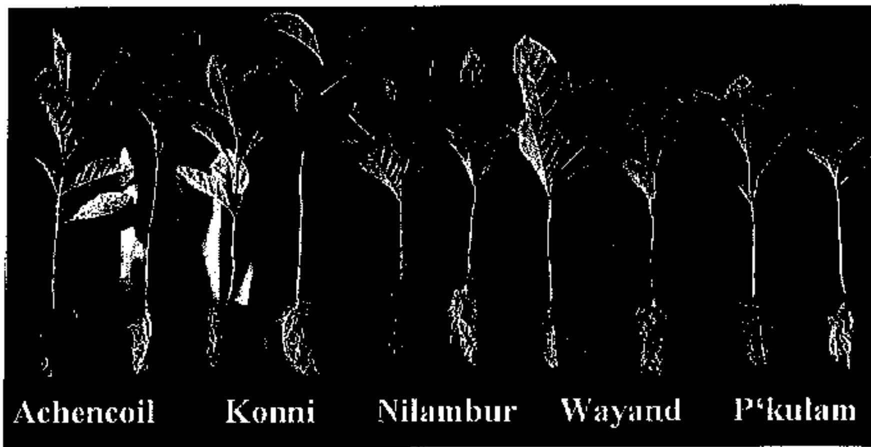


Fig. 4.19. Ninety days old root trainer seedlings of different seed zones with root plugs and exposed root systems

Table 4.16. Details of seedling growth parameters of different SPAs in Kerala

SPA code	1 month after dibbling				2 months after dibbling				3 months after dibbling			
	Height (cm)		Basal dia. (mm)		Height (cm)		Basal dia. (mm)		Height (cm)		Basal dia. (mm)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
N_1	5.51	0.22	2.35	0.06	13.61	2.24	4.11	0.10	15.32	0.66	5.60	0.50
N_2	5.36	0.14	2.24	0.02	10.08	0.47	4.11	0.10	13.65	0.36	6.00	0.42
N_3	5.78	0.12	2.38	0.07	11.89	0.23	4.19	0.06	15.81	0.29	4.20	0.36
N_4	6.59	0.11	2.44	0.06	12.87	0.34	4.06	0.07	16.20	0.56	5.80	0.64
N_5	5.89	0.35	2.38	0.08	11.95	1.00	3.84	0.08	15.32	1.27	5.38	1.00
N_6	5.96	0.22	2.43	0.04	12.21	0.53	3.99	0.14	14.99	0.39	5.76	0.48
N_7	6.12	0.18	2.34	0.04	11.59	0.24	4.00	0.11	14.62	0.82	6.00	0.50
W1	4.72	0.09	2.24	0.04	9.04	0.37	3.22	0.09	11.32	0.64	4.56	0.75
W2	4.06	0.36	2.09	0.08	8.51	0.42	3.16	0.20	10.58	0.28	4.44	0.50
W3	4.42	0.58	1.87	0.20	6.85	0.63	2.81	0.13	9.55	0.87	4.10	0.94
W4	4.71	0.56	2.07	0.14	10.02	0.74	3.71	0.09	12.56	0.61	5.50	0.50
W5	4.17	0.48	1.86	0.17	8.35	0.56	3.43	0.11	11.91	0.26	4.80	0.33
W6	4.77	0.32	2.04	0.11	8.59	0.51	3.38	0.14	11.31	1.05	4.65	1.17
W7	5.38	0.16	2.01	0.01	9.33	0.30	3.49	0.13	11.64	0.64	5.02	0.64
W8	3.88	0.01	1.96	0.08	10.01	0.62	3.30	0.11	12.57	0.63	4.88	0.60
W9	5.02	0.47	2.13	0.11	9.74	0.64	3.61	0.10	12.40	0.36	5.10	0.34
P1	6.91	0.20	2.39	0.03	10.66	0.62	3.95	0.10	14.56	0.40	5.87	0.39
P2	6.32	0.12	2.34	0.05	10.22	0.24	3.72	0.07	13.92	0.32	5.22	0.27
P3	6.30	0.22	2.34	0.05	10.68	0.73	4.08	0.11	14.34	0.73	6.01	1.00

Table 4.16. Contd...

SPA code	1 month after dibbling				2 months after dibbling				3 months after dibbling			
	Height (cm)		Basal dia. (mm)		Height (cm)		Basal dia. (mm)		Height (cm)		Basal dia. (mm)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
P4	6.39	0.21	2.36	0.07	12.11	0.44	3.90	0.04	15.95	0.55	5.75	0.72
P5	5.96	0.28	2.35	0.03	10.74	0.61	3.95	0.14	13.72	0.80	5.80	0.83
P6	6.63	0.11	2.36	0.03	11.13	0.52	3.99	0.09	14.09	0.99	5.62	1.00
P7	5.09	0.28	1.88	0.07	9.02	0.30	3.53	0.14	11.63	0.30	5.19	0.23
P8	5.88	0.49	2.28	0.03	10.28	0.54	3.57	0.16	12.94	0.36	5.01	0.50
P9	6.41	0.33	2.22	0.07	11.37	0.48	3.58	0.12	13.89	0.54	5.32	0.90
K_1	7.04	0.45	2.25	0.10	10.46	0.52	3.74	0.10	14.46	0.49	5.50	0.62
K_2	5.81	0.28	2.23	0.04	10.12	0.38	3.54	0.04	14.32	0.39	4.85	0.40
K_3	5.96	0.16	2.44	0.04	9.97	0.74	3.66	0.11	13.71	0.48	5.01	0.23
K_4	6.69	0.20	2.49	0.08	11.06	0.48	3.88	0.25	15.45	0.65	5.52	0.50
K_5	7.33	0.17	2.52	0.05	12.50	0.61	3.77	0.19	16.77	0.67	5.20	0.66
K_6	6.50	0.21	2.38	0.07	11.36	0.94	3.97	0.12	16.02	1.18	5.78	1.16
K_7	6.42	0.20	2.58	0.10	10.46	0.32	3.72	0.17	14.11	0.51	5.01	0.83
K_8	6.87	0.26	2.39	0.03	11.96	0.44	3.74	0.15	16.04	0.57	5.21	0.91
K_9	7.04	0.19	2.39	0.03	10.98	0.66	3.72	0.12	14.19	0.76	5.11	0.53
K_{10}	6.77	0.45	2.53	0.14	11.81	0.82	3.83	0.17	16.16	0.55	5.23	0.64
A_1	6.08	0.19	2.40	0.05	8.83	0.25	3.41	0.16	12.07	0.25	4.52	0.38
A_2	6.78	0.46	2.34	0.07	10.91	0.63	3.85	0.12	14.89	0.52	5.08	0.62
A_3	7.07	0.41	2.41	0.08	11.20	1.21	3.54	0.09	14.37	0.60	4.88	1.00
Mean±SE	**5.91**	**0.09**	**2.28**	**0.02**	**10.59**	**0.15**	**3.71**	**0.03**	**13.88**	**0.17**	**5.22**	**0.04**
CD @ 5%	**1.10**		**0.28**		**2.48**		**0.45**		**2.32**		**0.46**	
CV (%)	**9.35**		**6.29**		**11.90**		**6.59**		**8.64**		**6.88**	

Table 4.17. Variation for seedling growth parameters in different seed zones

Seed zones	One month after dibbling				Two months after dibbling				Three months after dibbling			
	Plant height cm		Basal diameter mm		Plant height cm		Basal diameter mm		Plant height cm		Basal diameter mm	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Nilambur	5.89^{b}	0.10	2.36^{a}	0.02	12.03^{a}	0.38	4.04^{a}	0.04	15.13^{a}	0.28	5.53^{a}	0.12
Waynad	4.57^{c}	0.14	2.03^{b}	0.04	8.94^{b}	0.23	3.35^{b}	0.06	11.54^{b}	0.25	4.78^{b}	0.07
Parambikulam	6.21^{ab}	0.12	2.28^{a}	0.03	10.69^{ab}	0.20	3.80^{ab}	0.05	13.89^{a}	0.26	5.53^{a}	0.06
Konni	6.64^{a}	0.11	2.42^{a}	0.03	11.07^{a}	0.21	3.76^{ab}	0.05	15.12^{a}	0.25	5.24^{a}	0.04
Achencoil	6.64^{a}	0.23	2.38^{a}	0.03	10.31^{a}	0.53	3.60^{b}	0.09	13.78^{a}	0.45	4.83^{b}	0.08
Mean ±SE	**5.91**	**0.09**	**2.28**	**0.02**	**10.59**	**0.15**	**3.72**	**0.03**	**13.88**	**0.17**	**5.22**	**0.04**
CV (%)	**9.35**		**6.29**		**14.23**		**7.67**		**10.90**		**7.70**	

Note: Values super scribed with same letter are not significantly different;

4.6.2 Leaf area and seedling biomass

Leaf area showed statistically significant differences among different SPAs, which ranged from 97.14 (W9) to 222.8 cm^2 (N5) with mean value of 171.16 cm^2 (Table 4.20). A significant difference between seed zones was observed for leaf area, where Parambikulam seed zone recorded an average highest leaf area of 192.8 cm^2, followed by Nilambur 177.71 cm^2 and Konni 176.43 cm^2 seed zones (Table 4.21).

Seedling biomass such as shoot dry weight, root dry weight and total dry weight of seedlings at one month, two and three months, showed significant differences among teak SPAs (Table 4.18). Root dry weight of seedling recorded highest co-efficient of variation in comparison to shoot dry weight and total dry weight of seedling (Table 4.18). Highest total seedling biomass after 90 days growth was recorded in SPA- W8 (4.80 g) and lowest in SPA W5 (2.48 g). The overall mean was 4.04g. In general when optimal leaf biomass increases, total biomass production would also substantially increase. Higher leaf area and total biomass of seedlings are good indicators of higher photosynthetic carbon fixation at seedling stage.

Shoot dry weight (SDW) and total dry weight (TDW) of seedlings after two months of dibbling showed significant variation among all studied seed zones but there was no significant difference in root dry weight (RDW, Table 4.19). Three months after dibbling, SDW of seedlings showed significant differences among the seed zones, while the RDW and TDW did not show significant difference. This may be due to restricted growth of root system in root trainers (150 cc). Initially (60 days), seedlings from Parambikulam and Nilambur seed zones recorded highest biomass (Table 4.18). Whereas at later stage (after 90 days), seedlings from Achencoil, Konni and Parambikulam seed zone recorded highest biomass.

Table 4.18. Details of leaf area and seedling biomass characteristics of different SPAs in Kerala

SPA code	Two months after dibbling						Three months after dibbling							
	SDW (g)		RDW (g)		TDW (g)		SDW (g)		RDW (g)		TDW (g)		Leaf area (cm²)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
N_1	1.75	0.03	0.69	0.01	2.42	0.04	2.61	0.33	1.64	0.17	4.24	0.34	176.08	18.25
N_2	1.63	0.06	0.91	0.04	2.54	0.09	2.07	0.20	1.06	0.13	3.13	0.27	166.40	16.75
N_3	1.96	0.05	0.74	0.02	2.70	0.06	2.75	0.15	1.39	0.07	4.15	0.14	161.63	32.00
N_4	1.82	0.07	0.82	0.03	2.64	0.09	2.51	0.36	1.42	0.15	3.92	0.26	148.59	15.75
N_5	2.52	0.10	1.36	0.05	3.88	0.15	2.68	0.24	1.86	0.34	4.54	0.45	222.76	9.00
N_6	2.00	0.06	0.92	0.03	2.93	0.09	2.55	0.30	1.62	0.14	4.17	0.43	170.52	16.05
N_7	1.98	0.03	0.89	0.01	2.87	0.03	2.57	0.21	1.28	0.15	3.85	0.16	198.01	19.05
W1	1.79	0.10	0.95	0.05	2.73	0.15	2.29	0.10	1.47	0.18	3.77	0.21	172.33	7.00
W2	1.13	0.08	0.68	0.05	1.82	0.13	2.77	0.06	1.52	0.16	4.29	0.10	142.65	18.95
W3	1.00	0.06	0.49	0.03	1.50	0.10	1.79	0.02	1.64	0.04	3.42	0.03	119.47	14.50
W4	0.84	0.08	0.46	0.05	1.30	0.13	2.47	0.09	1.55	0.08	4.01	0.16	113.72	8.10
W5	0.98	0.05	0.89	0.04	1.88	0.09	1.55	0.10	0.93	0.01	2.48	0.11	133.09	6.70
W6	1.09	0.06	0.74	0.04	1.83	0.09	1.92	0.09	1.21	0.18	3.13	0.27	154.40	16.25
W7	1.51	0.07	1.04	0.05	2.55	0.12	2.27	0.08	1.25	0.25	3.52	0.30	150.40	9.85
W8	2.10	0.15	1.06	0.08	3.16	0.23	2.59	0.03	2.22	0.15	4.80	0.13	198.83	8.60
W9	1.22	0.05	0.82	0.04	2.04	0.11	2.61	0.02	1.59	0.07	4.18	0.06	97.14	26.75
P1	1.85	0.05	0.75	0.02	2.60	0.07	2.53	0.24	1.64	0.22	4.16	0.37	164.96	18.40
P2	1.91	0.08	0.79	0.03	2.70	0.11	2.34	0.13	1.58	0.18	3.92	0.25	186.46	14.75
P3	1.94	0.06	0.74	0.02	2.67	0.08	2.50	0.13	1.54	0.07	4.04	0.12	186.04	18.25
P4	2.45	0.05	0.81	0.02	2.95	0.07	2.87	0.28	1.74	0.22	4.61	0.39	191.99	8.60
P5	2.10	0.10	1.94	0.36	4.04	0.43	2.48	0.10	1.77	0.05	4.25	0.09	216.69	8.65
P6	2.15	0.07	0.92	0.03	3.07	0.10	2.38	0.28	2.06	0.11	4.44	0.36	192.29	22.55
P7	1.67	0.07	0.80	0.04	2.46	0.10	2.23	0.12	1.46	0.17	3.69	0.19	178.08	41.40
P8	2.47	0.11	1.04	0.05	3.51	0.16	2.34	0.32	1.42	0.25	0.75	0.47	218.14	26.60
P9	1.94	0.05	0.89	0.02	2.83	0.07	2.68	0.30	1.84	0.47	4.52	0.63	200.13	12.65
K_1	1.55	0.04	0.70	0.02	2.25	0.06	2.92	0.26	1.39	0.38	4.31	0.61	140.84	10.40
K_2	2.11	0.05	0.67	0.02	2.78	0.07	2.74	0.06	1.31	0.20	4.05	0.17	152.09	21.50
K_3	1.30	0.11	0.48	0.04	1.78	0.15	2.43	0.13	1.52	0.11	3.94	0.08	187.64	18.10
K_4	1.82	0.04	0.67	0.02	2.48	0.06	2.75	0.22	1.68	0.12	4.42	0.19	169.58	24.70
K_5	1.89	0.05	0.93	0.03	2.83	0.07	2.68	0.10	1.69	0.12	4.37	0.17	186.08	5.00
K_6	2.25	0.06	1.04	0.03	3.29	0.09	2.91	0.30	1.62	0.14	4.53	0.43	178.58	6.75
K_7	0.64	0.08	0.95	0.12	1.59	0.20	2.49	0.17	1.35	0.16	3.83	0.27	205.83	26.65
K_8	1.96	0.12	0.85	0.05	2.80	0.17	2.65	0.08	1.57	0.06	4.22	0.13	170.32	16.40
K_9	1.79	0.06	0.74	0.03	2.53	0.08	2.36	0.19	1.19	0.05	3.55	0.20	188.58	26.65
K_{10}	2.08	0.06	0.79	0.02	2.87	0.08	2.87	0.10	1.69	0.21	4.57	0.24	184.71	32.80
A_1	1.55	0.11	0.89	0.06	2.44	0.17	2.49	0.08	1.58	0.16	4.08	0.23	143.28	10.85
A_2	1.79	0.09	0.95	0.05	2.73	0.13	2.55	0.18	1.58	0.12	4.13	0.27	157.96	9.65
A_3	2.06	0.07	1.02	0.03	3.08	0.10	2.71	0.28	1.64	0.13	4.36	0.31	177.71	11.85
Mean±SE	**1.74**	**0.04**	**0.86**	**0.02**	**2.61**	**0.05**	**2.49**	**0.04**	**1.54**	**0.03**	**4.04**	**0.06**	**171.16**	**3.50**
CD @ 5%	**0.27**		**0.26**		**0.47**		**0.70**		**0.66**		**1.05**		**68.30**	
CV (%)	**8.24**		**16.09**		**9.77**		**14.49**		**23.31**		**13.58**		**21.54**	

Table 4.19. Seed zone variation for seedling biomass characteristics

Seed Zones	Two months after dibbling						Three months after dibbling					
	SDW		RDW		TDW		SDW		RDW		TDW	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Nilambur	1.95^{a}	0.05	0.90^{a}	0.04	2.85^{a}	0.09	2.53^{a}	0.10	1.47^{a}	0.08	3.99^{a}	0.13
Wayanad	1.30^{b}	0.07	0.79^{a}	0.04	2.09^{b}	0.10	2.25^{b}	0.07	1.49^{a}	0.07	3.74^{a}	0.12
Parambikulam	2.02^{a}	0.04	0.97^{a}	0.07	2.98^{a}	0.09	2.48^{ab}	0.07	1.67^{a}	0.07	4.15^{a}	0.12
Konni	1.74^{ab}	0.07	0.78^{a}	0.03	2.52^{ab}	0.09	2.68^{a}	0.06	1.50^{a}	0.06	4.18^{a}	0.09
Achencoil	1.80^{ab}	0.08	0.95^{a}	0.03	2.75^{ab}	0.10	2.59^{ab}	0.10	1.60^{a}	0.07	4.19^{a}	0.15
Mean±SE	**1.74**	**0.04**	**0.86**	**0.02**	**2.61**	**0.05**	**2.50**	**0.04**	**1.54**	**0.03**	**4.04**	**0.06**
CV (%)	**21.32**		**31.06**		**20.91**		**16.97**		**25.67**		**16.53**	

RDW = Root dry weight; SDW= Shoot dry weight; TDW= Total dry weight
Note: Values superscribed with same letter are not significantly different

4.6.3 Seedling growth indices

Seedling growth indices such as shoot to root ratio, sturdiness quotient (SQ) and Quality Index (QI) were calculated at the age of 90 days after dibbling and results are as follows.

Shoot to root ratio ranged from 1.09 (W3) to 2.69 (K1) with mean shoot to root ratio of 1.72 observed among different teak SPAs. Sturdiness quotient ranged from 3.30 (P7) to 4.45 (K5) with overall mean of 3.74, highest quality index was recorded in W8 and it was lowest in W5 (Table 4.20).

Significant difference among teak seed zones was observed for sturdiness quotient, while quality index and shoot root ratio did not vary significantly among different seed zones (Table 4.21). Among the seed zones, Parambikulam had the highest quality index of (0.8) and Konni was the lowest (0.71).

Highest shoot to root ratio (1.91) in root trainer seedlings was observed in Konni seed zone and the lowest (1.56) was in Parambikulam seed zone (Table 4.21). Wayanad seed zone recorded lower Sturdiness quotient whereas Konni seed zone recorded highest sturdiness quotient.

A cluster analysis was carried out to compare the performance of seed zones with respect to five seedling characteristics *viz.*, height, basal diameter, leaf area, total dry weight, sturdiness quotient and quality index. The cluster analysis was done by using average linkage method and Euclidian distance as distance measure. The result of cluster analysis is shown in dendogram (Figure 4.20).

Table 4.20. Details of seedling growth indices of different SPAs in Kerala

SPA code	Shoot to root ratio		Sturdiness Quotient		Quality Index	
	Mean	SE	Mean	SE	Mean	SE
N_1	1.65	0.27	3.74	0.21	0.79	0.04
N_2	2.01	0.27	3.32	0.11	0.60	0.07
N_3	2.00	0.18	3.78	0.10	0.72	0.02
N_4	1.92	0.50	3.99	0.11	0.67	0.03
N_5	1.55	0.23	3.95	0.26	0.82	0.07
N_6	1.57	0.09	3.78	0.22	0.78	0.06
N_7	2.15	0.46	3.68	0.29	0.68	0.07
W1	1.64	0.22	3.53	0.19	0.74	0.07
W2	1.88	0.23	3.38	0.13	0.83	0.08
W3	1.09	0.04	3.39	0.23	0.77	0.05
W4	1.60	0.03	3.38	0.14	0.81	0.04
W5	1.66	0.10	3.48	0.04	0.48	0.01
W6	1.69	0.22	3.33	0.19	0.65	0.01
W7	2.00	0.31	3.32	0.09	0.68	0.11
W8	1.19	0.10	3.81	0.14	0.97	0.06
W9	1.66	0.09	3.43	0.07	0.83	0.03
P1	1.61	0.19	3.69	0.14	0.79	0.09
P2	1.53	0.17	3.76	0.14	0.75	0.07
P3	1.63	0.13	3.53	0.23	0.79	0.02
P4	1.71	0.21	4.09	0.12	0.80	0.08
P5	1.40	0.08	3.55	0.10	0.86	0.03
P6	1.15	0.10	3.53	0.23	0.95	0.04
P7	1.60	0.22	3.30	0.08	0.76	0.05
P8	1.79	0.32	3.64	0.07	0.70	0.10
P9	1.64	0.29	3.89	0.14	0.83	0.14
K_1	2.69	0.83	3.86	0.06	0.70	0.15
K_2	2.32	0.47	4.08	0.08	0.65	0.07
K_3	1.65	0.22	3.75	0.09	0.74	0.04
K_4	1.68	0.23	4.02	0.29	0.78	0.03
K_5	1.59	0.13	4.45	0.09	0.73	0.04
K_6	1.79	0.07	4.06	0.33	0.78	0.07
K_7	1.95	0.29	3.82	0.22	0.67	0.07
K_8	1.69	0.05	4.30	0.17	0.70	0.03
K_9	1.98	0.19	3.84	0.26	0.61	0.01
K_{10}	1.75	0.18	4.23	0.12	0.77	0.07
A_1	1.62	0.12	3.56	0.17	0.79	0.05
A_2	1.63	0.11	3.87	0.10	0.75	0.05
A_3	1.67	0.20	4.07	0.17	0.77	0.07
Mean ±SE	**1.72**	**0.04**	**3.74**	**0.03**	**0.75**	**0.01**
CD @ 5%	**NS**		**NS**		**0.24**	
CV %	**30.60**		**8.82**		**17.32**	

Table 4.21. Variation for seedling growth indices in different seed zone

Seed zones	Quality Index		Sturdiness Quotient		Shoot: root ratio		Leaf area (cm^2)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Nilambur	0.72 ^{a}	0.02	3.75 ^{ab}	0.08	1.83 ^{a}	0.11	177.71 ^{ab}	7.80
Wayanad	0.75 ^{a}	0.03	3.45 ^{b}	0.05	1.60 ^{a}	0.07	142.45 ^{b}	6.53
Parambikulam	0.80 ^{a}	0.03	3.66 ^{b}	0.06	1.56 ^{a}	0.07	192.75 ^{a}	6.84
Konni	0.71 ^{a}	0.02	4.04 ^{a}	0.06	1.91 ^{a}	0.11	176.43 ^{ab}	6.46
Achencoil	0.77 ^{a}	0.03	3.84 ^{ab}	0.10	1.64 ^{a}	0.08	159.65 ^{ab}	7.09
Mean ±SE	**0.75**	**0.01**	**3.74**	**0.03**	**1.72**	**0.04**	**171.16**	**3.50**
CV (%)	**18.95**		**9.60**		**30.54**		**23.14**	

Note: Values superscribed with same letter are not significantly different;

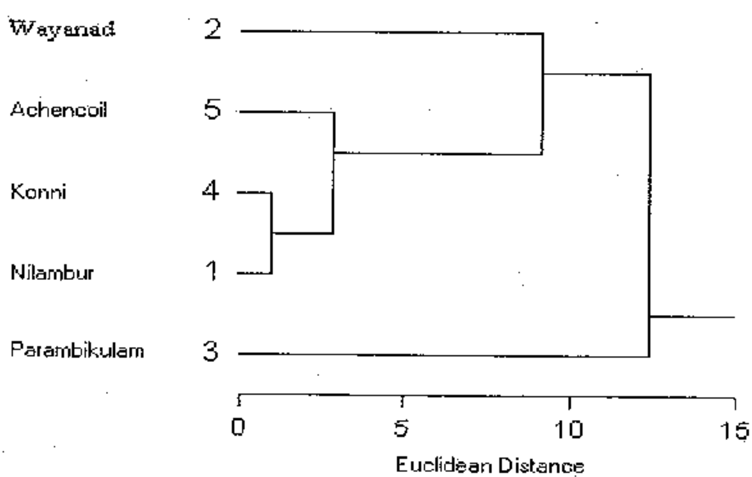


Fig. 4.20. Dendrogram for five seed zones based on five seedling characters *viz.*, height, basal diameter, leaf area, total dry weight, sturdiness quotient and quality index

Cluster analysis showed that five seed zones could be grouped into three major groups using Euclidean distance at 0- 15 scales. Seed zones from Konni, Nilambur and Achencoil were placed in one group, whereas Wayanad and Parambikulam were in two separate groups. It suggests that Parambikulam seed zone was more diverse in seedling growth characteristics than that of Wayanad and group1, which includes Konni, Nilambur and Achencoil seed zones. The dendrogram also suggests that the nursery stock raised from seed zones originating from similar range of altitude and rainfall (Table 2 & Figure 3.2), perform in similar fashion. For example, Nilambur, Konni and Achencoil seed zones receiving high rainfall and located in comparatively lower altitude (54-250 m msl) come under group I. Wayanad only seed zone in group II receives moderate rainfall and located in higher altitude (775-850 m msl).Whereas Parambikulam seed zones, which forms a separate group was located in medium altitude (544-546m msl) and receives low rainfall.

4.6. 4 Chlorophyll fluorescence parameters

Changes in chlorophyll fluorescence efficiency provide important information on photosynthetic activity of studied plants. This is a rapid and convenient method for non-destructive estimates of photosynthetic performance. The results of chlorophyll fluorescence studies recorded are as follows.

Chlorophyll fluorescence meter was used to record chlorophyll fluorescence parameters such as Fv/Fm, Fv/Fo, Fo/Fm, ETo/RC, DIo/RC, ETo/CSo and PI (absolute). The results are presented in Table 4.22. Among all fluorescence measurements, Fv/Fm and PI (absolute) are probably simplest to identify the superior seed source/genotype for large scale plantation programmes. Higher value of these parameters indicate genotypes or seed zone, suitable for drier conditions or wasteland development programmes as these genotypes may withstand high stress or environmental fluctuation.

Chlorophyll fluorescence parameters such as Fv/Fm, Fv/Fo, ETo/RC, DIo/RC and Performance index (absolute) showed wide ranging values among teak SPAs (Table 4.22). PI (absolute) and DIo/RC registered moderate co-efficient of variation and rest of the characters recorded lower CV. SPA- A3 recorded lowest Fo/Fm (0.21), DIo/RC (0.38) and highest Fv/Fo (3.85). The opposite trend was observed in SPA-N5 for these characters. ETo/RC ranged between 0.96 (N1, W3, W4) and 1.09 (K8) with overall mean of 1.03. While, SPA- W9 recorded highest ETo/CSo (356.5) and P6 registered least (281.6). Among all these parameters, Performance index which indicates the overall seedling growth and vigour ranged from 22.44 (N1) to 48.38 (A3) showing wide variation among SPAs (Table 4.22).

Table 4.22. Details of chlorophyll fluorescence parameters of different SPAs in Kerala

SPA code	Fv/Fm		Fv/Fo		Fo/Fm		ETo/RC		DIo/Rc		ETo/CSo		PI (abs)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
N_1	0.78	0.11	3.06	0.11	0.25	0.01	0.96	0.05	0.56	0.05	284.09	10.73	22.44	2.65
N_2	0.79	0.07	3.12	0.07	0.24	0.01	1.01	0.01	0.54	0.02	297.08	4.40	23.25	1.48
N_3	0.79	0.12	3.28	0.12	0.24	0.01	0.99	0.01	0.51	0.03	295.81	5.93	27.33	2.99
N_4	0.78	0.16	3.12	0.16	0.25	0.02	0.99	0.02	0.59	0.09	298.04	7.31	25.92	2.55
N_5	0.78	0.15	2.99	0.15	0.26	0.01	0.98	0.04	0.58	0.04	292.47	13.51	23.77	3.00
N_6	0.79	0.08	3.27	0.08	0.24	0.01	1.02	0.02	0.51	0.03	299.38	7.10	27.87	1.67
N_7	0.80	0.14	3.48	0.14	0.23	0.01	1.04	0.03	0.46	0.03	320.26	6.80	35.85	3.90
W1	0.80	0.15	3.39	0.15	0.23	0.01	1.02	0.01	0.48	0.04	308.10	8.94	33.47	4.75
W2	0.78	0.07	3.18	0.07	0.24	0.01	1.00	0.03	0.54	0.04	295.24	8.68	30.51	2.47
W3	0.79	0.15	3.35	0.15	0.24	0.01	0.96	0.05	0.50	0.06	296.55	12.29	33.96	2.48
W4	0.78	0.05	3.10	0.05	0.25	0.01	0.96	0.03	0.57	0.03	285.70	5.45	26.83	2.78
W5	0.78	0.15	3.12	0.15	0.25	0.01	0.98	0.03	0.53	0.04	289.82	9.72	28.26	2.01
W6	0.79	0.22	3.30	0.22	0.24	0.02	1.03	0.01	0.52	0.06	311.57	3.10	34.04	4.89
W7	0.79	0.11	3.19	0.11	0.24	0.01	1.05	0.02	0.56	0.04	327.92	8.45	27.99	5.02
W8	0.80	0.11	3.46	0.11	0.23	0.01	1.04	0.03	0.48	0.03	342.04	9.42	33.90	2.73
W9	0.80	0.09	3.50	0.09	0.23	0.01	1.04	0.03	0.46	0.02	356.54	13.24	41.62	2.84
P1	0.79	0.12	3.33	0.12	0.24	0.01	1.03	0.04	0.51	0.03	315.24	9.03	31.34	2.62
P2	0.81	0.02	3.63	0.02	0.22	0.01	1.08	0.01	0.44	0.01	335.72	7.19	39.04	2.29
P3	0.79	0.12	3.22	0.12	0.24	0.01	1.06	0.01	0.52	0.03	323.91	4.68	29.47	0.86
P4	0.78	0.15	3.18	0.15	0.24	0.01	1.02	0.03	0.52	0.03	315.51	9.64	26.55	1.70
P5	0.79	0.18	3.19	0.18	0.24	0.01	1.00	0.02	0.54	0.05	306.85	11.75	26.20	4.28
P6	0.78	0.08	3.04	0.08	0.25	0.01	0.99	0.05	0.55	0.01	281.56	11.12	22.91	4.09
P7	0.78	0.09	3.11	0.09	0.24	0.01	1.07	0.02	0.55	0.02	313.44	5.93	25.48	1.67
P8	0.79	0.13	3.20	0.13	0.24	0.01	1.08	0.02	0.55	0.04	317.06	6.80	29.47	2.45
P9	0.80	0.10	3.45	0.10	0.23	0.01	1.06	0.03	0.47	0.02	325.09	8.25	35.84	2.31
K_1	0.80	0.15	3.34	0.15	0.23	0.01	1.08	0.02	0.51	0.05	323.52	2.48	31.23	5.80
K_2	0.79	0.07	3.31	0.07	0.24	0.01	1.05	0.05	0.54	0.03	311.67	14.42	31.68	2.37
K_3	0.79	0.04	3.19	0.04	0.24	0.01	1.08	0.03	0.54	0.02	329.05	2.16	27.11	1.41
K_4	0.79	0.09	3.37	0.09	0.23	0.01	1.04	0.02	0.51	0.04	326.19	3.30	31.97	2.30
K_5	0.79	0.19	3.19	0.19	0.25	0.02	1.01	0.05	0.56	0.07	318.63	13.62	28.19	3.19
K_6	0.78	0.19	3.12	0.19	0.25	0.02	1.05	0.01	0.58	0.07	323.02	8.18	25.03	4.33
K_7	0.79	0.05	3.44	0.05	0.23	0.01	1.02	0.03	0.48	0.02	318.02	5.67	34.54	2.12
K_8	0.81	0.08	3.56	0.08	0.22	0.01	1.09	0.01	0.46	0.02	325.70	5.59	34.99	2.24
K_9	0.79	0.17	3.30	0.17	0.24	0.01	1.07	0.04	0.53	0.04	310.49	11.82	27.99	4.42
K_{10}	0.80	0.10	3.54	0.10	0.22	0.01	1.04	0.01	0.45	0.02	310.90	5.88	36.31	2.71
A_1	0.80	0.10	3.50	0.10	0.22	0.01	1.03	0.01	0.44	0.02	320.65	2.78	38.30	4.94
A_2	0.80	0.03	3.51	0.03	0.22	0.01	1.03	0.01	0.45	0.01	337.48	3.77	35.57	1.36
A_3	0.82	0.07	3.85	0.07	0.21	0.01	1.01	0.01	0.38	0.01	331.78	4.87	48.38	1.55
Mean±SE	**0.79**	**0.002**	**3.30**	**0.002**	**0.24**	**0.002**	**1.03**	**0.01**	**0.51**	**0.01**	**313.12**	**1.81**	**30.97**	**0.63**
CD@ 5%	**0.02**		**0.326**		**0.014**		**0.077**		**0.099**		**22.10**		**8.55**	
CV (%)	**1.64**		**6.62**		**8.88**		**4.94**		**14.46**		**5.03**		**19.70**	

Fv/Fm, Fv/Fo, Fo/Fm, ETo/RC, ETo/CSo, DIo/RC, PI (absolute) show significant differences among seed zones (Table 4.23). Fv/Fo and ETo/CSo were found to be highest in Achencoil seed zone, while Fo/Fm had the lowest value. Nilambur seed zone recorded lowest values for ETo/Cso, ETo/Rc and Fv/Fo (Table 4.23). Higher values of Fv/Fm indicate high photosynthetic efficiency, which is highest in Achencoil seed zone followed by Konni. Considering Performance index, Achencoil seed zone is found to be superior (40.75), followed by Wayanad (32.29) and Konni (30.90) seed zones. Co-efficient of variation was high for the trait, PI (abs) and rest of other traits showed lowest CV.

Table 4.23. Seed zone variation for chlorophyll fluorescence parameters

Seed zones	Fv/Fm		Fv/Fo		Fo/Fm		ETo/RC		DIo/RC		ETo/Cso		PI_{ABS}	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	Se	Mean	SE	Mean	SE
Nilambur	0.77^{b}	0.002	3.19^{b}	0.049	0.24^{a}	0.003	1.00^{b}	0.010	0.54^{a}	0.016	298.16^{b}	3.404	26.63^{b}	1.191
Wayanad	0.78^{ab}	0.003	3.29^{b}	0.044	0.24^{a}	0.003	1.01^{b}	0.010	0.51^{a}	0.013	312.61^{ab}	4.758	32.29^{b}	1.254
Parambikulam	0.77^{b}	0.002	3.26^{b}	0.044	0.24^{a}	0.003	1.04^{a}	0.010	0.52^{a}	0.010	314.93^{ab}	3.462	29.59^{b}	1.123
Konni	0.78^{ab}	0.002	3.33^{b}	0.041	0.23^{ab}	0.003	1.05^{a}	0.009	0.52^{a}	0.013	319.72^{a}	2.641	30.90^{b}	1.087
Achencoil	0.79^{a}	0.003	3.62^{a}	0.061	0.22^{b}	0.003	1.02^{ab}	0.005	0.42^{b}	0.012	329.97^{a}	2.930	40.75^{a}	2.315
Mean±SE	**0.77**	**0.001**	**3.30**	**0.022**	**0.24**	**0.001**	**1.03**	**0.005**	**0.51**	**0.006**	**313.74**	**1.819**	**30.91**	**0.626**
CV (%)	1.80		7.90		7.09		5.18		14.92		6.66		22.86	

Note: Values superscribed with same letter are not significantly different

4.7 Soil analysis

The productivity of teak SPAs in terms of tree growth and their potential to produce large quantity of quality seeds depends upon the nourishment they derive from soil in addition to superior genetic origin. Hence, information on physical and chemical properties of soil is essential to understand their impact on the performance of SPAs and also for scientific management of SPAs to get the expected returns. Keeping these issues in mind soil analysis was carried out. The results of soil analysis of different SPAs carried out as per the standard procedures are given below.

4.7.1 Soil physical properties

Soil components such as sand, silt and clay content did not show significant variation among different teak seed zones of Kerala (Table 4.24). Layer wise analysis also did not show significant variation. Considering mean values, Nilambur and Parambikulam seed zones recorded highest clay content as compared to other seed zones (Figure 4.21), whereas Konni seed zone recorded maximum silt content. With respect to physical parameters of soil such as bulk density, water holding capacity and soil pH, there was no significant variation among different seed zones (Figures 4.21 & 4.22). Layer wise analysis also did not show significant variation.

Wayanad seed zone showed highest bulk density and soil pH in all the three layers, followed by Nilambur and Parambikulam seed zones (Figure 4.22). Konni SPAs were more acidic than other SPAs. Konni and Achencoil seed zones recorded highest water holding capacity in all the three layers in comparison to other seed zones. It is noticed that soils of SPAs of Konni seed zone had low in bulk density and high water holding capacity. (Table 4.25) Lower water holding capacity was recorded in Wayanad seed zone.

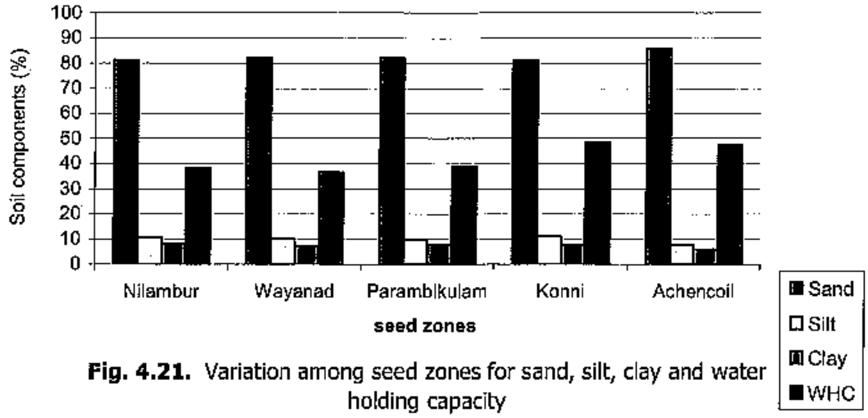


Fig. 4.21. Variation among seed zones for sand, silt, clay and water holding capacity

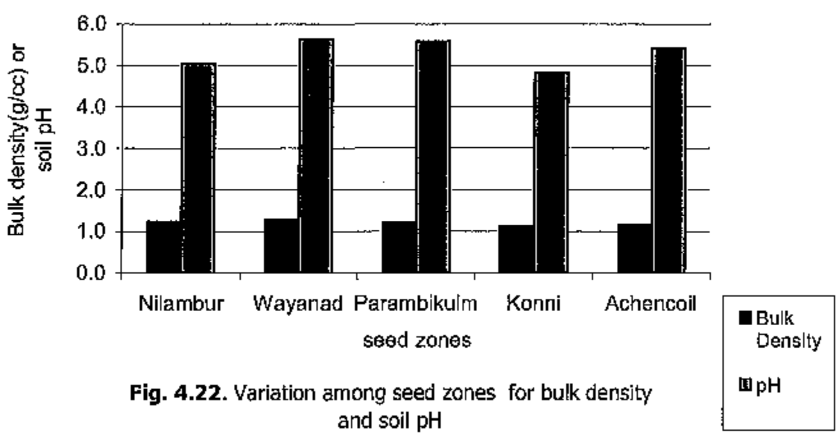


Fig. 4.22. Variation among seed zones for bulk density and soil pH

Details of soil components and physical properties of soil for each seed production areas are presented in the (Table 4.24).

Table 4.24. Details of soil components and soil physical properties (Pooled values of three layers) of different SPAs in Kerala

SPA code	Sand (%)	Silt (%)	Clay (%)	Bulk density (g/cc)	Water holding capacity (%)	pH
N_1	90.00	5.70	4.30	1.30	36.50	5.00
N_2	84.30	8.30	7.30	1.30	39.40	5.10
N_3	75.70	14.30	10.00	1.20	40.10	5.10
N_4	76.00	13.00	11.00	1.20	36.60	5.10
N_5	77.70	12.30	10.00	1.20	38.10	4.80
N_6	81.70	11.00	7.30	1.20	41.10	5.00
N_7	83.30	9.30	7.30	1.30	35.30	5.20
W1	79.70	12.70	7.70	1.30	35.80	5.80
W2	81.30	10.70	8.00	1.30	43.90	5.70
W3	81.00	12.00	7.00	1.20	36.10	5.80
W4	83.00	11.00	6.00	1.30	36.10	5.60
W5	83.00	11.30	5.70	1.20	36.70	5.50
W6	83.70	8.00	8.30	1.30	34.30	5.60
W7	82.70	9.30	8.00	1.30	36.20	5.60
W8	83.00	9.00	8.00	1.30	37.00	5.50
W9	82.70	9.00	8.30	1.30	33.70	5.70
P1	85.00	8.30	6.70	1.30	38.20	5.50
P2	80.30	11.70	8.00	1.20	41.70	5.50
P3	84.70	8.00	7.30	1.20	37.60	5.70
P4	83.70	8.70	7.70	1.20	40.60	5.60
P5	82.70	10.00	7.30	1.20	37.70	5.70
P6	83.70	9.70	6.70	1.20	41.60	5.50
P7	78.00	11.30	7.30	1.20	38.90	5.60
P8	80.30	10.30	9.30	1.20	38.90	5.50
P9	81.30	9.70	9.00	1.20	35.60	5.60
K_1	68.70	18.70	12.70	1.10	47.40	5.10
K_2	84.30	10.00	5.70	1.20	44.60	4.90
K_3	83.70	8.30	8.00	1.10	46.60	4.60
K_4	86.30	7.70	6.00	1.00	45.50	4.70
K_5	78.70	11.70	9.70	1.20	50.40	4.60
K_6	80.00	11.30	8.70	1.10	46.50	4.80
K_7	82.70	10.30	7.00	1.20	49.70	4.80
K_8	79.30	12.30	8.30	1.10	51.60	4.90
K_9	81.00	11.30	7.00	1.10	53.30	4.80
K_{10}	87.30	8.00	4.70	1.10	49.60	5.10
A_1	84.30	8.50	7.20	1.10	49.40	5.20
A_2	86.30	8.30	5.30	1.20	48.80	5.40
A_3	87.00	6.70	6.30	1.20	45.40	5.60

Table 4.25. Seed zone variation for soil components and physical properties (pooled values of three layers)

Seed zones	Soil components (%)						Bulk density		Water holding capacity (%)		pH	
	Sand		Silt		Clay							
Layer 1												
Seed zones	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Nilambur	82.92	1.67	9.71	1.08	7.35	0.62	1.21	0.02	39.06	0.99	4.99	0.08
Wayanad	84.11	0.92	9.55	0.71	6.33	0.37	1.26	0.02	35.92	0.71	5.64	0.04
Parambikulam	82.89	1.11	9.88	0.70	7.22	0.62	1.19	0.02	40.21	1.34	5.63	0.03
Konni	82.80	2.36	10.70	1.67	6.50	0.72	1.14	0.03	47.96	0.96	4.88	0.07
Achencoil	86.33	1.45	8.50	0.76	5.16	0.73	1.16	0.01	47.04	1.95	5.50	0.17
Mean±SE	**83.43**	**0.76**	**9.88**	**0.53**	**6.68**	**0.29**	**1.19**	**0.01**	**41.56**	**0.91**	**5.30**	**0.06**
F-ratio *	**0.399 ns**		**0.299 ns**		**1.126 ns**		**5.14***		**22.33***		**38.03***	
P-level	**0.01**		**0.01**		**0.01**		**0.01**		**0.01**		**0.01**	
CV (%)	**5.83**		**34.07**		**26.51**		**4.88**		**7.40**		**3.29**	
Layer 2												
Seed zones	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Nilambur	80.07	2.21	11.43	1.29	8.50	0.96	1.23	0.02	37.98	0.67	5.06	0.03
Wayanad	82.11	0.56	10.22	0.43	7.67	0.47	1.30	0.01	38.47	0.34	5.63	0.04
Parambikulam	82.44	0.38	9.67	0.37	7.89	0.35	1.21	0.03	38.97	1.13	5.59	0.03
Konni	81.30	1.51	10.90	0.81	7.60	0.81	1.08	0.02	48.19	1.00	4.82	0.05
Achencoil	85.67	0.33	7.83	0.44	6.50	0.29	1.16	0.02	48.18	1.28	5.37	0.09
Mean±SE	**81.88**	**0.61**	**10.30**	**0.36**	**7.76**	**0.30**	**1.19**	**0.02**	**41.83**	**1.15**	**5.28**	**0.06**
F-ratio *	**1.349 ns**		**1.853 ns**		**0.613 ns**		**23.12***		**6.38***		**78.65***	
P-level	**0.01**		**0.01**		**0.01**		**0.01**		**0.01**		**0.01**	
CV (%)	**4.48**		**20.92**		**24.08**		**4.33**		**13.43**		**2.26**	
Layer 3												
Seed zones	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Nilambur	80.89	1.95	10.57	1.06	8.54	0.94	1.24	0.01	37.64	0.96	5.06	0.04
Wayanad	80.93	0.61	10.98	0.81	8.09	0.47	1.28	0.01	35.82	0.51	5.65	0.04
Parambikulam	81.49	1.20	9.69	0.45	7.92	0.60	1.20	0.02	38.06	1.71	5.53	0.03
Konni	79.93	1.58	11.22	0.86	8.84	0.85	1.11	0.02	49.18	0.85	4.82	0.05
Achencoil	85.80	0.65	7.57	0.55	6.63	0.92	1.15	0.01	48.08	0.65	5.35	0.09
Mean±SE	**81.31**	**0.66**	**10.31**	**0.40**	**8.17**	**0.34**	**1.19**	**0.01**	**41.29**	**1.05**	**5.27**	**0.06**
F-ratio *	**2.08 ns**		**2.75 ***		**1.08 ns**		**17.97***		**39.03***		**83.74***	
P-level	**0.01**		**0.01**		**0.01**		**0.01**		**0.01**		**0.01**	
CV (%)	**4.81**		**22.14**		**25.82**		**4.27**		**7.61**		**2.37**	

ns = non significant, *significant at 0.01 level

4.7.2 Soil chemical properties

Soil organic carbon, total nitrogen, available phosphorous, potassium, calcium, magnesium and sodium are important elements for growth and productivity of plants. Soil chemical analysis results for different seed production areas are presented in the Table 4.26.

There were significant differences among seed zones as well as between layers of soil for all the chemical properties analyzed, except magnesium (Table 4.27). Organic carbon content was maximum in top soils (1.76 per cent), followed by middle (1.27 per cent) and third layer (1.07 per cent). Highest organic carbon content was recorded in Parambikulam seed zone, followed by Wayanad, Konni and Achencoil (Figure 4.23). This could be due to highest humus content found in the top layers and organic carbon moves from top to bottom layers.

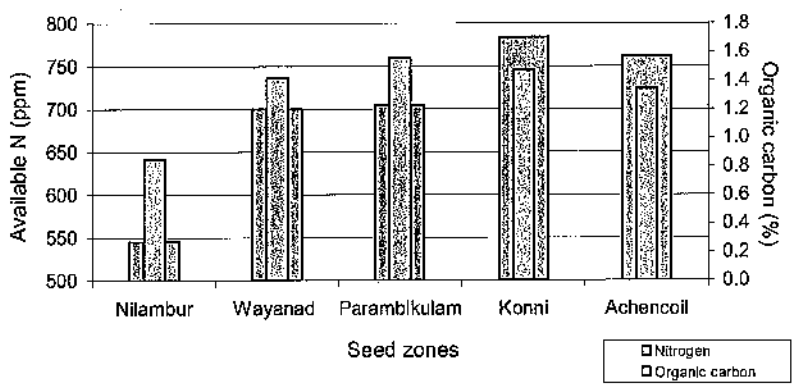


Fig. 4.23. Variation among seed zones for available nitrogen and organic carbon

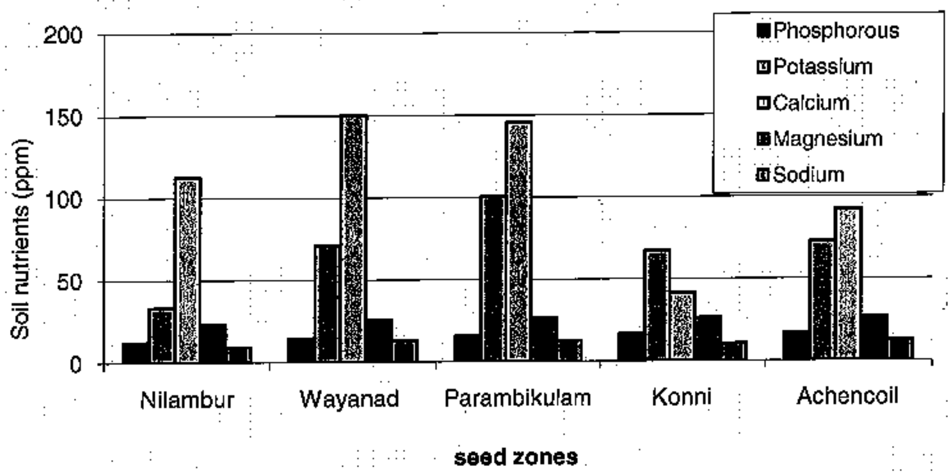


Fig. 4.24. Variation among seed zones for soil nurients

Parambikulam and Wayanad seed zones were very rich in soil nutrients such as, potassium, calcium and magnesium (Table 4.27). Konni and Achencoil seed zones also showed maximum phosphorous, nitrogen and organic carbon, where as potassium content was very poor (Figure 4.24). Overall nutrient content of Parambikulam seed zone was better as compared to other seed zones.

For examining the similarity among SPAs with respect to soil parameters, cluster analysis was carried out considering SPA as entities and soil parameters (both chemical and physical) as characters. Clustering was done using average linkage method and Euclidian distance as distance measure. The dendrogram obtained is shown in Figure 4.25.

Table 4.26. Details of chemical properties of soil (Pooled values of three layers) of different SPAs in Kerala

SPA code	Organic carbon (%)	Total N (ppm)	Available nutrients (ppm)				
			P	K	Na	Ca	Mg
N_1	1.90	532	8.00	34.70	8.10	104.00	15.00
N_2	0.50	448	6.70	27.50	9.00	109.30	27.00
N_3	0.70	588	7.00	24.20	6.10	133.30	38.70
N_4	0.80	560	8.30	14.70	14.30	148.00	33.00
N_5	0.90	560	9.70	62.30	11.50	95.30	16.00
N_6	0.40	560	8.30	28.50	7.20	100.70	16.30
N_7	0.60	560	8.30	35.40	8.70	90.70	17.70
W1	1.60	756	9.70	84.30	13.20	191.30	25.30
W2	1.30	700	8.70	69.70	11.30	160.70	20.00
W3	1.50	756	9.30	77.20	17.00	173.30	26.70
W4	1.40	560	10.70	41.50	12.20	146.70	22.30
W5	1.80	784	10.00	113.80	12.80	158.70	33.00
W6	1.00	616	9.70	67.20	11.90	108.00	18.70
W7	1.40	672	11.00	69.80	10.60	135.30	27.00
W8	1.40	700	10.00	45.30	10.70	132.70	24.30
W9	1.50	700	11.00	46.80	16.50	134.70	33.00
P1	1.60	756	11.30	82.30	11.10	97.30	26.70
P2	1.90	840	9.70	131.70	10.80	198.70	32.00
P3	1.70	700	10.70	105.20	11.00	141.30	21.60
P4	1.70	728	9.70	67.20	13.90	150.70	22.30
P5	1.90	728	10.30	138.80	16.90	162.70	28.30
P6	1.20	588	9.00	77.50	15.40	116.00	24.30
P7	1.60	728	12.30	133.50	12.10	167.30	29.70
P8	1.00	616	9.00	59.50	11.00	130.00	24.70
P9	1.20	644	12.70	92.80	12.90	133.30	32.30
K_1	1.20	784	13.00	54.30	10.20	41.30	23.30
K_2	1.20	840	11.00	70.30	12.10	45.30	13.00
K_3	1.50	728	12.30	77.70	10.10	22.00	39.00
K_4	2.10	840	10.30	79.80	10.20	24.70	20.70
K_5	1.80	756	12.70	70.00	10.00	23.30	45.70
K_6	1.40	868	11.30	52.50	9.90	30.00	32.00
K_7	1.20	728	10.70	56.80	9.80	31.70	17.00
K_8	1.00	868	12.70	50.70	10.60	36.70	32.00
K_9	1.40	784	12.30	69.30	12.00	94.00	23.70
K_{10}	1.50	560	11.00	72.00	11.00	59.30	16.00
A_1	1.60	798	11.70	72.80	11.50	80.70	19.80
A_2	1.50	756	12.00	59.70	11.70	120.00	31.70
A_3	0.90	728	11.00	70.30	13.30	66.70	29.30

Table 4.27. Seed zone variation for chemical properties of soil across three layers

Seed zones	Organic carbon (%)		Total N (ppm)		Available (in ppm)									
					P		K		Na		Ca		Mg	
Layer 1														
Seed zones	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Nilambur	1.16	0.30	540.0	35.98	12.18	0.47	46.47	7.26	9.0	± 2.56	119.1	± 20.7	22.36	± 6.59
Wayanad	1.99	0.09	746.7	35.53	14.55	0.47	111.39	10.30	13.46	± 4.69	171.1	± 25.4	22.78	± 6.04
Parambikulam	2.07	0.18	728.0	46.43	15.77	0.62	123.06	17.70	12.84	± 4.92	173.7	± 33.9	28.09	± 7.51
Konni	1.75	0.14	890.4	66.50	17.10	0.57	95.90	4.62	11.79	± 3.04	49.00	± 29.8	26.20	± 11.9
Achencoil	1.58	0.18	840.0	0.00	17.33	0.66	95.33	7.97	16.67	± 1.53	115.3	± 28.5	26.33	± 6.66
Mean±SE	**1.76**	**0.09**	**749.4**	**29.61**	**15.31**	**0.38**	**96.85**	**6.55**	**12.31**	**± 4.18**	**125.6**	**± 58.2**	**25.14**	**± 8.35**
F-ratio *	**3.78 ***		**6.31 ***		**11.23 ***		**6.13***		**2.50***		**30.68***		**0.687 ns**	
P-level	**0.01**		**0.01**		**0.01**		**0.01**		**0.01**		**0.01**		**0.01**	
CV (%)	**29.13**		**19.42**		**10.46**		**33.53**		**31.54**		**22.59**		**33.78**	
Layer 2														
Seed zones	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Nilambur	0.79	±0.37	558.0	± 86.5	7.35	±1.70	26.64	±16.32	9.57	± 2.82	111.6	±25.2	23.79	±12.0
Wayanad	1.27	±0.21	709.3	±103.8	9.44	±1.21	56.50	±22.44	12.06	± 1.27	142.7	±25.7	27.22	±09.7
Parambikulam	1.44	±0.35	690.7	±117.1	9.33	±1.22	95.50	±31.02	11.33	± 0.73	129.3	±49.7	25.11	±03.3
Konni	1.48	±0.40	764.4	±133.9	10.90	±0.99	56.65	±16.35	10.21	± 0.68	40.50	±21.7	26.30	±27.2
Achencoil	1.16	±0.20	686.0	±105.7	10.67	±0.58	64.33	±07.37	11.33	± 1.53	79.00	±22.6	26.83	±07.7
Mean±SE	**1.27**	**±0.40**	**689.7**	**±127.9**	**9.51**	**±1.69**	**60.89**	**±30.85**	**10.88**	**± 1.69**	**101.8**	**±50.8**	**25.82**	**±15.2**
F-ratio *	**5.15***		**3.51***		**9.41***		**10.09***		**3.51***		**14.89***		**0.055 ns**	
P-level	**0.01**		**0.01**		**0.01**		**0.01**		**0.01**		**0.01**		**0.01**	
CV (%)	**26.31**		**16.45**		**12.83**		**35.98**		**13.74**		**31.59**		**62.31**	
Layer 3														
Seed zones	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Nilambur	0.61	±0.45	537.3	±62.5	4.71	±1.50	27.01	±11.70	09.22	± 2.97	106.64	±21.0	23.79	±09.3
Wayanad	1.01	± 0.41	644.0	±78.6	6.00	±1.00	45.81	±28.77	13.14	± 3.48	137.62	±25.6	26.46	±04.7
Parambikulam	1.18	± 0.51	694.06	±63.6	6.44	±1.59	83.37	±29.60	13.87	± 4.39	133.37	±26.5	27.29	±04.6
Konni	1.18	± 0.35	697.90	±49.4	7.20	±0.79	48.96	±19.45	09.98	± 1.22	34.96	±15.2	26.21	±23.8
Achencoil	1.27	± 0.47	758.80	±80.7	6.67	±2.08	57.83	±22.91	10.70	± 3.57	82.67	±29.4	27.23	±04.6
Mean±SE	**1.07**	**± 0.47**	**660.91**	**±115.1**	**6.24**	**±1.50**	**52.93**	**±29.71**	**11.53**	**± 3.63**	**99.45**	**±46.9**	**26.17**	**± 12.6**
F-ratio *	**3.15***		**5.76***		**3.97***		**7.54***		**4.02***		**37.36***		**0.102 ns**	
P-level	**0.01**		**0.01**		**0.01**		**0.01**		**0.01**		**0.01**		**0.01**	
CV (%)	**40.75**		**14.69**		**20.89**		**45.00**		**28.10**		**23.33**		**50.44**	

ns = non significant, * significant at 0.01 level

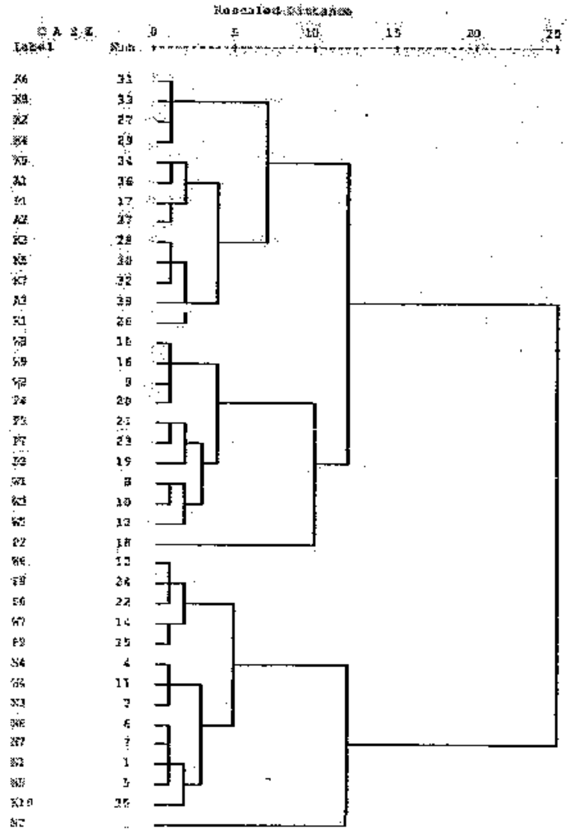


Fig. 4.25. Dendrogram showing resemblance among SPAs based on soil parameters

All the 38 SPAs can be grouped in 6 natural clusters at 20 per cent distance level and they are as follows.

Group/Cluster	SPA
1	K_6, K_8, K_2, K_4
2	K_9, A_1, P_1, A_2, K_3, K_5, K_7, A_3, K_1
3	W_8, W_9, W_2, P_4, P_5, P_7, P_3, W_1, W_3, W_5
4	P_2
5	W_6, P_8, P_6, W_7, P_9, N_4, W_4, N_3, N_6, N_7, N_1, N_5, K_{10}
6	N_2

Dendogram showed that SPAs, K_6, K_8, K_2, K_4 could be grouped into one luster as these SPAs were similar for all the analyzed soil characteristics. SPA-P2 and N2 are grouped in to two different clusters indicating distant soil haracteristics.

For examining the similarity among seed zones with respect to soil arameters, a cluster analysis was carried out taking seed zone as entities nd soil parameters as characteristics. Clustering was done using average inkage method and Euclidian distance as distance measure. The lendrogram obtained is shown in the Figure 4.26.

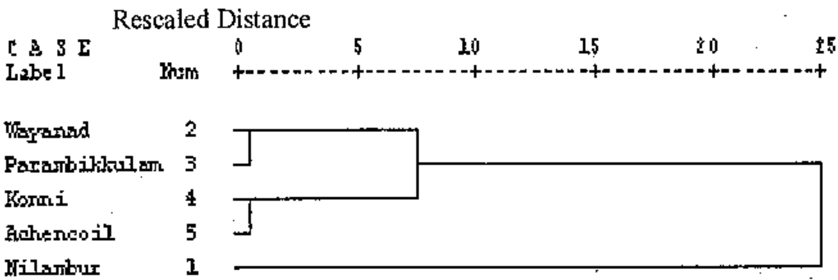


Fig. 4.26. Dendrogram showing resemblance among Seed zones based on soil parameters

At 20 per cent distance, seed zones could be grouped into 3 natural clusters. Seed zones Wayanad and Parambikulam were similar in their soil properties and grouped in to cluster1. Achencoil and Konni seed zones also had similarity in soil properties but entirely different from cluster -1. Nilambur zone alone was grouped into a separate cluster and it was different from cluster-1 and cluster - 2 for some of the soil parameters. The result reveals that soils of Wayanad and Parambikulam seed zones were almost same for the analysed soil properties. Whereas Nilambur seed zone alone becoming separate group and more diverse than that of clusters 1 and 2.

Group/Cluster	SPA
1	Wayanad, Parambikulam
2	Konni, Achencoil
3	Nilambur

4.8 RAPD analysis to estimate the genetic variation

To assess the genetic variations in SPAs, RAPD analysis was carried out using five primers from OPB series (OPB 01, OPB 06, OPB 07, OPB 08 and OPB 10) and one primer from OPE series (OPE 04), out of the 40 primers of OPB and OPE series tested. The primers were selected based on the number and reproducibility of amplified products.

4.8.1 RAPD analysis of eight SPAs using DNA from individual trees

Nine trees from each of the eight SPAs (two SPAs from each of the four seed zones, excluding Achencoil seed zone) were screened for estimating genetic diversity within and between SPAs. Seventy-five RAPD bands were scored for statistical analysis. The molecular size of the PCR amplification products mostly ranged between 100-1000 base pairs (Figure 4.28). Assuming that each RAPD product represented a single locus, 97.4 percent of all the loci were found to be polymorphic.

Within the eight SPAs, percentage of polymorphic loci (ppl) varied from 15.6 (W9 and P1) to 29.9 (K8) (Table 4.28). Similarly, Nei's (1973) gene diversity index (h) varied from 0.06 (W9 and P1) to 0.11 (K8). The magnitude of genetic differentiation among subpopulations (Gst) was 0.7360 indicating that 73.6 percent of the total diversity was between SPAs while the rest (26.4 per cent) of the total variations occurred within SPAs.

The estimates of Nei's genetic distance (D) were calculated for all pair wise SPA comparisons (Table 4.29). Unweighted Pair Group Method with Arithmetic Means (UPGMA) dendrogram was constructed to group the SPAs using Nei's genetic distance. The eight SPAs displayed two major clusters under UPGMA clustering with Nilambur SPAs (N3 and N4; D=0.03) being the most similar and Wayanad (W9) and Konni (K7) as the most distant SPAs, D=0.59 (Figure 4.27). Wayanad seed zone is genetically more distant form all other seed zone (D= 0.40 to 0.59) compared to distance between others (D= 0.23 to 0.39). The UPGMA dendrogram of the eight SPAs from the four seed zones constructed based on the genetic distance between SPAs revealed that SPAs within a seed zone are genetically closer and they are included in single cluster.

Table 4.28. Genetic diversity measures obtained in RAPD analysis of eight SPAs

Seed Zones	Gene diversity (h)	Number of polymorphic loci (npl)	Per cent of polymorphic loci (ppl)
Nilambur (N3)	0.08	18	23.4
Nilambur (N4)	0.09	19	24.7
Wayanad (W1)	0.09	17	22.1
Wayanad (W9)	0.06	12	15.6
Parambikulam (P1)	0.06	12	15.6
Parambikulam (P2)	0.09	14	18.2
Konni (K7)	0.09	21	27.3
Konni (K8)	0.11	23	29.9

Table 4.29. Nei's (1978) measures of genetic distance observed among eight SPAs

Seed zones	K7	K8	W1	W9	N3	N4	P1	P2
K7	****							
K8	0.03	****						
W1	0.55	0.51	****					
W9	0.59	0.56	0.04	****				
N3	0.33	0.37	0.42	0.51	****			
N4	0.33	0.36	0.45	0.55	0.03	****		
P1	0.36	0.37	0.43	0.52	0.29	0.25	****	
P2	0.35	0.39	0.40	0.49	0.26	0.23	0.04	****

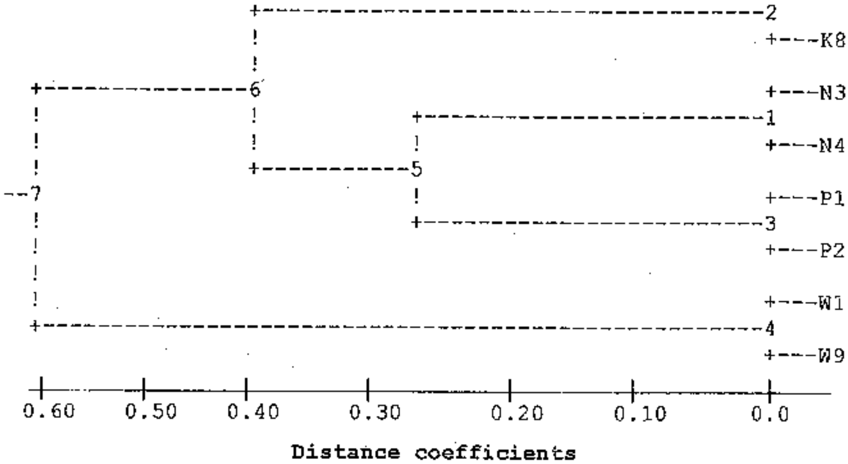


Fig. 4.27. Dendrogram based on Nei's (1978) genetic distance between eight SPAs of four seed zones: Method = UPGMA

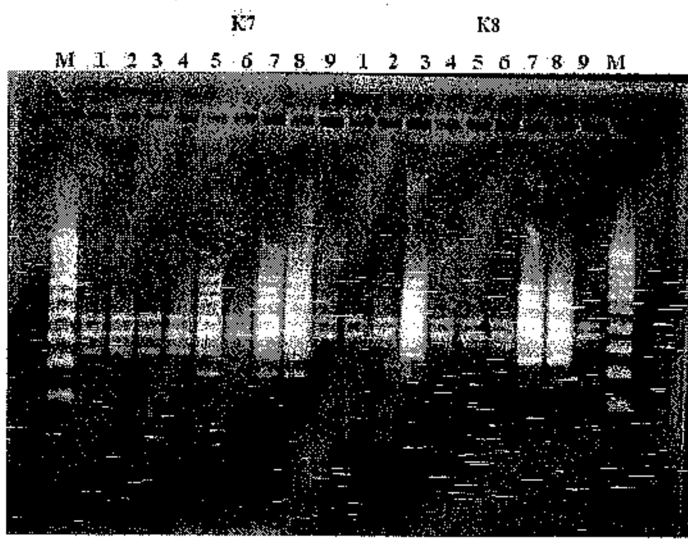


Fig. 4.28. RAPD profile of 18 trees selected from 2 Konni SPAs, viz. SPA (K7) and SPA (K8) using OPB-10 primer; 1-9: trees of each SPA; M: 100 bp DNA marker

4.8.2 RAPD analysis of 26 pooled DNA samples from 26 SPAs

Pooled DNA samples of 15 trees from each of the twenty six SPAs were screened for estimating the diversity of SPAs within seed zone and between the seed zones using the same set of six primers. Eighty eight RAPD bands were scored for analysis (Figure 4.30). The gene diversity ranged between 0.14 for Achencoil to 0.24 for Konni seed zone. Like wise, the percentage of polymorphic loci was highest for Konni (73.86 per cent) and lowest (32.95 per cent), for Achencoil seed zone (Table 4.30).

The estimates of Nei's genetic distance (D) were calculated for pair-wise comparison of the all 26 SPAs (Table 4.31). A UPGMA dendogram was constructed to group the SPAs based on Nei's genetic distance (Figure 4.29). The UPGMA dendrogram comprised of mainly three clusters. Nilambur seed production areas (N1 and N7 and N5 and N7) were the most genetically identical (D=0.18) and Parambikulam (P5) and Wayanad (W5) were the most diverse SPAs among the 26 SPAs (D=0.74). When all the SPAs were considered as separate component and allowed to align in clusters based on genetic distances between them, clustering of SPAs from different seed zone origin into one cluster was seen. This indicated a probable mixing of stumps or seeds of different seed zone origin while raising plantations.

Table 4.30. Genetic diversity measures obtained in Seed zones using 26-pooled DNA samples

Seed Zones	Gene diversity (h)	Number of polymorphic loci (npl)	Per cent of polymorphic loci (ppl)
Nilambur	0.18	40	45.45
Wayanad	0.19	48	54.55
Parambikulam	0.23	54	61.36
Konni	0.24	65	73.86
Achencoil	0.14	29	32.95

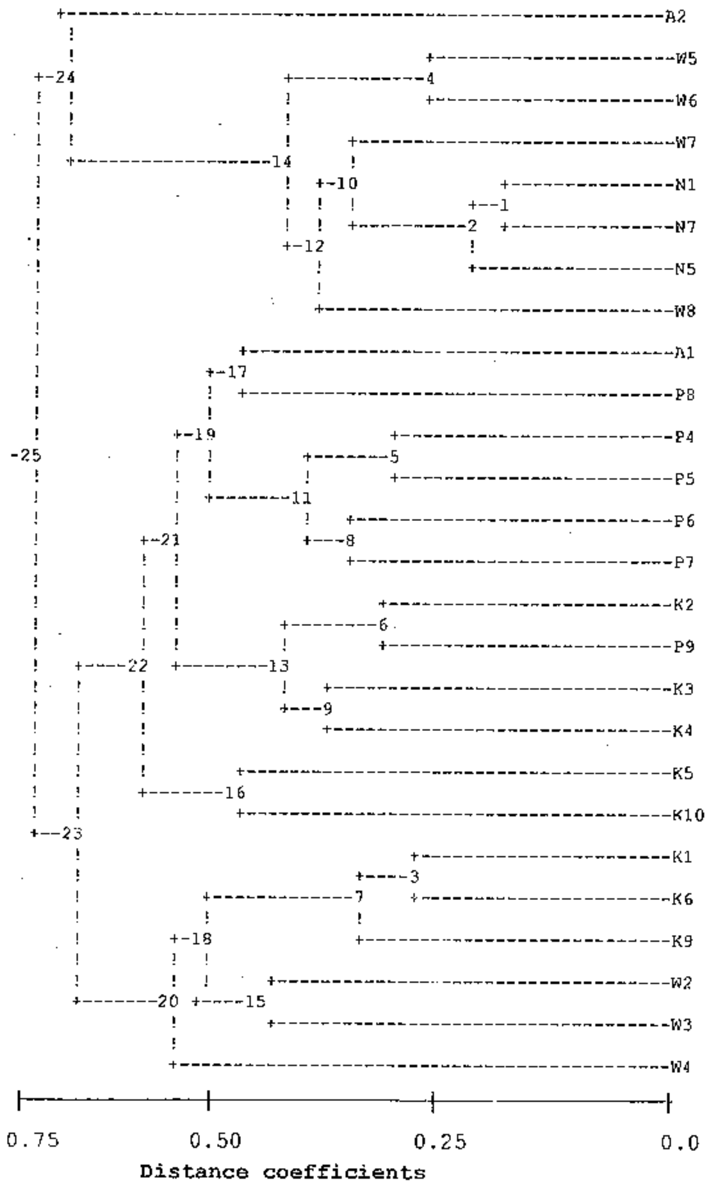


Fig. 4.29. Dendrogram based on Nei's (1978) genetic distance using pooled DNA samples

Table 4.31. Nei's (1978) measures of genetic distance observed among 27 SPAs

	A	C	K1	K2	K3	K4	K5	K6	K9	K10	M2	M3	M4	M5	M6	M7	M8	N1	N5	N7	P4	P5	P6	P7	P8	P9
A	***																									
C	0.000	****																								
K1	0.51	0.42	****																							
K2	0.35	0.37	0.40	****																						
K3	0.61	0.55	0.51	0.35	****																					
K4	0.51	0.45	0.42	0.24	0.27	****																				
K5	0.38	0.40	0.47	0.42	0.42	0.37	****																			
K6	0.47	0.45	0.20	0.33	0.43	0.26	0.43	****																		
K9	0.40	0.35	0.23	0.30	0.37	0.32	0.37	0.26	****																	
K10	0.55	0.38	0.45	0.33	0.51	0.45	0.33	0.45	0.38	****																
M2	0.53	0.43	0.33	0.53	0.53	0.47	0.49	0.43	0.27	0.62	****															
M3	0.53	0.55	0.43	0.53	0.61	0.51	0.57	0.37	0.37	0.51	0.32	****														
M4	0.57	0.51	0.40	0.57	0.53	0.37	0.53	0.40	0.40	0.59	0.32	0.45	****													
M6	0.51	0.53	0.61	0.63	0.55	0.42	0.55	0.53	0.45	0.53	0.51	0.63	0.37	****												
M7	0.55	0.49	0.45	0.55	0.59	0.38	0.51	0.38	0.38	0.53	0.43	0.59	0.40	0.20	****											
M8	0.49	0.47	0.63	0.57	0.57	0.47	0.49	0.40	0.47	0.50	0.61	0.53	0.53	0.37	0.30	****										
M9	0.53	0.55	0.47	0.57	0.49	0.40	0.53	0.40	0.37	0.55	0.49	0.53	0.49	0.37	0.24	0.32	****									
N1	0.45	0.43	0.55	0.53	0.53	0.51	0.45	0.51	0.37	0.63	0.42	0.49	0.53	0.40	0.24	0.35	0.20	****								
N5	0.45	0.37	0.55	0.49	0.57	0.40	0.49	0.47	0.37	0.51	0.39	0.45	0.45	0.30	0.30	0.29	0.35	0.20	****							
N7	0.43	0.32	0.57	0.43	0.47	0.45	0.37	0.45	0.42	0.45	0.40	0.55	0.55	0.32	0.29	0.24	0.33	**0.18**	**0.18**	****						
P4	0.55	0.32	0.49	0.33	0.43	0.38	0.40	0.42	0.42	0.29	0.63	0.47	0.63	0.65	0.60	0.54	0.67	0.72	0.63	0.53	****					
P5	0.59	0.45	0.53	0.40	0.40	0.38	0.51	0.53	0.49	0.35	0.63	0.51	0.59	0.65	**0.74**	0.51	0.59	0.72	0.59	0.65	0.23	****				
P6	0.49	0.37	0.59	0.45	0.42	0.37	0.49	0.55	0.37	0.37	0.53	0.49	0.42	0.37	0.51	0.42	0.57	0.53	0.38	0.47	0.37	0.27	****			
P7	0.45	0.44	0.51	0.38	0.35	0.33	0.45	0.40	0.37	0.33	0.49	0.45	0.38	0.47	0.55	0.42	0.49	0.57	0.49	0.47	0.30	0.24	0.26	****		
P8	0.51	0.35	0.45	0.40	0.37	0.32	0.59	0.42	0.38	0.42	0.51	0.51	0.55	0.42	0.42	0.51	0.47	0.56	0.47	0.49	0.35	0.32	0.37	0.37	****	
P9	0.61	0.40	0.47	0.23	0.35	0.30	0.49	0.30	0.33	0.37	0.45	0.49	0.53	0.63	0.59	0.45	0.53	0.61	0.49	0.40	0.33	0.43	0.45	0.42	0.43	****

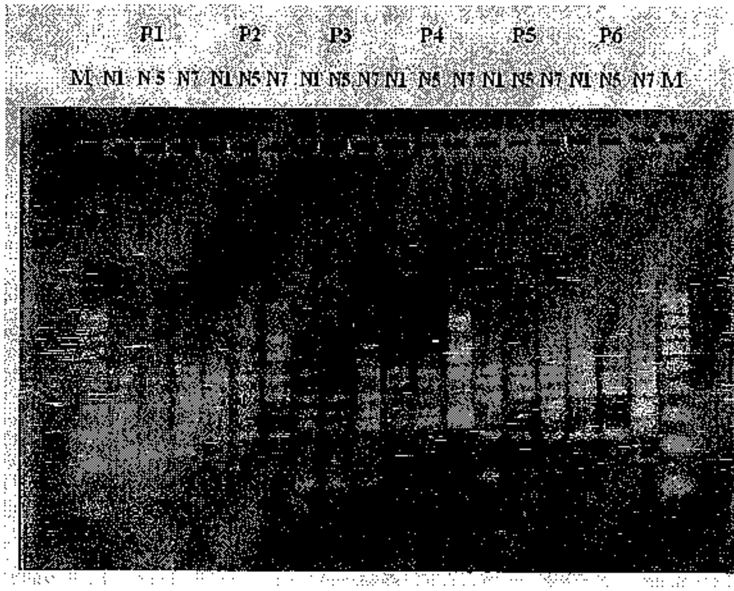


Fig. 4.30. RAPD profile of pooled DNA of three Nilambur SPAs (N1), (N5) and (N7) using six Operon primers.P1-P6: the six operon primers used; M: 100bp DNA marker

4.9 Ranking of teak SPAs in Kerala

Ranking of SPAs was done using rank index developed considering the results of four important parameters *viz.*, fruit production, germination percentage, Dickson quality index and Performance index, giving equal weightage to all the parameters. Ranking index ranges from 10.35 (SPA-W4) to 26.39 (P2). Among all the SPAs of Kerala, SPAs- P2, N4, P1, N7, P4, P3, A3, N3, P6 and K8 were ranked as top ten in their respective orders (Table 4.32). Among the top ten ranks, five were from Parambikulam seed zone followed by three from Nilambur seed zone and one each from Achencoil and Konni seed zones. None of the SPAs from Wayanad seed zone was in the top ten ranks. Poor fruit production and germination percentage might have excluded them from the top ten.

Table 4.32. Ranking of seed production areas of teak in Kerala

SPA	Fruit yield kg/ha	Germination percentage	Performance Index	Quality Index	Ranking Index	Rank
P2	53.52	12.23	39.04	0.75	26.39	1
N_4	40.04	32.22	25.92	0.67	24.71	2
P1	48.91	15.27	31.34	0.79	24.08	3
N_7	36.6	21.84	35.85	0.68	23.74	4
P4	50.4	11.32	26.55	0.8	22.27	5
P3	46.99	9.06	29.47	0.79	21.58	6
A_3	12.81	17.81	48.38	0.77	19.94	7
N_3	13.33	35.23	27.33	0.72	19.15	8
P6	44.7	7.55	22.91	0.95	19.03	9
K_8	4.35	35.93	34.99	0.7	18.99	10
A_1	20.09	9.84	38.3	0.79	17.26	11
P9	26.05	4.53	35.84	0.83	16.81	12
K_7	3.1	27.68	34.54	0.67	16.50	13
P5	28.5	8.59	26.2	0.86	16.04	14
N_5	10.07	28.61	23.77	0.82	15.82	15
N_2	19.89	19.2	23.25	0.6	15.74	16
K_{10}	3.39	22.01	36.31	0.77	15.62	17
A_2	5.87	18.95	35.57	0.75	15.29	18
W9	13.07	4.9	41.62	0.83	15.11	19
K_1	2.66	24.8	31.23	0.7	14.85	20
N_6	15.8	14.41	27.87	0.78	14.72	21
K_4	3.67	22.37	31.97	0.78	14.70	22
K_2	2.34	22.97	31.68	0.65	14.41	23
P8	24.78	2.23	29.47	0.7	14.30	24
K_9	9.58	17.22	27.99	0.61	13.85	25
K_6	5.26	23.64	25.03	0.78	13.68	26
W1	12.68	7.29	33.47	0.74	13.55	27
P7	25.79	2.03	25.48	0.76	13.52	28
W3	15.49	1.44	33.96	0.77	12.92	29
N_1	17.64	10.66	22.44	0.79	12.88	30
W8	15.03	1	33.9	0.97	12.73	31
K_3	2.86	19.12	27.11	0.74	12.46	32
K_5	3.74	14.57	28.19	0.73	11.81	33
W2	15.18	0	30.51	0.83	11.63	34
W7	14.59	2.87	27.99	0.68	11.53	35
W6	11.13	0	34.04	0.65	11.46	36
W5	15.18	0	28.26	0.48	10.98	37
W4	13.74	0	26.83	0.81	10.35	38

Table 4.33. Location and other details of ranked SPAs in Kerala

SPA Code	Year of Planting	Age in years	Location	Forest Division	Extent (ha)	Rank
P2	1944	58	Thoonakadavu	Parambikulam WLD	35.00	1
N4	1945	57	Chathamporai	Nilambur	16.40	2
P1	1943	59	Thoonakadavu	Parambikulam WLD	30.00	3
N7	1961	41	Sankarncode	Nilambur	79.57	4
P4	1945	57	Thoonakadavu	Parambikulam WLD	10.00	5
P3	1945	57	Thoonakadavu	Parambikulam WLD	40.00	6
A3	1942	60	Achencoil	Achencoil	20.24	7
N3	1944	58	Chathamporai	Nilambur	37.12	8
P6	1947	55	Thoonakadavu	Parambikulam WLD	40.00	9
K8	1959	43	Kondodi	Konni	4.24	10
A1	1943	59	Chempala	Achencoil	126.90	11
P9	1955	47	Anapady	Parambikulam WLD	27.00	12
K7	1950	52	Nellidapara	Konni	10.72	13
P5	1946	56	Thoonakadavu	Parambikulam WLD	40.00	14
N5	1956	46	Erampadam	Nilambur	11.12	15
N2	1943	59	Chathamporai	Nilambur	27.04	16
K10	1963	39	Perunthu moozhy	Konni	10.00	17
A2	1943	59	Achencoil	Achencoil	9.00	18
W9	1939	63	Thettu Road	Wayanad North	14.00	19
K1	1947	55	Kummanoor	Konni	8.40	20
N6	1939	63	Edacode(North)	Nilambur	10.00	21
K4	1955	47	Nadavath umoozhy	Konni	11.22	22
K2	1949	53	Kummanoor	Konni	12.60	23
P8	1954	48	Peruvari	Parambikulam WLD	60.00	24
K9	1965	37	Kondodi	Konni	16.72	25
K6	1960	42	Kadiyar	Konni	15.88	26
W1	1948	54	Tholpetty	Wayanad North	28.94	27
P7	1953	49	Peruvari	Parambikulam WLD	40.00	28
W3	1953	49	Camp Road	Wayanad North	20.00	29
N1	1951	51	Kangirkadavu	Nilambur	13.12	30
W8	1963	39	Tholpetty	Wayanad North	10.95	31
K3	1950	52	Vattapara	Konni	12.54	32
K5	1956	46	Nadavathu moozhy	Konni	10.82	33
W2	1949	53	Tholpetty	Wayanad North	23.56	34
W7	1962	40	Tholpetty	Wayanad North	31.05	35
W6	1958	44	Thettu Road	Wayanad North	25.00	36
W5	1955	47	Camp Road	Wayanad North	26.00	37
W4	1954	48	Camp Road	Wayanad North	20.00	38
				Total	**985.15**	

Table 4.34. Ranking of seed production areas within each seed zone of Kerala

SPA	Fruit yield kg/ha	Germination percentage	Performance Index	Quality Index	Ranking Index	Rank
N_4	40.04	32.22	25.92	0.67	24.71	1
N_7	36.6	21.84	35.85	0.68	23.74	2
N_3	13.33	35.23	27.33	0.72	19.15	3
N_5	10.07	28.61	23.77	0.82	15.82	4
N_2	19.89	19.2	23.25	0.6	15.74	5
N_6	15.8	14.41	27.87	0.78	14.72	6
N_1	17.64	10.66	22.44	0.79	12.88	7
W9	13.07	4.9	41.62	0.83	15.11	1
W1	12.68	7.29	33.47	0.74	13.55	2
W3	15.49	1.44	33.96	0.77	12.92	3
W8	15.03	1	33.9	0.97	12.73	4
W2	15.18	0	30.51	0.83	11.63	5
W7	14.59	2.87	27.99	0.68	11.53	6
W6	11.13	0	34.04	0.65	11.46	7
W5	15.18	0	28.26	0.48	10.98	8
W4	13.74	0	26.83	0.81	10.35	9
P2	53.52	12.23	39.04	0.75	26.39	1
P1	48.91	15.27	31.34	0.79	24.08	2
P4	50.4	11.32	26.55	0.8	22.27	3
P3	46.99	9.06	29.47	0.79	21.58	4
P6	44.7	7.55	22.91	0.95	19.03	5
P9	26.05	4.53	35.84	0.83	16.81	6
P5	28.5	8.59	26.2	0.86	16.04	7
P8	24.78	2.23	29.47	0.7	14.30	8
P7	25.79	2.03	25.48	0.76	13.52	9
K_8	4.35	35.93	34.99	0.7	18.99	1
K_7	3.1	27.68	34.54	0.67	16.50	2
K_{10}	3.39	22.01	36.31	0.77	15.62	3
K_1	2.66	24.8	31.23	0.7	14.85	4
K_4	3.67	22.37	31.97	0.78	14.70	5
K_2	2.34	22.97	31.68	0.65	14.41	6
K_9	9.58	17.22	27.99	0.61	13.85	7
K_6	5.26	23.64	25.03	0.78	13.68	8
K_3	2.86	19.12	27.11	0.74	12.46	9
K_5	3.74	14.57	28.19	0.73	11.81	10
A3	12.81	17.81	48.38	0.77	19.94	1
A1	20.09	9.84	38.3	0.79	17.26	2
A2	5.87	18.95	35.57	0.75	15.29	3

Table 4.35. Location and other details of ranked SPAs within the seed zones

Seed zone	SPA Code	Year of Planting	Age in years	Location	Forest Division	Extent (ha)	Rank
Nilambur	N4	1945	57	Chathamporai	Nilambur	16.40	1
	N7	1961	41	Sankarncode	Nilambur	79.57	2
	N3	1944	58	Chathamporai	Nilambur	37.12	3
	N5	1956	46	Erampadam	Nilambur	11.12	4
	N2	1943	59	Chathamporai	Nilambur	27.04	5
	N6	1939	63	Edacode(N)	Nilambur	10.00	6
	N1	1951	51	Kangirkadavu	Nilambur	13.12	7
					Total	**194.37**	
Wayanad	W9	1939	63	Thettu Road	Wayanad (N)	14.00	1
	W1	1948	54	Tholpetty	Wayanad (N)	28.94	2
	W3	1953	49	Camp Road	Wayanad (N)	20.00	3
	W8	1963	39	Tholpetty	Wayanad (N)	10.95	4
	W2	1949	53	Tholpetty	Wayanad (N)	23.56	5
	W7	1962	40	Tholpetty	Wayanad (N)	31.05	6
	W6	1958	44	Thettu Road	Wayanad (N)	25.00	7
	W5	1955	47	Camp Road	Wayanad (N)	26.00	8
	W4	1954	48	Camp Road	Wayanad (N)	20.00	9
					Total	**199.5**	
Parambi-kulam	P2	1944	58	Thoonakadavu	P'kulam WLD	35.00	1
	P1	1943	59	Thoonakadavu	P'kulam WLD	30.00	2
	P4	1945	57	Thoonakadavu	P'kulam WLD	10.00	3
	P3	1945	57	Thoonakadavu	P'kulam WLD	40.00	4
	P6	1947	55	Thoonakadavu	P'kulam WLD	40.00	5
	P9	1955	47	Anapady	P'kulam WLD	27.00	6
	P5	1946	56	Thoonakadavu	P'kulam WLD	40.00	7
	P8	1954	48	Peruvari	P'kulam WLD	60.00	8
	P7	1953	49	Peruvari	P'kulam WLD	40.00	9
					Total	**322.00**	
Konni	K8	1959	43	Kondodi	Konni	4.24	1
	K7	1950	52	Nellidapara	Konni	10.72	2
	K10	1963	39	Perunthumoozhy	Konni	10.00	3
	K1	1947	55	Kummanoor	Konni	8.40	4
	K4	1955	47	Nadavathumoozhy	Konni	11.22	5
	K2	1949	53	Kummanoor	Konni	12.60	6
	K9	1965	37	Kondodi	Konni	16.72	7
	K6	1960	42	Kadiyar	Konni	15.88	8
	K3	1950	52	Vattapara	Konni	12.54	9
	K5	1956	46	Nadavathumoozhy	Konni	10.82	10
					Total	**113.14**	
Achencoil	A3	1942	60	Achencoil	Achencoil	20.24	1
	A1	1943	59	Chempala	Achencoil	126.90	2
	A2	1943	59	Achencoil	Achencoil	9.00	3
					Total	**156.14**	
				Grand Total		**985.15**	

Table 4.36. Ranking of seed zones of Kerala

Seed Zones	Fruit yield kg/ha	Germination percentage	Performance Index	Quality Index	Ranking Index	Rank
Parambikulam	36.97	8.09	29.59	0.80	19.34	1
Nilambur	19.49	23.17	26.63	0.72	18.11	2
Achencoil	11.47	15.53	40.75	0.77	17.50	3
Konni	3.74	23.03	30.90	0.71	14.69	4
Wayanad	14.01	1.94	32.29	0.75	12.25	5

SPAs within the seed zones have also been ranked as a guideline for collection of seeds within the seed zone (Table 4.34). Among the Nilambur seed zone, N4, N7 and N3 were the three top ranking SPAs. Similarly, W9, W1 and W3 from Wayanad, P2, P1 and P4 from Parambikulam, and K8, K7 and K10 from Konni. Among the three SPAs from Achencoil, A3 was the top-ranking SPA. The details of ranked SPAs like, SPA code, year of planting, age in years, location, extent and ranking position are given in Table 4.33. Similar details of SPAs ranked within the seed zone are given in Table 4.35.

Seed zones have also been ranked considering the mean values of the above said parameters for the zones. The respective ranks are as follows, Parambikulam, Nilambur, Achencoil, Konni and Wayanad (Table 4.36). From the ranking of seed zones it can be seen that the Parambikulam and Nilambur seed zones are in first and second position and there is not much difference with respect to rank index value, indicating that these two seed zones are almost similar in all the parameters considered for ranking.

5. DISCUSSION

Kerala teak is known all over the world for its quality and it is largely grown as plantation crop in South East Asian countries. In India, at present there are 1.5 million hectares of teak plantations of which 75300 hectares are in Kerala. About 1000 hectares of teak plantations are felled and replanted annually after the rotation age of 60 years. Approximately 2.5 million seedlings (root trainer seedlings and stumps) are raised annually and utilized for replanting teak by the forest department as well as for planting by farmers in homesteads. The Kerala Forest Department has established 1250 hectares of teak seed production areas, in 5 seed zones viz. Wayanad, Nilambur, Parambikulam, Konni and Achencoil of which currently 985 hectares are used for collection of seeds. On an average, during good seed years, 15 to 20 metric tones of seeds are collected annually for departmental use as well as for supplying to other agencies within and out side the State. The demand for quality seeds of teak is increasing day by day in the local, national and international markets.

The productivity of teak plantations in Kerala is low as compared to expected productivity, which is indicated by present MAI of 3.11 m^3 per hectare against the potential MAI 8.38 m^3 per hectare at the rotation age of 60 years (Nair *et al.,)* 1996). One of the reasons for the low productivity of teak in Kerala is poor quality planting stock raised out of poor quality seeds. Hence, attempts have to be made to supply the source identified quality seeds for raising quality nursery stock to improve the productivity of teak plantations. Considering these issues, an attempt was made to evaluate all the SPAs of Teak in Kerala in terms of various tree, seed, nursery, soil and genetic parameters so that SPAs with superior quality seeds could be identified as a seed sources for raising promising teak plantations, within and out side the state. Katwal (2005) has reported a genetic gain of 5 to 8 per cent from the seeds collected from seed production areas. It was also intended to use the information generated in the present study for the future management of SPAs so that large quantity of quality seeds could be supplied on continuous basis to all ser agencies. The important findings of the study are discussed in this chapter.

5.1 Tree growth parameters

Tree parameters studied in this investigation such as tree height, clear bole height, crop diameter, crown diameter, stem form, stand density and tree volume depend upon several factors such as topography (latitude, longitude, altitude, slope), climate (rainfall, temperature, humidity), edaphic (soil type, nutrient status/ site quality), genotype and age.

Considering tree parameters such as tree height, clear bole height, crop diameter, crown diameter, stem forms, site quality and site index which contribute towards the eliteness of trees and the productivity of plantations, Nilambur seed zone, emerged as superior seed zone compared to other seed zones. Most of the SPAs of Nilambur were located in site quality-II (six out of seven) and the site index, which reflects the productive capacity of the site, was highest for Nilambur zone. RAPD analysis also showed that SPAs in Nilambur seed zone have comparatively higher gene diversity. All these factors might have contributed for the better tree parameters in this zone.

These findings are in conformity with Suri (1984) who reported better performance of Nilambur provenance in provenance trial conducted by him. curiously Champion and Seth (1968) reported average tree height of 36 m and average DBH of 64 cm at 62 years old plantations in site quality II sites, which is much higher than the parameters recorded in the SPAs of Kerala. This could be due variations with respect to site, climate genetic and age factors.

Nagarajan *et al.*, 1996 and Kumar *et al.*, (1997) have reported that many of the tree parameters studied are inheritable. Hence, it is advisable to collect seeds from this seed zone for raising planting stock for overall better performance of future teak plantations.

Of the seven SPAs in Nilambur seed zone, six were in site quality II. Site index, which reflects the productive capacity of the site, was also highest for

Nilambur seed zone. Hence, it is suggested that future selection of SPAs can be made from the better performing teak plantations in Nilambur seed zone, since there are limitations of converting teak plantations of Parambikulam and Wayanad seed zones, as they are located in Wildlife Sanctuaries.

If we consider the tree volume, barring two SPAs, which are in site quality IV (P7 & P8) average tree volume was highest in Parambikulam seed zone. As most of the SPAs in Parambikulam seed zone were located around Parambikulam dam, availability of high soil moisture all through out the year might have contributed for the better growth of trees. Soil analysis also showed that the Parambikulam seed zone was relatively rich in majority of the soil nutrients analyzed (highest percentage of organic carbon, highest available potassium, comparatively higher availability of P, Ca, Mg and Na). All these factors possibly might have contributed for highest tree volume (barring two SPAs in site quality IV) in this zone. Crop diameter and crown diameter are also comparatively higher.

Significantly higher tree density was noticed in SPAs of Wayanad seed zone. This variation could be due to restricted thinning carried out in these SPAs as they are located in Wayanad Wildlife Sanctuary. Probably higher tree density has resulted in lowest crop diameter in this zone for want of sufficient growing space.

Considering the stem roundness, Konni and Achencoil seed zones appear to be relatively better as compared to other seed zones. Hence, it would be advisable to collect seeds from SPAs of these seed zones if teak with less fluting is preferred.

5.2 Phenological parameters

The study of different phenological phases of different teak seed zones reveal that there is variation with respect to different phenological phases within and between the SPAs as well as among the seed zones situated in different geographical areas. These observations are confirmed by the studies of Enescu (1987) who found that the geographic location and overall climate influence the biorhythms and certain physiological processes in plants.

Nagarajan *et al.*, (1996a) have also reported the influence of geographical factors on different phonological phases in teak.

Literature available on different phenological phases in seed production areas (SPAs) of teak in the country is scanty. Only recently studies conducted by Gunaga and Vasudeva (2003a) showed variations among 25 clones of Karnataka with respect to vegetative and reproductive phenologies of teak. They reported that flowering in the clonal seed orchard started in May and continued till August, with peak flowering from May to September, the period of flowering to fruit maturity took about nine months. Sudheendrakumar (1993) observed that, in Nilambur provenance most of the leaf fall in teak occurred during December to February and leaf flushing began in late March completed by April.

Flowering period in teak seed orchard took around six to eight months in East Jawa, (Palupi and Owens, 1998). However, they found that flower bud initiation started between December and January and flowering was noticed, between mid- January to May. There is also a report of stray flowering of teak during January in Tirunnelvelly district of Tamil Nadu (Krishnamurthy, 1973).

In addition to the genetical factors, these variations in phenology could be due to climatic factors such as rainfall, temperature, relative humidity, light, wind speed and biotic factors such as availability of pollinators. The observed variations among different SPAs for different phenological parameters may be due to the specific behavior of the seeds from where the seed was originally collected to raise the SPAs.

In Nilambur, Konni and Achencoil seed zones fruit fall is relatively earlier than other seed zones. Hence, for early nursery operations, seeds can be collected from these seed zones. In Parambikulam, Konni and Achencoil seed zones leaf shedding is much earlier than other seed zones. Hence, fire protection measure shall be advanced in these seed zones due to early leaf accumulation.

Close observations of flowering patterns within each SPAs reveal that there are some odd performers with respect to flowering. These odd performers may loose the opportunity of cross-pollination, leading to inbreeding. To avoid inbreeding, it is better to eliminate such odd performers after monitoring their flowering pattern at least over a period of few years.

Several researchers have recorded asynchronous flowering in clonal seed orchards of many tropical tree species (Gunaga *et al.*, 2005a; Nagarajan *et al.*,(1996), which could be due to geographic factors, specially day light length and latitudinal differences. The genetic value of seeds collected from trees with asynchronous flowering is considered to be low with comparison to seeds collected from synchronously flowering trees (Danusevicius, 1987). Hence it is advisable to collect the seeds from the synchronously flowering trees.

5.3. Fruit and seed characteristics

Fruit production in seed production areas depends on factors such as phenology, flowering behavior, pollination, soil nutrient status, age, climate, topography, edaphic, total reserve food present in the mother plants, insect pest and diseases (Gunaga and Vasudeva, 2005b).

As far as the size of the fruit is concerned, there was no significant difference between the seed zones, but Wayanad seed zone produced relatively bigger sized fruits. There was significant variation in fruit weight among different seed zones. Fruit weight was relatively higher in Wayanad seed zone as compared to other seed zones, the lowest being Nilambur seed zone.

Higher fruit yield per hectare is an important parameter in which all plantation managers are interested, as this information is very often used for planning seed collection and subsequent nursery operations. Recently, Gunaga and Vasudeva have reported variation in fruit yield in seed production areas in Karnataka, which varied from 32.7 to 97.08 per hectare with overall mean of 57.15 kg per hectare (Personal Communication).

In the present study fruit yield/hectare ranged from 3.74 kg to 36.97 kg/ha in SPAs of different seed zones. Significant difference is observed between the seed zones but within the seed zone the variation is relatively less. Such a vide variation in fruit yield could be due to several factors such as poor soil fertility, tree parameters, heavy wind and rainfall during flowering and fruiting, poor fruit setting due to lack of insect pollinators and alternate bearing.

The significantly higher fruit yield (36.97Kg/ha) in the SPAs of Parambikulam seed zone could be due to better tree parameters such as higher tree volume (Table 7), comparatively better crop diameter (Table 5) and tree height (except for trees in SPAs-P7 and P8, which are in site quality IV;Table 8). The spread of the crown, which contributes for the total fruit yield, is also comparatively larger in this seed zone in comparison to other seed zones (Table 5).

The status of soil nutrients like available K (highest), percentage organic carbon (highest) and total Nitrogen, available P, Ca, Mg, Ca are comparatively higher in Parambikulam seed zone as shown in Figures 10 and 11. In addition, as SPAs in Parambikulam seed zone are located in the vicinity of Parambikulam Dam, there was better availability of soil moisture all throughout the year. This could be an additional factor contributing towards better tree growth and high fruit production in Parambikulam SPAs.

Fruit yield in the SPAs of Konni seed zone was lowest as compared to the SPAs of other seed zones. Many of the tree parameters like crown diameter (lowest), crop diameter (better only to Wayanad seed zone, which was lowest), tree height (lowest) coupled with low available K which is essential for higher fruit production, along with other factors listed above by Gunaga and Vasudeva, (2005b) like alternate bearing might have affected the fruit yield in the SPAs of Konni zone.

Low fruit production in clonal seed orchards of teak was reported by Gunaga and Vasudeva (2005b). Major causes reported were asynchronous flowering, low frequency of pollinators, heavy rain coinciding with peak flowering season, unsuitability seed orchard sites, non-flowering individuals. Apart from these, alternate bearing was also one of the reported causes for poor fruit yield. Generally teak trees fruit well almost every year, whereas in Nilambur, two out of every five years were reported to be poor seed years (Troup, 1921).

There is no significant difference in mean number of carpels / fruit in different seed zones which ranges from 3.90 to 4.00 with a mean of 3.98. The number of seeds per fruits for seed zones ranges from 0.95 to 1.10 with a mean of 1. 06.

Suri (1984) observed that the teak seeds from moist localities are comparatively heavier and bigger in dimension than those from the dry localities. Dabral (1976) found that the emptiness was influenced significantly by the site but not by age. Gupta and Kumar (1976) observed that out of sun dried teak fruit collected from 23 sources, in 15 sources empty fruits were in large number; majority of fruits contained only one seed, three and four seeded fruits were less in number.

The qualitative characters such as nature of calyx, hairiness on fruits and splitting of fruits showed considerable difference among the seed zones. Majority of the SPAs in Parambikulam and Wayanad seed zones have loose calyx as compared to other seed zones. Loose calyx may help in better dispersal of fruits. Konni seed zone showed less hairiness with no splitting of fruits.

Hairiness on fruit also shows variation among SPAs. Majority of SPAs (24) show low hairiness on the fruits, where as only 7 SPAs have high and another 7 SPAs recorded medium hairiness. However, fruits from all SPAs of Konni and Achencoil seed zones showed low hairiness. Higher hairiness of fruits which possibly helps in retaining the moisture content for long time is useful characteristic in seed germination. These observations conform with that of Hanumantha *et al.,* (2001), who reported significant variation in hairiness of teak fruits belonging to different clonal origin. Clones from Thithimatti in Karnataka had medium hairiness and clone No.13 and 37 had high and low hairiness respectively.

In the present study fruits from only 15 SPAs showed highest percentage of splitting was observed in SPA- WI (46%) and W2 (37%), (Table 12). Hanumantha *et al.,* (2001) have also reported splitting behavior in teak fruits of different clones in southern Karnataka (Thittimatti origin). The SPAs of Wayanad seed zone of Kerala are geographically nearer to southern seed zone of Karnataka (Thittimatti), and both these seed zones exhibit splitting behaviour. Hence, this splitting behaviour could be due to similar edaphic and climatic factors prevailing in the region and close genetical relationship.

Hairiness and splitting of fruits may help in better absorption and retention of moisture during pre-sowing treatment of fruits leading to better germination. Hanumantha *et al.,* (2001) indicated that the splitting of fruits might facilitate quick germination of fruits. These morphological differences might be useful in easy identification of fruits of different SPAs and the variation in these qualitative traits may also be useful in teak improvement programme.

5.4. Seed germination

Seed germination is one of the best indicators of superiority of a seed source. All plantation resource managers are highly interested in this aspect as germination behaviour of a seed source has significant influence on all nursery operations.

In this study, year-to-year variation with respect to seed germination was observed in different SPAs. The overall germination percentage of freshly collected fruits from different SPAs in the first season (year 2002) was 9.37 per cent and in second season (year 2003) it was 10.14 per cent. This observation is in conformity to earlier findings where Tewari (1992) also reported such inconsistency in germination of teak fruits.

In the present study highly significant variation was observed in seed germination among different seed zones. Considering two years data, Nilambur and Konni seed zones show better germination as compared to other seed zones (Table 15a &15b). During the 1st season the germination percentage in Wayanad (0.44) and Parambikulam (3.06) seed zones was very low. In fact when the trial was repeated during the 2nd season there was no appreciable improvement in germination percentage in these two seed zones (Wayanad 2.17 and Parambikulam 2.31) indicating that some intrinsic factors within the fruit strongly inhibit the germination of seeds, which requires further detail investigation.

Though the percentage of viable seeds In Parambikulam (44.62%) and Wayanad (40.05%) seed zones was fairly good, the average germination percentages during the second seasons germination trail are only 2.31 and .17 respectively. Earlier studies conducted by Sivakumar *et al., (2002)* revealed that seed germination in Parambikulam seed zone was 3.3 per cent and in Wayanad seed zone was 4.5 per cent. This was irrespective of the fact that the seed viability of Parambikulam seed zone was 81.67 per cent and that of Wayanad seed zone was 71.43 per cent. This indicates that the factors other than seed viability are strongly influencing the germination behaviour of these two seed zones, which requires further investigation.

Dormancy period in teak seeds which affects the germination is known to vary from four weeks to a maximum of 3 years within a seed lot Keiding (1985) due to a number of complex and possibly interrelated factors. Teak exhibits both seed-coat dormancy (exogenous dormancy) and embryo dormancy (endogenous dormancy) at the same time. Exogenous dormancy in teak is mainly due to the presence of hard stony pericarp, which prevents the exchange of gases and exerts mechanical resistance to embryo growth (Joshi and Kelkar, 1975; Tewari, 1992). Gupta and Pattanath (1975) have reported that inhibitors present in mesocarp can also induce chemical dormancy in teak.

Several authors have reported poor germination of seeds from natural forest and from clonal seed orchards (Indira and Basha, 1999; Mathew and Vasudeva, 2003). Several researchers followed different pre-sowing treatments to increase germination percentage of teak fruits and to release seed dormancy (Moss, 1892; Dalmale, 1901; Wimbush, 1927, Bryndum, 1966; Joshi and Kelkar, 1975; Tewari, 1992; Chacko *et al., 1997).*

Indira and Basha (1999) compared percentage of germination of teak seeds collected from plantations, seed production areas as well as seed orchards and found significant difference among them. The percentage germination ranged from 16.6 to 32.99 for plantations, 6.11 to 32.15 for seed production areas, 2.08 to 29.75 for plus trees and seeds obtained from seed orchards showed the least germination, which ranged from 0.97 to 16.39 per cent.

Prasad and Jalil (1986) observed that germination of seeds from orchards varied from 4.2 to 37.8 per cent and seeds of natural stands showed higher germination, which varied from 13.93 to 54.52 per cent. Poor seed germination in teak clones of Karnataka, which ranged from 0.39 to 11.09 per cent with average germination percentage of 5.77 up to 140 days of sowing, has also been observed by Mathew (2001)

Reasons for lower fruit germination in teak have been reported by several authors. Probably the fertility index of the site, followed by factors such as the presence of water soluble germination inhibitors in the mesocarp of fruits and the phenomenon of after ripening probably influence seed germination in teak (Gupta and Pattanath, 1975). Whereas Mathew (2001) controlled these factors while testing germination of teak fruits obtained from clones of Karnataka by collecting only the fully matured and about to drop fruits and stored for one year. Further before sowing the seeds, mesocarp of fruits was physically removed and hence influence of a putative water soluble germination inhibitor could also be eliminated. Even after controlling these factors, he still obtained poor germination of 0.39 to 11.09 per cent indicating the above said factors may not be decisive for germination.

Delay and non-uniform germination are major problems associated with teak fruits. In the present study, most of the seed lots commenced germination after seven to ten days of sowing. There was no germination in SPAs *viz.* W2, W4, W5, W6 and W8 even after 120 days of sowing in vermiculite. Most of the SPAs in Nilambur and some of SPAs of Konni origin show early germination *(i.e.* seven days after dibbling). Whereas in fruits of SPAs of Wayanad and Parambikulam seed zones germination was delayed and it commenced after 12 days of sowing. Chacko *et al.*, (1997) reported that germination of teak fruit in irrigated nursery bed commenced five days after sowing. Whereas Mathew (2001) reported that most of the half-sib families of teak clones started germination after 4 days of sowing. These findings are almost in conformity with the present study.

5.5. Seed viability

Viability of teak seeds depends upon the seed size, seed source, seed year and climatic conditions during flowering and fruiting period. The viability of seeds directly influences germination percentage of seeds provided all other conditions like pre-treatment of seeds, *etc.* are favourable for germination. In the present study, the viability of teak seeds ranges from 31.65 (W7) to 62.30 per cent (P5 and K1) with overall mean of 50.29 per cent. Among the seed zones of Kerala, Konni (47.75 percent) and Nilambur (47.71per cent) seed zones had significantly higher viable seeds than other seed zones. This was reflected in the higher germination percentage of these two seed zones (Nilambur 24.35 per cent, Konni 24.79 per cent) in comparison with other seed zones.

Chacko *et al.* (1997) reported germination percentage of 43 to 65 per cent when teak seeds with 62 to 64 per cent viability were subjected to germination trial. They also indicated the multiplication factor of 0.43 to 0.65 for prediction of germination percentage. In the present study, when this multiplication factor was verified with the germination percentage of seed lots from different SPAs, there was variation. This could be due to intrinsic and extrinsic factors present in teak fruit leading to poor germination, which requires further detailed investigation.

5.6. Seedling growth and physiological parameters in root trainers

Study reveals that Nilambur and Parambikulam seed zones are the best seed zones for mass production of quality seedlings in root trainers. In root trainers, the tap root system undergoes air and light pruning and gives raise to large number of secondary and tertiary roots increasing the surface area for absorption of water and nutrients both from surface and subsurface layers (Plates 17, 19 and 21). The healthy root system of seedlings raised in root trainers helps in better and quick establishment leading to higher survival percentage in the field. The higher survival percentage of teak seedlings raised in root trainer was reported to be more than 90 by Khedhker and Subramanian, (1995) and Prabhu (1998).

The performance of a seed source at a given site depends partly on the site conditions and partly on provenance region from where the seed was collected (Glover, 1987 and Chadhar, 1994). Gupta *et al.,* (1992) reported that the seed source, which exhibited better performance during the initial stages of growth were found to be better throughout. Results also indicated that evaluation of seed source at nursery level using all seedling attributes was important to determine the seedling quality and their vigour, which influences the growth and development of seedlings under different field conditions.

5.6.1 Seedling height and basal diameter

Usually root trainer nursery stock is transplanted between 90-100 days in the field. In this study, though the observations were recorded at 30, 60 and 90 days and the results of nursery parameters recorded at 90 days were used for comparison of performance of different seed sources.

There was a significant difference among SPAs of Kerala in respect to seedling growth parameters. Considering three months old seedlings, the seedling height varies from 10.58 (W2) to 16.77 cm (K5); whereas basal diameter ranges between 4.10 (W3) to 6.01 mm (P3; Table 18). These parameters also show significant difference among seed zones for (Table 19). Seedlings from Nilambur, Parambikulam and Konni seed zones were performing equally well.

Mathew (2001) found that seeds collected from clonal seed orchards of Karnataka showed variation for seedling height and collar diameter, where average seedling height of 6.36 and 7.70 cm and average collar diameter of 2.60 and 2.77 mm recorded at 60 and 90 days, respectively after sowing in polythene bags. The disparity and low values recorded by Mathew could be due to type of containers and potting mixture used. Such provenance variation has also been reported by Jayasankar *et al.,* (1999a) where significantly higher height and collar diameter were observed in Nilambur, Parambikulam and Malayattur natural provenances as compared to others.

5.6.2 Leaf area and biomass of seedlings

With respect to leaf area significant difference was observed among SPAs which ranged from 97.14 (W9) to 222.8 cm^2 (N5) with respect to leaf area. There was significant difference among different seed zones also for leaf area. Parambikulam seed zone recorded highest leaf area (192.8 cm^2), followed by Nilambur and Konni seed zones (Table 23). Mathew (2001) also reported variations in leaf area, which ranged from 608.4 to 1521.3 cm^2 at 300 days after sowing the progenies raised using seeds collected from clonal seed orchard of teak. Generally, more number of leaves and higher leaf area leads to increase in biomass.

The biomass production is a function of the photosynthetically active radiation falling on the leaves (Hazara and Tripathi, 1986). In general, when optimal leaf biomass increases, total biomass production would also substantially increase. Higher leaf area and total biomass of seedlings are good indicators of higher photosynthetic carbon fixation at seedling stage. Such variation has already been reported by Mathew (2001) among teak clones for biomass production at seedling level.

Ninety days old seedlings recorded significant differences among the seed zones for only shoot dry weight, whereas root dry weight and total dry weight did not show significant differences among seed zones. This could be due to restricted growth of seedlings in root trainers (150 cc) at later stages of growth. Initially (60 days), seedlings from Parambikulam and Nilambur seed zones recorded higher biomass (Table 21) as compared to other seed zones. However at later stage (after 90 days), seedlings from Achencoil, Konni and Parambikulam seed zone recorded higher biomass but there was no significant difference between the seed zones. Study carried out by Jayasankar et al., (1999a) using one-year-old teak seedlings of different seed zones also showed similar results, where Parambikulam, Nilambur and Malayattur seed zones with higher leaf area and leaf dry weight put higher dry matter in comparison to other seed zones studied. However, there was no significant variation in root biomass between 60 to 90 days of growth among the seed zones.

There was no significant difference in root dry weight and total dry weight in 90 days old seedlings indicating that seedlings may not put more proportionate growth beyond this period in the limited growing media in root trainers and hence they should be transplanted before 90 days of growth for better survival, establishment and growth in the field.

5.6.3 Seedling growth indices

The growth indices such as shoot to root ratio, sturdiness quotient and Dickson quality index are the tools for evaluation of seed sources in the Nursery. These growth indices were calculated as per the procedures narrated inmaterials and methods and the performance of different seed sources in root trainers were evaluated.

There was no significant difference in shoot to root ratio if we consider seed zones. But it was highest in Konni and Nilambur seed zones indicating that the seedlings from these zones have better root system comparing to other seed zones.

If we consider the seed zones, sturdiness quotient range from 3.45 (Wayanad) to 4.04 (Konni; Table 23) indicating that seedlings from Wayanad and Parambikulam seed zone are sturdier than others. The better SQ in Wayanad seed zone could be due to lower height (11.54 cm; Table 19) in comparison with other seed zones, which brings down the sturdiness quotient, a ratio of total shoot height to collar diameter. Generally, seedlings of Wayanad seed zone showed stunted growth in root trainers as compared to other seed zones. Thompson (1985) reported that SQ for tropical species is usually lower and the lower the SQ betters the performance of seedlings. The present study it indicated that seedling raised using seeds from Wayanad and Parambikulam are suitable for planting under harsh field conditions, as the SQ is better.

Dickson quality index, which takes in to account other parameters like sturdiness quotient and shoot root ratio, did not differ significantly among the seed zones. Parambikulam seed zone recorded highest score of 80, indicating overall better performance of seedlings raised from the seeds collected from this zone.

Cluster Analysis of seedling growth parameters showed that largely Wayanad and Parambikulam seed zones stand apart as two separate groups and other three seed zones cluster together to form a another group. The comparison of results of all the nursery parameters studied also indicated almost similar trend where Wayanad seed zone stands apart in many seedlings parameters. Nilambur, Konni and Achencoil seed zones showed similar trend for many seedlings parameters studied.

5.6.4 Chlorophyll fluorescence parameter

Variations in chlorophyll fluorescence provide important information on photosynthetic ability of studied plants. This is a rapid, non-destructive and convenient method to estimate the photosynthetic ability of plants. Chlorophyll flourometer was used to record the chlorophyll fluorescence parameters.

Among all the parameters studied, the performance index was the best parameter to evaluate photosynthetic ability of seedlings, as this index considers out come of other parameters. The performance index shows significant differences among SPAs as well as seed zones. The Achencoil seed zone shows the maximum PI value as compared to others indicating that probably this was the photosynthetically most efficient seed zone. Further seedlings raised out of the seeds collected from this zone may perform better under harsh field conditions because of high photosynthetic efficiency.

The studies made with respect to chlorophyll florescence parameters are very scanty in tropical tree species. Husein et *al.*,(2004a) reported diurnal variation in Fv, Fm, Fv and Fv *IFm* in different *Ficus* spp. Maximum Fv *IFm* of 0.736 and 0.758 was observed *Ficus nemoralis* and *F. roxburgii*, respectively. Such diurnal changes in chlorophyll fluorescence of different species have been reported by Ehleringer et *al.*,(1986) and Joshi (1995). Chacko (2005) reported variation in chlorophyll fluorescence of seedlings grown under different shade and irrigation regimes in teak. He has also observed variation in performance Index (PI), which ranged from 4.6 to 35.0 in teak seedlings. The values conform with the result obtained in the present study where the mean PI value is 30.97.

5.7. Soil analysis

No significant variation was observed with respect to sand, silt and clay content between SPAs and seed zone of teak in Kerala. The bulk density was lower in SPAs of Konni and Achencoil seed zones and higher in Wayanad, Nilambur and Parambikulam seed zones. This could be due to the fact that Konni seed zone was relatively free from trampling by wild life and cattle, whereas Wayanad and Parambikulam seed zones are within wildlife sanctuaries, which are subjected to soil compaction by wild animals. Nilambur seed zone was surrounded by human habitations and hence subjected to trampling by cattle leading to compaction and increase in bulk density.

Water holding capacity of Konni, Achencoil and Parambikulam seed zones was much higher in comparison with other seed zones (Figure 8). Organic carbon content was also found to be higher in Konni, Achencoil and Parambikulam seed zones (Figure 10), indicating that the soils are rich in humus, which would facilitate retention of water resulting in higher water holding capacity of soil.

In different seed zone the soil pH ranges from 4.62 to 5.80.Soil of Konni seed zone are more acidic compared to other seed zones. Puri (1951), Banarjee et *al.,* (1986), Tewari (1992) observed that good teak occurs in soils where the pH values range from 6.5 to 7.5. Aparanji (2000) reported that teak plantations growing in different bio-climatic zones of Karnataka showed significant variation in respect of chemical properties of soils. Bulk density varied from 1.15 to 1.6 g / cc and soil pH of 6.2 - 8.2.

The organic carbon was highest in Parambikulam seed zone followed by Konni and Wayanad seed zones. Similarly total nitrogen was highest in

Konni seed zone, followed by Achencoil and Parambikulam seed zones. Even though total N, organic carbon and other nutrients analyzed are found to be low in Nilambur seed zone, many of the tree parameter studied were better. This could be due to genetic and other climatic factors. RAPD analysis also showed that Nilambur seed zone has relatively more gene diversity (Table 30).

Total nitrogen, available phosphorous and potassium are the three major elements that influence the tree growth as well as fruit production. In the present study, the total N ranges from 532 (Nl) to 868 ppm (K8) and it was highest in Konni seed zone followed by Achencoil seed zone. Available P ranged from 6.7 (N2) to 12.7 ppm (K5). There was significant difference among seed zones for total N and available P. Available K ranged from 14.7 (N4) to 138.8 ppm (P5). Among all the seed zones, Parambikulam seed zone has highest available K, which may be the contributing factor for superior tree parameters including high fruit production.

Balagopalan and Jose (1991) reported significant differences for physical and chemical properties of soil among five different vegetation types taken up for study which included teak plantation of Trichur forest division in Kerala.

They recorded variation among three layers of soil in respect of different soil parameters such as sand, silt, clay, soil pH, bulk density, water holding capacity, organic carbon, total nitrogen and available phosphorous. The respective mean values of the above components for three layers were 74.6%, 6.8%, 18.6%,6.1, 1.4g/cc, 32.9%, 1.0%,654 ppm and 14.68 ppm. Results of the present study are also in conformity with the above results of Balagopalan and Jose (1991).

Variation in chemical properties such as organic carbon (3.4-12 %), available nitrogen (174-950 kg/ha), phosphorous (12-57kg/ha), potassium (115-500 kg/ha), exchangeable calcium (11-27.5 me/l) and magnesium (4-14 me/l) among teak plantation of Karnataka has been reported by Aparanji (2000). Samapudhi (1967) reported that teak soil of Thailand was found to contain 29 ppm of exchangeable potassium in comparison with non-teak soils (about 20 ppm).

Parambikulam seed zone has highest percentage of organic carbon, available potassium and comparatively higher content of total nitrogen, available P, Ca, and Mg. The water holding capacity as explained earlier was also relatively high. All these factors combined with climatic factors, might have influenced the tree parameter, especially tree volume, crop diameter and crown diameter as well as fruit yield which was highest (36.97 kg per ha; Table 10).

The cluster analysis of soil parameters shows that five seed zones can be clubbed into three groups. Wayanad and Parambikulam seed zones were clustered in one group. These seed zones are situated in Wildlife Sanctuaries with relatively higher elevation and receive similar management inputs as compared to other seed zones. Nilambur seed zone stands apart as another group. This was also indicated by site quality except one SPA which is in site quality III; all other SPAs fall in site quality II. Konni and Achencoil seed zones are geographically closely located and constitute another group.

5.8. RAPD analysis to estimate the genetic variation

In teak, population genetic diversity structure and genetic status of superior plus trees have been studied using molecular (isozymes/RAPDs) markers in recent years (Kertadikara and Prat, 1995; Kjaer and Suangtho, 1995; Changtragoon and Schmidt, 2000; Watanabe and Widyatmoko, 2004). All these studies showed that teak is an out breeding species and revealed variation between and within populations. The natural populations from the Western Ghats region showed more diversity compared to those from Central India (Nicodemus *et al.,* 2005). Understanding the genetic diversity status of the thirty four seed production areas of teak *(Tectona grandis* L.) belonging to four seed zones namely Konni (12 SPA), Wayanad (9 SPA), Nilambur (5 SPA) and Parambikulam (8 SPA) will be useful in deciding strategies for management of SPAs and for ascertaining the quality of seeds for raising future plantations.

Among the eight SPAs used for detailed analysis, trees located in the two SPAs from Konni are found to be more divergent genetically than other SPAs by virtue of their higher gene diversity indices (h) and percentage of polymorphic loci. Generally, gene diversity within all the SPAs is poor which indicated relatedness among trees within SPAs. Inbreeding among these trees may result in poor seed set, low seed viability and unhealthy seedlings. Nellidappara (K7) and Kondodi (K8) SPAs of Konni seed zone showed the highest gene diversity and percentage of polymorphic loci. At the same time, Thettu Road (W9) SPA of Wayanad and Thoonakkadavu (PI) SPA of Parambikulam showed the lowest gene diversity and percentage of polymorphic loci. Low level of polymorphism and genetic diversity observed within most of the SPAs may be due to narrow genetic base of seeds used for raising plantations (SPAs). It may also be noted that SPAs are heavily thinned plantations, which reduced the original genetic diversity. Although, no information is available regarding the source of seed lots used for raising these plantations (SPA), the genetic relatedness of trees within individual SPAs of a seed zone might be indicative of the existence of half sib progenies. Probably, the plantations might have been raised using seeds of a couple of mother trees of very narrow genetic base. Considering the low level of genetic diversity within the SPAs for raising future plantations, seeds should be collected from as many trees as possible and bulked to maintain a broad genetic base in the resulting plantations. While the genetic diversity indicators such as gene diversity index and percentage of polymorphic loci within the studied SPAs (among trees) are poor (Table 30) , the diversity indicators among SPAs within a seed zone are higher (Table 32). Hence, it may be better to pool the seeds from different SPAs of a seed zone for raising plantations.

The impact of higher genetic diversity in a breeding population is generally reflected in their progenies in terms of better seed germination, seedling vigour and field adaptability. In the present study, genetic diversity parameters such as gene diversity index and percentage of polymorphic loci were comparatively higher for Konni and Nilambur SPAs. Many of the seedling parameters studied are also comparatively higher for Konni and Nilambur seed zones. Probably this could be a reflection of the higher genetic diversity of trees in the SPAs of the seed zones from where the seeds were collected.

5.9. Ranking of teak SPAs in Kerala

The ultimate aim of maintaining seed production areas m the state is to obtain quality seeds in large quantity for raise the quality nursery stock for improving the productivity of teak plantations. All the SPAs in the state have been ranked considering the results of four important parameters studied that have direct influence on the quantity and quality of the seeds produced as well as on the quality of nursery stock. These included two seed parameters *viz.*, the total fruit yield per hectare and germination percentage and two nursery parameters viz., Dickson quality index and Performance index. Equal weightage was given to all these parameters in the ranking index developed for ranking SPAs.

Among 38 SPAs of Kerala, SPAs- P2, N4, PI, N7, P4, P3, A3, N3, P6 and K8 have been ranked as top ten ranking SPAs in their respective orders (Table 34). None of the SPAs from Wayanad seed zone was in the top ten ranks. Poor fruit production and low germination percentage have probably affected the ranking of the SPAs from Wayanad seed zone.

SPAs within the seed zones have also been ranked as a guideline for the collection of seeds by the Forest Department in respective seed zones and the ranking is given in Table 36. The location and other details of all 38 ranked

SPAs and ranking of SPAs within the seed zones are provided in (Table 35 & 37) respectively

Teak seed zones of Kerala have also been ranked as per the rank index developed considering the mean values of above said parameters for each zone. The ranking position is shown in Table 38. From the ranking of seed zones it can be seen that the Parambikulam and Nilambur seed zones are in first and second position and there is no much difference with respect to ranking values, indicating that these two seed zones are almost similar to all the parameters considered for ranking. It is pertinent to note that almost all tree parameters evaluated in the study are also comparatively much better in these two zones as compared to other seed zones in the State. Therefore it is advisable to collect seeds from Parambikulam and Nilambur seed zones followed by other seed zones from the SPAs as per their ranking for raising quality nursery stock leading to improvement in the productivity of teak plantations in Kerala.

6. CONCLUSIONS AND RECOMMENDATIONS

Considering tree growth parameters like tree height, clear bole height, diameter, crown diameter, tree volume and stem form, Parambikulam and Nilambur seed zones emerge out to be superior in comparison to other seed zones. As many of the tree parameters are reported to be inheritable, collection of seeds from these seed zones for nursery operations may improve the productivity of teak plantations.

Site index, which reflects the productive capacity of SPAs, is highest in Nilambur seed zone. This indicates that Nilambur seed zone is potential site for teak. Hence more SPAs may be considered in Nilambur seed zone, as there are limitations of converting more areas in Parambikulam and Wayanad seed zones, since these seed zones are located in wildlife sanctuaries.

Out of the 38 SPAs, five SPAs (W6, P7, P8, K1 and K3) are in site quality IV and the seeds collected from these SPAs may not perform better. Hence, it is suggested to eliminate these SPAs from the list of SPAs and to manage other SPAs more scientifically so that the required quantity of quality seeds can be collected from these SPAs.

There are variations among different seed zones for different phenological phases indicating wide variability among seed zones. This could be due to local, climatic and edaphic factors in addition to genetic make up of the population. Trees, which show consistently asynchronous flowering, shall be identified and culled from the existing SPAs to reduce inbreeding and production of genetically superior seeds. Plantations raised using seeds collected from synchronously flowering SPAs shall be converted into SPAs in the long run to encourage cross breeding and to improve the genetic base of the seeds. Clonal/seedling seed orchads may be raised using clonal material/seeds collected from synchronously flowering trees of different seed zones to widen the genetic base of the clonal/seedling seed orchads.

The fruit yield was highest in Parambikulam seed zone, followed by Nilambur. Whereas Konni seed zone registered very low fruit yield. There was significant variation in germination percentage of teak fruits collected from different seed zones. The germination percentage in Parambikulam and Wayanad seed zones was low compared to other zones, though the percentage of viable seeds was fairly good which requires further investigation.

As majority of the tree parameters in Parambikulam seed zone are comparatively better and the fruit production per ha is the highest, improvement in germination percentage of seeds collected from this seed zone may promote productivity in teak plantations.

Teak seedling growth in root trainers showed no significant variation in total root dry weight and total dry weight at 90 days of seedling growth. This indicated that, seedlings after 90 days may not put additional growth for want off sufficient nutrients and space in the root trainer cells of 150 cc capacity. Hence, it is advisable to transplant the teak root trainer nursery stock raised in 150 cc cells before the congestion sets in for better field performance and economizing on nursery maintenance.

As per chlorophyll fluorescence parameters, the performance index, which is one of the best index for determining the photosynthetic ability of seedlings, was highest in Achencoil seed zone. Hence, for planting in harsh field conditions including wastelands, seeds from Achencoil seed zone may be preferred.

All the analyzed soil parameters showed that Parambikulam seed zone was better placed than other seed zones, which was reflected, in better tree parameters and highest fruit yield per hectare. These indicate that the SPAs in other seed zones should also be managed scientifically to improve the physical and chemical properties of the soil for their better performance.

RAPD analysis showed that SPAs selected from Konni and Nilambur seed zones had comparatively higher gene diversity and percentage of polymorphic loci than those SPAs selected from other zones. At the same time, SPAs of Wayanad and Parambikulam showed the lowest gene diversity and percentage of polymorphic loci. This indicates that SPAs of Konni and Nilambur seed zones are genetically superior to the SPAs of other three seed zones. As the gene diversity in SPAs is generally low, it is suggested to pool seeds of different SPAs for nursery operations to improve the genetic base of the seeds.

The ultimate aim of maintaining SPAs is to collect large quantity of quality seeds to raise quality nursery stock. As total fruit yield, germination percentage, quality and performance index have direct bearing on quality and quantity of seeds produced and nursery stock raised, the 38 SPAs in the State have been ranked based on the rank index developed taking into consideration the above parameters giving equal weightage to all the parameters.

It is suggested that in all future plantation programmes seed source details are recorded in plantation journals as well as in working plans with all other details including details on viability and germinability of seeds, as these details are essential for any future improvement in seed/nursery/tree improvement programmes. It is also suggested to maintain journals for seed production areas similar to plantation journals.

The results of the study, carried out for the first time in the State, indicate that the information generated has significant applied value in obtaining quality seeds for improving the productivity of teak plantations in Kerala and also for scientific management of SPAs, so that large quantity of quality seeds are available on a continuous basis for future plantation programmes.

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