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Impact of Environmental Factors and Altitude on Growth and Reproductive Characteristics of Teak (*Tectona grandis* Linn. f.) in Southern India

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Abstract

The effect of different environmental conditions and altitudes on the growth and reproductive characteristics in 12 teak plantations at 4 different blocks (Cauvery canal bank, Topslip and Parambikulam (Tamil Nadu), Nilambur and Wayanad (Kerala) of Southern India was investigated. The annual rainfall and mean monthly temperature of the study areas varied significantly from 1390 to 3188 mm and 16 to 38°C respectively. The teak plantations in Cauvery canal bank which grow in continuous moisture condition (8-10 months) retain the leaf for longer period due to moisture resulting continuous supply of photosynthates leads to fast and outstanding growth. The girth at breast height (GBH) of 34-years-old tree in canal area was similar to that of 40 to 49-years-old trees in other locations, indicating that teak plantations with regular watering and silvicultural practices may be harvested at the age of 30 years. The leaf fall, flowering and fruiting showed significant variations in different teak plantations due to environmental factors and altitudes. It was found that increase of rainfall enhances number of flowers in the inflorescence in teak. Tholpatty (block-IV) showed more flowering in a inflorescence (3,734-3,744) compared to other plantations (1,678-3,307). Flowering in Nilambur and Wayanad coincided with heavy rainfall resulting low fruitset (1.1-2.3%) probably heavy rainfall ensuing restriction of pollinators for effective pollination. On the other hand, flowering in Cauvery canal bank (Block-I) was not coincided with high rainfall exhibited high fruitset (2-3%). About 66 to 76% of the fruits in different plantations were empty, and it is one of the main reasons for poor germination in teak. The seeds of Topslip and Parambikulam (Block-II) showed higher seed weight, maximum seed filling and good germination indicating that the environmental factors and altitude play significant role in fruit setting and seed filling in teak. In addition, the teak plantations in Topslip and Parambikulam showed good growth suggesting that plantations in the altitude range of approximately 550-700 m may be suitable for converting into seed production areas for production of quality seeds.

Key Words: altitude, growth, phenology, rainfall, *Tectona grandis*

Introduction

Teak is one of the most important timber species in the world, and in India about 50% of the global teak plantations (1.7 m ha) are established in different environmental conditions and different altitudes. The growth of teak tree is often influenced by a number of eco-climatic factors (Tewari 1992; Palanisamy et al. 2005; Surendra 2013). Moist teak of Western Ghats region in Peninsular India was reported to have good growth and tree form (Kjaer and Suangtho 1995), while teak growing in Nilambur, Kerala state is known for superior wood quality all over the world (Prabhu

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2007). The International provenance trials of teak established in Thailand indicates that Indian teak provenances are performing better compared to local, Indonesian and African provenances (Kertadikara and Prat 1995; Shrestha et al. 2005). In India, about 20,000 ha of teak plantations are established in Cauvery canal banks of Tamil Nadu (Kala et al. 2005). The rotation period of teak in India is 50 to 80 years whereas teak growing in canal areas showed fast growth with good girth and height within 20 years due to continuous moisture, and harvested at the age of 30 years (Palanisamy et al. 2005; Palanisamy et al. 2009). The teak productivity in India is very low (2.85 m^3/ha/year) when compared to other countries. Nevertheless, the influence of rainfall, temperature and altitude related to teak growth is not clearly understood.

Phenological changes in tree species are mainly caused by seasonal rainfall (Eamus and Prior 2001) and duration, and intensity of seasonal drought (Mooney et al. 1995). According to Surendra (2013) the leafless period in natural teak populations in Karnataka was more in low rainfall areas with high temperature compared to high rainfall areas with low temperature. Flowering phenology was well studied in most of the temperate and sub-temperate species such as radiate pine, loblolly pine, black pine and *Eucalyptus citriodora* (Matziris 1994). However, it is poorly understood in tropical species (Corlett 1998). Teak produced profuse flowering of about 3,000 to 8,000 flowers in an inflorescence while the fruitset percentage was very low (1%), and the reason for low fruitset in teak is not clearly known. High fruit set with maximum seed filling are the important criteria for converting a better plantation into seed production area.

Seed size often controls the germination and initial seedling growth in many tree species which plays pivotal role in plantation establishment (Murali 1997). The larger seeds enhanced seed viability, germination, survival rate, growth and biomass in teak seedlings (Singh et al. 2006; Gunaga et al. 2011; Jijeesh and Sudhakara 2013). Further, teak shows moderate germination (30-50%) in moist areas and poor germination (5-10%) in dry areas (Palanisamy 2014), but the reason for low germination is not clearly understood. Teak fruit is a drupe with 4 locules, and seed filling varies from 0 to 4 depending upon the locations. Understanding the seed filling is an important criterion for nursery establishment, no systematic study has been made in teak (Troup 1921; Murty 1973; Ghosh 1977; Palupi and Owens 1997). The seed filling in teak from different locations within India showed emptiness of 13 to 86% (Gupta and Kumar 1976). In teak, the superior plantations are converted into seed production areas (SPA) for production of quality seeds for plantation programme. In India, teak is planted in large scale every year (20,000 ha) and supply of quality seed material is the major constraint and most of the teak planta-

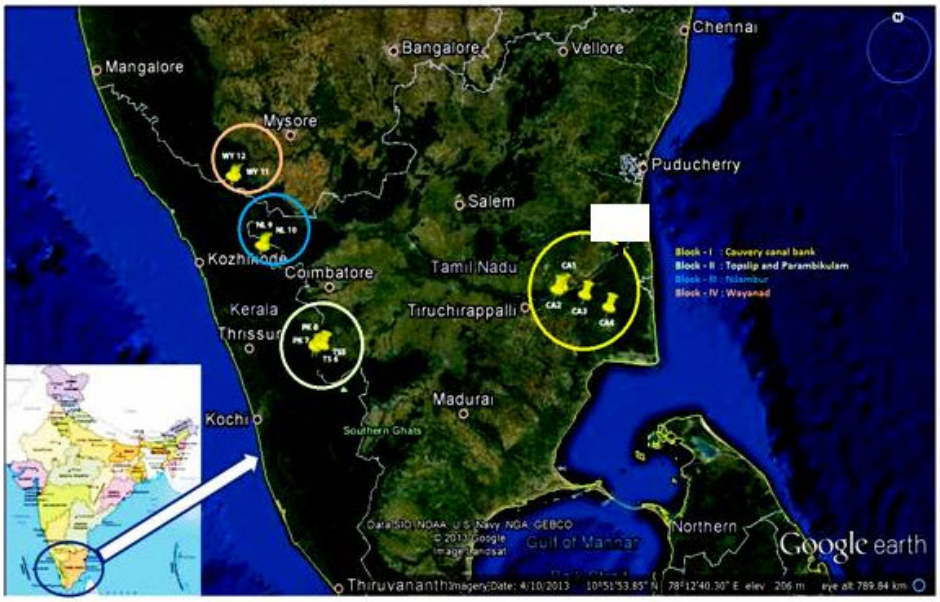

Fig. 1. Map showing the study sites.

tions are established with seeds of unselected source resulting low productivity. Although seed production areas are established, no study has been made to understand the suitability of location for SPA and the environmental factors on flowering, fruit setting and seed filling in teak. The rotation period of teak in India is 50 to 80 years, and no attempt has been made to reduce the rotation period. Keeping all these points in view, this study was undertaken to analyze the impact of environmental factors and altitude on growth, flowering, fruitset and seed characteristics of teak growing in different environmental conditions which will be helpful for establishing suitable SPA for quality seed production, and also for harvesting the teak in short period.

Materials and Methods

Study locations

A total of 12 teak plantations in different environmental conditions of Tamil Nadu and Kerala were selected and classified into four blocks (Block-I, II, III, and IV) based on rainfall, temperature and altitude (Fig. 1). The first block was Cauvery canal bank located between 10°40'N to 10°51'N and 79°00'E to 79°25'E and altitude ranged from 49 to 71 m. This block comprises four teak plantations *viz*. Nadupadugai (CA1), Neivasal (CA2), Pillaivaikkal (CA3) and Koraiyaru (CA4). The second block was Topslip (Tamil Nadu) and Parambikulam (Kerala) which lies between 10°25'N to 10°26'N and 76°46'E to 76°50'E and altitude varies from 543 to 691 m. This block includes four plantations namely Seechali, Tamil Nadu (TS5), Kozhikamuthi, Tamil Nadu (TS6), Thoonakadavu, Kerala (PK7) and Seechali, Kerala (PK8). The third block was Nilambur (Kerala) which consisted of two plantations namely Cherupuzha (NL9) and Nedungayam (NL10), and it was located between 11°17'N and 76°19'E to 76°20'E and, altitude varied from 53 to 63 m. The fourth block was named as Wayanad (Kerala) which falls between 11°52'N to 11°53'N and 76°04'E to 76°05'E with an altitude range of 765 to 787 m and it covered Tholpatty (WY11) and Begur (WY12) plantations. Further, the block-II, III and IV were growing under natural conditions and received maximum rainfall during south-west monsoon (June to September), whereas teak trees in block-I growing in continuous moisture condition for 8 to 10 months due to water in the canal and it received north east monsoon (November and December) (Table 1).

Environmental factors

The latitude, longitude, and altitude of each study locations were recorded using a GPS (Garmin GPSMAP 62s). The rainfall and temperature data for all the study blocks were collected from respective meteorological centers. The mean monthly rainfall, total annual rainfall and minimum and maximum temperature (average values of two years) in all study locations were recorded.

Table 1. Details of different teak plantations in four blocks of Tamil Nadu and Kerala

Block no.	Block name	Plantations	State	Year of planting	Plantation code	Latitude (°N)	Longitude (°E)	Altitude (m)
I	Cauvery canal banks (Tamil Nadu)	Nadupadugai	Tamil Nadu	1977	CA1	10°51'	79°00'	50
		Pillaivaikkal	Tamil Nadu	1993	CA2	10°49'	78°57'	71
		Neivasal	Tamil Nadu	1978	CA3	10°46'	79°12'	50
		Koraiyaru	Tamil Nadu	1977	CA4	10°40'	79°25'	49
II	Topslip (Tamil Nadu) and Parambikulam (Kerala)	Seechali	Tamil Nadu	1934	TS5	10°26'	76°50'	688
		Kozhikamuthi	Tamil Nadu	1930	TS6	10°26'	76°50'	691
		Thoonakadavu	Kerala	1945	PK7	10°26'	76°46'	595
		Seechali	Kerala	1942	PK8	10°25'	76°46'	543
III	Nilambur (Kerala)	Cherupuzha	Kerala	1971	NL9	11°17'	76°19'	63
		Nedungayam	Kerala	1970	NL10	11°17'	76°20'	53
IV	Wayanad (Kerala)	Tholpatty	Kerala	1962	WY11	11°53'	76°05'	787
		Begur	Kerala	1969	WY12	11°52'	76°04'	765

Growth

In each teak plantation, 30 trees were marked in 5 replications (6 trees in each replication) for studying growth and reproductive characteristics. The study was conducted periodically for two consecutive years during 2010 and 2011. Since same age groups of teak plantations were not available, the existing plantations of different age groups were used for this investigation. The age of trees varied from 18 to 34 in Cauvery canal bank, 77 and 81in Topslip, 66 to 69 in Parambikulam, 40 and 41in Nilambur and 42 to 49 in Wayanad. Growth parameters such as height, GBH, branching pattern and number of branches per tree were recorded.

Phenology

Observation on leaf fall and leaf flushing was made at regular intervals during the study period by standard methods (Gunaga 2000; Hanumantha 2000; Surendra 2013). Flowering data was recorded during flowering season while fruiting observation was noticed from fruit initiation to complete maturation (Morellato et al. 2000; Marques et al. 2004). The number of inflorescences per branch, flowers per inflorescence, fruits per inflorescence and fruitset percentage was recorded by standard procedure (Hanumantha 2000).

Seed characteristics

The 100 seed (fruit) weight of different locations was recorded using electronic balance. Seed parameters such as seed area, seed length, seed breadth, roundness and seed equal diameter were estimated using Image Analyzer (Leica QWin V3, Leica Microsystems Ltd., Switzerland).

The extent of variation on seed filling in different teak plantations was recorded. About 100 fruits were randomly selected from each plantation (5 replications of each 20 fruits) and subjected to X-ray radiography after removing their calyx (Kamra 1973). The fruits were spread directly on the envelope containing the film and pasted with a cellotape (Kamra 1976). The exposure conditions were, kV=14, mA=5, focus-film distance=50 cm, exposure time=1½ to 6 minutes depending upon the thickness of the seeds. The film was kept in X-ray developer for 5-10 minutes followed by 5-10 minutes in X-ray fixer then the number of empty locules were counted with light exposed white background. The proportion of seed filling (or) emptiness was expressed in relation to the total number of locules.

Table 2. Details of rainfall and temperature in four different blocks during 2010 and 2011

Month	Block-I (Cauvery canal bank)				Block-II (topslip and parambikulam)				Block-III (nilambur)				Block-IV (wayanad)			
	Rainfall (mm)		Temperature* (°C)		Rainfall (mm)		Temperature* (°C)		Rainfall (mm)		Temperature* (°C)		Rainfall (mm)		Temperature* (°C)	
	2010	2011	Max	Min	2010	2011	Max	Min	2010	2011	Max	Min	2010	2011	Max	Min
J	34	26	27	23	0	0	28	26	5	0	31	20	46	22	31	16
F	0	3	28	24	18	20	28	24	0	8	35	20	0	22	31	20
M	0	0	30	26	2	36	29	22	0	35	37	24	15	67	31	20
A	31	125	33	29	27	159	28	21	98	122	38	26	218	182	33	20
M	52	11	34	29	22	71	31	26	115	30	36	24	94	56	32	20
J	53	26	33	29	401	548	27	21	579	1,198	33	23	551	1,178	28	19
J	53	105	32	28	505	306	23	21	511	396	30	22	637	672	27	19
A	188	156	31	28	138	239	24	20	297	370	33	23	395	605	28	20
S	88	74	29	27	199	171	25	23	267	216	33	23	384	384	28	20
O	88	78	29	26	234	151	23	21	289	183	31	21	183	0	28	20
N	494	466	28	26	338	216	24	21	270	35	32	22	0	0	29	20
D	309	330	28	26	31	0	25	21	4	0	31	20	0	0	29	21
TR/MT	1,390	1,400	30	27	1,915	1,701	26	22	2,435	2,593	33	22	2,523	3,188	30	20

TR, Total Rainfall; MT, Mean Temperature.

The germination study on teak seeds of different locations was conducted in the Institute during the study period. About 100 fruits per location were subjected to pre-germination treatment by alternate soaking and drying with cow dung slurry (Chacko et al. 1997).

The seeds were soaked in cow dung slurry in night (12 h) followed by sunlight drying (12 h) and it was continued for 7 days. The pre-treated seeds from each location were sown in the nursery bed in a randomized block design with 5 replications of each 20 seeds. The germination percentage was calculated periodically at weekly intervals upto 40 days from date of sowing. The seed germination study was carried out in 10 plantations and experiment was not conducted for 2 plantations of Cauvery canal bank (Block-I) namely Pillaivaikkal (CA2) and Koraiyaru (CA4).

Results

Environmental factors

Among the four blocks the Cauvery canal bank (Block-I) and Nilambur (Block-III) occur in lower altitudes (49-71 m) whereas Topslip and Parambikulam (Block-II) and Wayanad (Block-IV) located in higher altitudes (543 to 787 m) which makes prominent changes in growth, phenology and seed characteristics of teak (Table 1). The meteorological data like rainfall and temperature for all the four study blocks are given in Table 2. During 2010 and 2011, the total rainfall was maximum in Wayanad (2,523-3,188 mm) followed by Nilambur (2,435-2,593 mm) and Topslip and Parambikulam (1,701-1,915 mm) whereas minimum rainfall was recorded in Cauvery canal bank (1,390-1,400 mm). The temperature was maximum in low altitude areas of block-I (27 to 34^{o}C) and III (31 to 38^{o}C) whereas high altitude areas like block-II and block-IV the maximum temperature was in the range of 23 to 31^{o}C and 27 to 33^{o}C respectively. In block-II, III and IV the maximum temperature was less in the month of July, whereas maximum rainfall was noticed in June and July during south-west monsoon. On the other hand, in block-I the maximum temperature was less in January and high rainfall was observed in the months of November and December during north-east monsoon (Table 2).

Growth

The age of the trees in 12 selected plantations in 4 blocks varies from 18 to 81and it was minimum in Cauvery canal bank (18-34) and maximum in Topslip and Parambikulam (66-81) (Table 3). The block-II showed maximum tree height (24.40-26.30 m) followed by block-III and IV (19.85-23.28 m) while minimum tree height was recorded

Table 3. Growth variation in different teak plantations of Tamil Nadu and Kerala

Block no.	Block name	Plantation (code)	Age	Height (m)	GBH (cm)	No. of Br./Tree*
I	Cauvery canal banks (Tamil Nadu)	Nadupadugai (CA1)	34	19.65^{d}	142.68^{d}	9.58^{g}
		Pillaivaikkal (CA2)	18	12.38^{f}	103.93^{g}	9.88^{g}
		Neivasal (CA3)	33	15.00^{e}	113.50^{fg}	10.30^{g}
		Koraiyaru (CA4)	34	16.50^{e}	131.30^{de}	12.20^{ef}
II	Topslip (Tamil Nadu) and Parambikulam (Kerala)	Seechali (TS5)	77	26.20^{a}	197.10^{c}	14.50^{d}
		Kozhikamuthi (TS6)	81	26.30^{a}	243.10^{a}	13.40^{de}
		Thoonakadavu (PK7)	66	24.40^{ab}	201.80^{bc}	18.80^{b}
		Seechali (PK8)	69	25.20^{ab}	215.20^{b}	20.70^{a}
III	Nilambur (Kerala)	Cherupuzha (NL9)	40	21.63^{cd}	142.32^{d}	12.19^{ef}
		Nedungayam (NL10)	41	20.50^{d}	125.40^{ef}	11.90^{f}
IV	Wayanad (Kerala)	Tholpatty (WY11)	49	23.28^{bc}	138.50^{de}	17.04^{c}
		Begur (WY12)	42	19.85^{d}	127.88^{def}	18.08^{bc}
		Mean	-	20.91	156.89	14.05
		SD	-	4.56	44.78	3.75

Mean values with the same letters superscripted are not significantly different at $p < 0.05$.
*Number of branches per tree.

in block-I (12.38-19.65 m). Though the tree height was less in Cauvery canal bank (Block-I), the GBH showed significant increase due to moisture condition which was fairly comparable to 40 to 49-year-old trees of Nilambur and Wayanad (Table 3). The GBH of 34-years-old tree of block-I (CA1) (142.68 cm) was similar to that of 40-years-old tree in NL9 (142.32 cm) and more than that of 41, 42 and 49-years-old trees in NL10, WY12 and WY11 respectively (125.40, 127.88,138.50 cm) of block-III and IV. However, trees in block-I showed maximum GBH and attain the harvestable girth (113-142 cm) at the age of 33 to 34 years. The maximum GBH was noticed in block-II (197.10-243.10 cm). The maximum number of branches per tree was recorded in high altitude plantations of PK8 (20.70), PK7 (18.80) of block-II and Wayanad of block-IV (17-18), while minimum number of branches were noticed in low altitude of Cauvery canal bank of block-I and Nilambur of block-III (9.58-12.20) (Table 3).

Phenology

Teak shows significant variation in phenological cycles among the four study locations due to environmental factors such as seasonal rainfall, temperature and altitude (Table 4). In teak approximately 90 days were conceded for every transitional state of phenology (leaf fall, leaf flushing, flowering and fruiting) and their timings may vary between the blocks. The time duration between leaf flushing and leaf fall in Tamil Nadu and Kerala was about 9 months. In Cauvery canal bank (Block-I), leaf fall started very late in mid-February when fruits were completely matured and continue upto April followed by initiation of leaves in the month of May. Flowering initiated in August and continues upto October, with peak flowering in September followed by fruit emergence in November to January and fruit maturation started from December and continues upto the end of February (Table 4). The block-I (Cauvery canal bank) received maximum rainfall during north-east monsoon (November and December) after flowering (Tables 2, 4). In block-II (Topslip and Parambikulam), leaf fall started in January and continues upto March followed by leaf flushing in April to June. Flowering was observed in July to September followed by fruiting in October to December. On the other hand, phenological phases occurred about 2 to 3 months early in block-III (Nilambur) and block-IV (Wayanad) compared to block-I and II probably high temperature advances leaf fall which was followed by leaf flushing and flowering. In block-III, the leaf fall, leaf flushing, flowering and fruiting was noticed in November to January, February to April, May to July and August to October respectively. In block-IV, leaf fall starts during the month of December and complete leaf fall was observed in February, leaf initiation begins in March while flowering started in the month of June and fruiting in September.

The number of inflorescences per branch ranged from 11.24 to 36.65 in 2010 and 11.42 to 29.94 in 2011 (Table 5). The maximum number of inflorescences per branch was recorded in NL9 for both the years 2010 (36.65) and 2011 (29.94). It was found that NL9 and NL10 (Block-III), WY11 (Block-IV) and PK8 of Parambikulam (Block-II) showed more inflorescences in a branch compared to other plantations. The number of flowers per inflorescence in 2010 and 2011 ranged from 1678 to 3734 and 1689 to 3744 respectively in different locations. It was observed that Tholpatty plantation (WY11) showed more number of flowers in both the years (3,734-3,744) compared to other plantations (1,678-3,307). The maximum number of flower production per inflorescence was in the order of WY11 > TS6 > TS5 > NL10 in 2010 and WY11 > NL9 > WY12 > TS6 in 2011 indicating that the number of flowers per inflorescence in all the blocks were increased with increasing average rainfall of both the years (Block IV > III > II and > I) (Fig. 2). The number of fruits per inflorescence varied

Table 4. Vegetative and reproductive phenophases of teak in four different blocks of Tamil Nadu and Kerala

Phenological phase	Cauvery canal bank (Block-I)	Topslip and parambikulam (Block-II)	Nilambur (Block-III)	Wayanad (Block-IV)
Leaf fall	Feb-Apr	Jan-March	Nov-Jan	Dec-Feb
Leaf flushing	May-July	April-June	Feb-Apr	Mar-May
Flowering	Aug-Oct	July-Sep	May-July	June-Aug
Fruiting	Nov-Jan	Oct-Dec	Aug-Oct	Sep-Nov

Table 5. Flowering, fruiting and fruitset (%) in different teak plantations of Tamil Nadu and Kerala during 2010 and 2011

Block no.	Block name	Plantation (Code)	No. of Infl./Branch*		No. of flowers/Infl.**		No. of fruits/Infl.#		Fruitset (%)	
			2010	2011	2010	2011	2010	2011	2010	2011
I	Cauvery canal banks (Tamil Nadu)	Nadupadugai (CA1)	14.30^{f}	14.03^{e}	1680.11^{g}	2366.05^{d}	44.80^{d}	50.71^{d}	2.67^{b}	2.26^{ab}
		Pillaivaikkal (CA2)	13.07^{fg}	13.54^{e}	1678.80^{g}	1909.00^{e}	41.11^{de}	39.05^{gh}	2.44^{c}	2.08^{bcd}
		Neivasal (CA3)	13.20^{fg}	14.02^{e}	1941.33^{f}	2488.67^{cd}	58.61^{c}	49.65^{de}	2.99^{a}	2.17^{abc}
		Koraiyaru (CA4)	23.80^{c}	18.46^{cd}	1890.00^{fg}	2426.00^{d}	56.20^{c}	45.82^{ef}	2.87^{a}	2.05^{cd}
II	Topslip (Tamil Nadu) and Parambikulam (Kerala)	Seechali (TS5)	12.12^{g}	12.48^{ef}	3067.04^{c}	2714.52^{bc}	76.64^{b}	55.60^{c}	2.50^{bc}	1.98^{de}
		Kozhikamuthi (TS6)	11.24^{h}	11.42^{f}	3307.40^{b}	2845.70^{b}	96.48^{a}	66.32^{b}	2.93^{a}	2.25^{ab}
		Thoonakadavu (PK7)	19.04^{e}	18.94^{bc}	1744.92^{fg}	1689.46^{e}	22.12^{g}	30.76^{i}	1.30^{fg}	1.86^{e}
		Seechali (PK8)	19.20^{e}	20.50^{b}	2259.40^{e}	2505.70^{cd}	24.36^{fg}	34.68^{hi}	1.10^{g}	1.37^{g}
III	Nilambur (Kerala)	Cherupuzha (NL9)	36.65^{a}	29.94^{a}	2250.88^{e}	2941.28^{b}	37.55^{e}	41.59^{fg}	1.67^{e}	1.61^{f}
		Nedungayam (NL10)	21.95^{d}	17.26^{d}	2936.16^{c}	2462.00^{cd}	40.52^{de}	35.00^{hi}	1.36^{f}	1.28^{g}
IV	Wayanad (Kerala)	Tholpatty (WY11)	28.42^{b}	20.31^{b}	3734.56^{a}	3744.00^{a}	75.08^{b}	86.02^{a}	2.01^{d}	2.32^{a}
		Begur (WY12)	13.63^{fg}	12.53^{ef}	2555.36^{d}	2888.00^{b}	29.24^{f}	35.00^{hi}	1.15^{g}	1.28^{g}
		Mean	18.89	16.95	2420.50	2581.70	50.23	47.52	2.08	1.88
		SD	7.58	5.14	691.25	532.14	22.49	15.68	0.72	0.39

Mean values with the same letters superscripted are not significantly different at $p<0.05$.
*Number of inflorescences per branch; **Number of flowers per inflorescence; #Number of fruits per inflorescence.

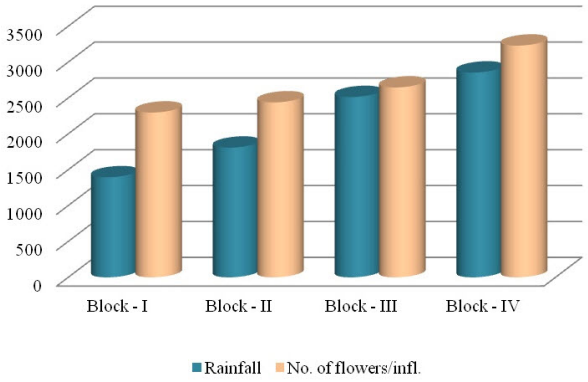

Fig. 2. Relationship between annual rainfall and number of flowers per inflorescence in four different blocks (mean values of 2010 and 2011).

from 22.12 to 96.48 in different plantations in both the years (Table 5). The maximum number of fruits in an inflorescence was noticed in TS6 (96.48), TS5 (76.64) of Topslip in 2010 and WY11 of Wayanad (86.08) in 2011. The amount of fruit production in Cauvery canal bank (Block-I) for both the years was ranged from 39.05 to 58.61. However, all the plantations in this block showed high fruitset in 2010 and 2011(2.05-2.99%) followed by TS5, TS6 and WY11 (1.98-2.93%), and in all other locations it ranged from 1.10 to 1.86 % (Table 5).

Seed characteristics

The 100 seed weight in all the 12 plantations significantly varied from 50 to 88 g with an average of 67 g (Table 6). The maximum seed weight was recorded in PK7 (88 g), TS5 (81 g) and PK8 of block-II (78 g) while, CA3 of block-I showed minimum seed weight (50 g). The seeds of Topslip and Parambikulam (Block-II) showed higher seed weight (65-88 g), seed area (1.79-2.01 cm^2), seed length (1.62-1.7 cm), seed breadth (1.45-1.49 cm), roundness (1.23-1.35 cm) and equal diameter (1.50-1.59 cm) compared to all other plantations. The seed filling and germination percentage of teak seeds from different plantations are given in Table 7. The teak fruit contains four locules, mostly filled with 1 or 2 seeds and rarely with 4 seeds. The mean percentage of single and two seed filling was comparatively higher (11.32%, 10.55%) than three (5.02%) and four seed filling (1.21%). Highest single seed filling was noticed in NL10 (13.70%) followed by PK8 (13.16%) and in all other locations it varied from 9.23 to 12.22%. However, the percentage of two seed filling was high in TS5 (14.70%) and PK7 (13.53%) of block-II compared to other plantations (7.99 to 11.62%). The results of total seed filling (1-4 locules) revealed that the percentage of seed filling varied from

Table 6. Morphological variations of teak seeds in different teak plantations of Tamil Nadu and Kerala

Block no.	Block name	Plantation (code)	100 seed weight (g)	Seed area (cm^2)	Seed length (cm)	Seed breadth (cm)	Round-ness (cm)	Equal diameter (cm)
I	Cauvery canal banks (Tamil Nadu)	Nadupadugai (CA1)	66^{ef}	1.54^{cd}	1.50^{cde}	1.34^{bcd}	1.65^{a}	1.39^{cde}
		Pillaivaikkal (CA2)	57^{gh}	1.41^{de}	1.43^{e}	1.28^{d}	1.23^{bcde}	1.32^{e}
		Neivasal (CA3)	50^{i}	1.33^{e}	1.40^{e}	1.24^{d}	1.14^{e}	1.29^{e}
		Koraiyaru (CA4)	54^{h}	1.58^{c}	1.53^{bcde}	1.34^{bcd}	1.21^{cde}	1.40^{bcde}
II	Topslip (Tamil Nadu) and Parambikulam (Kerala)	Seechali (TS5)	81^{b}	1.89^{ab}	1.66^{ab}	1.49^{a}	1.32^{cd}	1.54^{ab}
		Kozhikamuthi (TS6)	65^{ef}	1.83^{b}	1.63^{abc}	1.46^{ab}	1.23^{bcde}	1.51^{abc}
		Thoonakadavu (PK7)	88^{a}	2.01^{a}	1.71^{a}	1.53^{a}	1.34^{b}	1.59^{a}
		Seechali (PK8)	78^{bc}	1.79^{b}	1.62^{abcd}	1.45^{abc}	1.35^{b}	1.50^{abcd}
III	Nilambur (Kerala)	Cherupuzha (NL9)	72^{c}	1.44^{cde}	1.48^{cde}	1.28^{d}	1.34^{bc}	1.34^{e}
		Nedungayam (NL10)	61^{fg}	1.52^{cd}	1.49^{cde}	1.33^{bcd}	1.19^{de}	1.38^{cde}
IV	Wayanad (Kerala)	Tholpatty (WY11)	68^{de}	1.50^{cd}	1.48^{cde}	1.32^{cd}	1.25^{bcde}	1.37^{de}
		Begur (WY12)	65^{ef}	1.48^{cde}	1.46^{de}	1.31^{d}	1.21^{cde}	1.36^{cde}
		Mean	67.08	1.61	1.53	1.36	1.29	1.42
		SD	11.67	0.23	0.13	0.12	0.15	0.12

Mean values with the same letters superscripted are not significantly different at $p < 0.05$.

Table 7. Seed filling and germination percentage of teak seeds in different teak plantations of Tamil Nadu and Kerala

Block no.	Block name	Plantation (code)	1 seeded	2 seeded	3 seeded	4 seeded	Total seed filling %	% of emptiness	% of germination
I	Cauvery canal banks (Tamil Nadu)	Nadupadugai (CA1)	9.23^{h}	11.62^{c}	6.53^{bc}	2.52^{a}	29.90^{bc}	70.10^{abc}	35.00^{e}
		Pillaivaikkal (CA2)	11.06^{def}	9.30^{ef}	2.74^{h}	0.88^{g}	23.97^{e}	76.03^{a}	**
		Neivasal (CA3)	10.15^{fgh}	10.46^{d}	4.64^{e}	1.70^{c}	26.94^{cd}	73.06^{abc}	45.00^{cd}
		Koraiyaru (CA4)	10.60^{efg}	9.88^{de}	3.69^{g}	1.29^{d}	25.45^{de}	74.55^{ab}	**
II	Topslip (Tamil Nadu) and Parambikulam (Kerala)	Seechali (TS5)	11.57^{cde}	14.70^{a}	6.95^{ab}	0.00^{h}	33.23^{a}	66.77^{c}	50.00^{b}
		Kozhikamuthi (TS6)	12.22^{bc}	10.19^{de}	4.11^{fg}	1.23^{de}	27.75^{cd}	72.25^{abc}	49.00^{bc}
		Thoonakadavu (PK7)	11.06^{def}	13.53^{b}	5.94^{d}	1.75^{c}	32.29^{ab}	67.71^{bc}	46.00^{bc}
		Seechali (PK8)	13.16^{ab}	7.99^{g}	7.15^{a}	0.78^{g}	29.07^{c}	70.93^{abc}	54.00^{a}
III	Nilambur (Kerala)	Cherupuzha (NL9)	11.84^{cd}	10.57^{d}	4.30^{ef}	2.17^{b}	28.88^{c}	71.12^{abc}	32.00^{e}
		Nedungayam (NL10)	13.70^{a}	8.83^{fg}	4.19^{efg}	1.14^{ef}	27.86^{cd}	72.14^{abc}	42.00^{d}
IV	Wayanad (Kerala)	Tholpatty (WY11)	11.73^{cde}	8.64^{fg}	3.70^{g}	0.00^{h}	24.07^{e}	75.93^{a}	49.00^{bc}
		Begur (WY12)	9.54^{gh}	10.95^{cd}	6.30^{cd}	1.06^{f}	27.85^{cd}	72.15^{abc}	48.00^{c}
		Mean	11.32	10.55	5.02	1.21	28.10	71.90	37.50
		SD	1.48	2.02	1.46	0.74	3.04	5.23	18.14

Mean values with the same letters superscripted are not significantly different at $p < 0.05$.
**Germination studies for CA2 and CA4 not studied.

23.97 to 33.23% and about 66 to 76% of fruits were empty resulting poor germination. Among the 12 plantations TS5 (Topslip) and PK7 (Parambikulam) of block-II showed highest seed filling (32.29 to 33.23%) (Table 7) with maximum seed weight (81 and 88 g) (Table 6). The percentage of germination was high in high altitude areas of Wayanad (Block-IV) and Topslip and Parambikulam (Block-II) (46-54%) compared to low altitude areas of Cauvery canal bank (Block-I) and Nilambur (Block-III) (32 to 45%).

Discussion

Teak is a deciduous tree species occurs naturally over a wide range of climatic conditions from the very dry area (semi arid plains) to the very moist area (western ghats) with an annual rainfall of < 600 mm and > 3,500 mm respectively (Kala et al. 2005). The optimum rainfall for teak growth is 1250 to 3750 mm, but it grows well even at low rainfall of 730 mm and at high rainfall of 5,000 mm (Kadambi 1972). In addition to annual rainfall (> 1,200 mm) teak requires a dry spell of at least 3 to 5 months with less than 60 mm precipitation for the production of good quality timber (Kaosa-ard 1981). Orwa et al. (2009) stated that teak growing in a wide range of climatic and edaphic conditions where mean annual temperature and mean annual rainfall varies from 14° to 36°C and 600 to 4,000 mm respectively. These reports are in concurrence with the present study that the annual rainfall in 12 different teak plantations were varied from 1,390-3,188 mm with highest rainfall in block-IV (2,523-3,188 mm) and block-III (2,435-2,593 mm) followed by block-II (1,701-1,915 mm) and less in block-I (1,390-1,400 mm) with dry spell of 3 to 5 months. The minimum and maximum temperature was in the range of 16 to 38°C (Table 2). Further, the block-I and III were located in low altitudes (49-71 m), while block-II and IV in high altitudes (543-787 m) (Table 1). In Andhra Pradesh (India) teak trees are grown in an altitude ranged from 76 to 914 m with rainfall ranged between 750 to 1,500 mm (Rao 2005), and Tewari (1992) reported that teak grows upto an altitude of 1,200 m.

Teak grows upto a height of 32 to 35 m in Panayancode, 23 to 35 m in Nilambur, 17 to 29 m in Thrissur (Kerala) and 18 to 30 m at Cauvery canal bank areas (Tamil Nadu) (Palanisamy et al. 2005; Palanisamy et al. 2009). The height and GBH in 12 selected teak plantations in 4 blocks varied significantly from 12.38 to 26.30 m and 103.93 to 243.10 cm respectively (Table 3) which probably due to the age and other environmental factors. Similar findings have been reported in teak growing in Adilabad, Warangal, Karimnagar, Nizamabad and Khammam districts of Andhra Pradesh, with a height of 15 to 20 m and GBH of 130 to 200 cm (Rao 2005). According to Surendra (2013) the height and GBH in the natural teak populations in Karnataka, India varied from 14.69 to 27.82 m and 58 to 147 cm respectively. Generally canal teak plantations showed fast growth with good girth. The GBH of 34-year-old teak tree of Cauvery canal bank (142.68 cm) was more than 40 to 49-year-old trees of Nilambur and Wayanad areas (125.40-142.32 cm) indicating that continuous moisture condition in Cauvery canal bank enhances GBH which confirms the earlier findings of Palanisamy et al. (2005) that the growth of 30-year-old canal teak was quite comparable with 50 to 60-year-old teak in Nilambur. The moisture condition also retains the leaf for longer period (February) resulting continuous supply of photosynthates for the growth of the tree. In India the rotation period of teak varies from 50 to 80 years in different states. The wood properties of fast growing canal teak under moisture condition did not show any significant variation and the wood properties of 34-year-old canal teak was similar to that of 67-year-old trees from Nilambur (Krishnamoorthy 2014) suggesting that the teak plantations with regular watering and silvicultural practices may be harvested at the age of 30 to 35 years.

In the Atlantic Rain Forest, leaf flushing and flowering occur in the warmer and rainy months when days are longer, whereas leaf fall was observed more frequently in the drier and colder months when days are shorter (Marques and Oliveira 2004). In India, leaf fall in teak started in the month of November and the tree become leafless for 3 to 4 months. In the present investigation, it was found that leaf fall was started early in Nilambur (November to January) when the maximum temperature was in range of 31 to 32°C followed by Wayanad (December to February) with 29 to 31°C and very late leaf fall was noticed in Topslip and Parambikulam (January to March) where the temperature was 24 to 29°C indicating that leaf fall was delayed in high altitude areas due to low temperature. Surendra (2013) reported that the leafless period was more in low rainfall areas with high temperature compared to high rainfall areas with low temperature in natural teak populations of Karnataka. However, leaf fall in Cauvery canal bank (Block-I) started in the month of February probably the continuous moisture condition retains the leaf for longer period irrespective of deciduous nature of the tree (Table 4). This corroborates the finding of Palanisamy et al. (2005) that the leafless period was very short in teak growing in moisture condition. The present study reveals that leaf fall duration in teak was almost 3 months irrespective of the locations and only the

time of occurrence varied between the locations probably due to altitude and environmental factors.

It was found that leaf flushing in teak started during dry season before the onset of monsoon rain i.e. May-July (Block-I), April-June (Block-II), February-April (Block-III) and March-May (Block-IV). This is in concurrence with the findings of Surendra (2013) that leaf initiation was started in March to April before monsoon season in natural teak populations in Karnataka. Similar leaf flushing pattern was observed in montane forests and Tai National Park in Côte d'Ivoire (Anderson et al. 2005). It was also found that leaf flushing in teak started earlier in low altitude areas of Nilambur (February) than the high altitude areas of Wayanad (March) and Topslip and Parambikulam (April). It confirms the results of Vitasse et al. (2009) that leaf flushing in Oak and Ash populations occurred late in higher elevation than in lower elevation. Similarly, Surendra (2013) reported that leaf initiation in natural teak populations in Karnataka took place late in high altitude than in low altitude areas. On the contrary, Beach populations showed early leaf flushing in higher altitude than those in lower altitude (Von Wuehlisch et al. 1995; Chmura and Rozkowski 2002). It was also found that leaf initiation in teak was delayed in low altitude areas of Cauvery canal bank (May) due to continuous moisture (upto January) which retains the leaf for longer period and leaf fall was late compared to other locations (Tables 1, 4).

Generally, in South India the period of flowering to fruit maturity in teak is about nine months. Flowering in teak initiated from May to July depending upon the location, and continues for 3 months and peak flowering (June and July) was coincided with south-west monsoon in block-II, III and IV (Table 4) which affects pollination. Conversely, Palupi and Owens (1998) stated that the period of flowering to fruit maturation in teak takes about 6-8 months in Indonesia and vegetative buds flush in the beginning of rainy season (October) followed by the appearance flower buds (December to January). On the other hand, in East Java, Thailand teak flowering started in mid-January and continue upto May, and peak flowering varied from mid-February to the end of March (Palupi and Owens 1998). It indicates that flowering in teak is mainly controlled by environmental factors and location. The flowering period in Cauvery canal bank (Block-I) was noticed from August to October which is not coincided the heavy rainfall and found suitable for better pollination.

The number of flowers per inflorescence in teak ranged from 1,200 to 2,700 in Thailand (Siripatanadilox 1974), 8,000 in Papua-New Guinea (White 1991) and 10,000 in India (Mathew et al.1987). The present study in 12 plantations showed that the number of flowers per inflorescence varied from 1,678 to 3,744 and the number of flowers increased with increasing annual rainfall which was in the order of Wayanad (Block-IV) > Nilambur (Block-III) > Topslip and Parambikulam (Block-II) > Cauvery canal bank (Block-I) (Fig. 2) presumably the rainfall influence the flower production in teak. Surendra (2013) reported that several factors including climate, soil and spacing influence flowering in teak. Nanda (1962) opined that the teak trees growing in close stands produced very less flowers.

Teak is a highly cross pollinated species in which bees and insects are the main pollinators. The movement of pollinators is limited during south-west monsoon which coincided with peak flowering in most of the teak growing areas in India including block-II, III and IV. The heavy rainfall limits the legitimate pollinators or floral visitors for effective pollination, and further the stigmatic exudates may be washed away in the stigma resulting low fruitset in teak (Table 5). This is supported by the findings of Surendra (2013) in natural teak populations in Karnataka. Heavy rainfall during the initiation of flowers affects the fruitset in several species of Acacias which are predominantly outcrossing in nature (Muona et al. 1991). In accordance with these view, Cauvery canal bank (Block-I) showed marginally high fruitset (2.05-2.99%) perhaps the minimum rainfall during peak flowering period enhance the fruit set (Table 2), whereas, the block-II, III and IV exhibited less fruitset due to heavy rainfall during peak flowering (1.10-2.93%) (Table 5) indicating that flowering and fruit setting in teak is expected to be related with environmental factors such as rainfall, temperature, light, soil fertility and biotic factors like pollinators.

The fruit set and germination percentage of teak seeds collected from different seed orchards was found to be low (Nagarajan et al. 1996a; Indira and Basha 1999). Even in the international scenario, it has been observed that teak seed orchards showed poor fruit set and low germination percentage (Vasudeva et al. 2004). Though abundant flow-

ers per inflorescence was observed (1,678-3,744), the fruits per inflorescence were comparatively less and ranged from 22 to 96 (2010) and 30 to 86 (2011) (Table 5) indicating that in addition to environmental factors there may be physiological and biochemical factors which probably control the fruitset in teak which needs to be investigated to improve seed production in teak orchards and seed stands. Surendra (2013) reported that the number of fruits per inflorescence in the natural teak populations was less (29-39) than plantations (Table 5) may be due to less stand density in natural populations which reduce the pollination resulting low fruitset, suggesting that for tree improvement programme the seed stand may be selected from plantations rather than natural populations.

The quality of seed has been found to play a significant role in germination, survival in the field and growth which leads to improve productivity in forest plantation (Pathak et al. 1980). It has been well established in the literature that seeds of a single species when collected from different sources and different altitudes differ in viability, germination, growth and biomass (Isik 1986; Singh et al. 2006). Similarly in teak, the seed size, weight, length and breadth varied significantly based on environmental factors (Nagarajan et al. 1996b; Tangmitcharoen and Owens 1997; Palupi and Owens 1998). These results are in confirmatory with the present findings that seed weight (100 seeds) in the selected plantations varied from 50 to 88 g (Table 6). Similarly Nicodemus (2007) reported that seed weight in seed production areas, natural populations and clonal seed orchards of teak varied from 50 to 83 g in Kerala and Tamil Nadu. The seeds of Topslip and Parambikulam (Block-II) showed higher seed weight (65-88 g), seed area (1.79-2.01 cm^2), seed length (1.62-1.7 cm), seed breadth (1.45-1.49 cm), roundness (1.23-1.35 cm) and equal diameter (1.50-1.59 cm) than block-I, III and IV (Table 6). In all the plantations except the canal bank the leaf fall started during late fruit development, whereas, canal teak retained the leaf upto complete fruit development (January) with supply of food materials to developing seed, but it did not show any significant increase in seed parameters (Tables 4, 6) indicating that in addition to food supply, environmental or genetic factors may also influence the seed characteristics in teak. Murali (1997) opined that the variation on seed characteristics could be due to different environments at the geographic origins of seed and seasonal variables.

Palupi and Owens (1998) reported that most of the mature fruits contained only one seed, few showed two seeds, but rarely contained three or four seeds. The recent studies on seed characteristics of teak revealed that the seed filling is very poor in clonal seed orchards of Kerala, and about 52% of fruits were filled with one seed followed by 25% with more than one seeds and remaining 23% was found to be empty (Nicodemus 2007). Similarly in the present findings it was found that 11.32% of the fruits were filled with one seed (mean of 12 plantations), followed by 10.55% with 2 seeds and 5.02% with 3 seeds and 1.12% with four seeds (Table 7). In total, about 28.10% of the fruits showed seed filling and about 71.90% of fruits were empty or seeds aborted during the early stages of fruit maturation (Table 7). Gupta and Kumar (1976) also reported that in teak provenances, 51% of the fruits have no seeds, about 35% with one seed, 12% with two seeds, 2% with three seeds and rarely fruits filled with 4 seeds (0.4%). The fruits of Topslip and Parambikulam (Block-II) exhibited highest percentage of total seed filling (27.75-33.23%) (Table 7), seed size and seed weight compared to other blocks (I, III and IV) probably the environmental factors in that locations influences seed characteristics. The bigger seeds and seed weight of Topslip and Parambikulam showed higher percentage of germination (46 to 54%) compared to other locations (Table 7) which is corroborated by the findings in *Pongamia pinnata*, *Vateria indica* and other tree species (Manonmani et al. 1996; Murali 1997; Gunaga et al. 2007). Variation in germination percentage in relation to altitude has been reported in several species (Miller and Cummins 1978; Lavorel 1987; Holm 1994; Mantoven 2002). This is in concurrence with the present findings that the percentage of germination in teak was comparatively higher (46-54%) in high altitudes (543-787 m) of block-II and IV than low altitudes (49-71 m) of block-I and III (32 to 45%). Similarly Lavorel (1987) reported that the seeds of *Calluna vulgaris* from higher altitude in Southern France showed better germination than those from lower altitude. Vera (1997) also opined that the seeds of *Calluna vulgaris, Erica cinerea* and *E. vagans* from higher altitude influence more germination percentage.

Seed filling is one of the main criteria for germination. The percentage of germination in natural teak population was poor and varies from 6.3 to 13.1% (Surendra 2013)

and 13.93 to 54.52% (Prasad and Jalil 1986). Palupi and Owens (1998) reported that teak germination was high in seed production areas (40-50%) than clonal seed orchards (10-20%) probably asynchronization of flowering among the clones in clonal seed orchards (Palanisamy personal communication). The present investigation confirms that the seeds from plantations showed good germination than natural populations probably due to more density of the trees and visit of more pollinators in plantations suggesting that plantations with good tree form, high fruitset with maximum seed filling and better germination percentage may be converted into seed production areas for producing quality seeds for operational planting programme.

Conclusion

The canal teak plantations grow in continuous moisture condition showed fast growth with good girth indicating that regular irrigation in teak may reduce rotation period to 30 years instead of normal rotation period of 50 to 80 years. The moisture condition in canal teak retained the leaf for longer period resulting continuous supply of photosynthates for the growth of the tree. The environmental factors such as rainfall, temperature and light, and biotic factors like pollinators control flowering and fruit setting in teak. High rain fall affects the pollination in teak. Though abundant flowers per inflorescence was observed in teak (1,678-3,744), the fruits per inflorescence were comparatively less (22 to 96) indicating that in addition to environmental factors there may be physiological and biochemical factors which probably control the fruit set in teak which needs to be investigated to improve seed production in teak orchards and seed stands. The seeds from Topslip and Parambikulam exhibited highest percentage of total seed filling (27.75-33.23%), seed size and seed weight resulting higher percentage of germination compared to other locations, probably the environmental factors and altitude (550-700 mm) in that locations suits for better seed characteristics suggesting that Topslip and Parambikulam may be the suitable area for establishing seed production areas and seed orchards for quality seed production. It is also found that seed filling is one of the main criteria for germination suggesting that the fruits filled with seeds may be separated and used for raising nursery instead of sowing all the seeds thereby reducing nursery activities. The production of quality teak seed for operational planting programme is the major constraint. The present investigation reveals that plantations with good tree form, high fruit set with maximum seed filling and better germination percentage may be selected and converted into seed production areas for producing quality seeds.

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