INTEGRATING SUSTAINABLE FERTIGATION PRACTICES IN TEAK (*TECTONA GRANDIS* LINN. F) CULTIVATION BY ENHANCING SOIL NUTRIENTS – A FIELD STUDY FROM FARMLANDS OF TAMIL NADU, INDIA

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Abstract. Teak (*Tectona grandis* Linn. f) is one of the most demanded tree crop in Asia owing to its timber utility and durability. A field trial was established in farmer’s field at Perur, Tamil Nadu, India to study the impact of fertigation on soil nutrient status, influencing the growth and productivity of teak (*Tectona grandis* Linn.f). Irrigation is scheduled based on computed water requirement (PE) of tree based on crop factor, daily rainfall and evapotranspiration as well as fertilizer as per the recommended dosage (RDF) of 150:100:100 NPK/ha. The irrigation treatments (50% PE, 75% PE, 100% PE, 125% PE) is allocated as main plot and fertilizer treatment (75% RDF, 100% RDF,125% RDF, 150% RDF) is allotted as subplot. The biometric attributes represented in terms of height (m), basal diameter (cm) and volume index (cm^3) were studied during high rainfall (9 Months After Treatment (MAT)) and low rainfall period (18 MAT). At 9 MAT, the maximum height (3.12 m), basal diameter (9.74 cm) and volume index (2903.28 m^3) were registered at I_3F_3 (100% PE 125% RDF), where at 18 MAT, I_4F_3(125% PE 125% RDF) registered maximum height (4.15 m) and volume index (7072.62 m^3) whereas I_3F_2(100% PE 100% RDF) recorded maximum basal diameter (13.12 cm). The soil nutrient status also varies significantly among different treatment regimes, favorably correlating towards tree growth. Hence, the current study aids to standardize the water and nutrient requirement of the crop, improving the yield and productivity of teak by sustainable utilization of resources.
Keywords: *teak, growth, productivity, computed water requirement, crop factor, biometric attributes*

Introduction

Teak (*Tectona grandis* Linn.f) is recognized as ‘the paragon of timbers’ (Masilamani and Annadurai, 2003) and is one of the most highly priced timbers across the world predominately distributed in tropical and subtropical countries and is native to South and Southeast Asian countries, mainly Bangladesh, India, Indonesia, Malaysia, Myanmar, Laos, Thailand, and Sri Lanka (Cowan and Nagel, 1965; White, 1991). Due to its strength, durability, captivating color, elegant figure, amenability for working and good finishing properties, it is considered as one of the most prominent tropical hardwood with significant demand for furniture, shipbuilding, building components, construction materials etc. (Midgley et al., 2017). Currently, teak is an important component of many plantation programs throughout the tropical world, while successful teak plantations are only found in discontinuous regions within the tropical climate zones (Kyaw et al., 2020). Although India accounts for 44% of the global teak resources but cannot meet up the rising demand of the country which was estimated to be almost half of the total round wood requirement (95 M m^3) in India (FAO, 2019). India alone consumes 70 to 100 per cent of teak logs from Africa and Latin America and 90,000 m^3 of teak is imported annually (Shrivastava and Saxena, 2017).

In the era of production forestry, it is desirable to exploit those mechanisms that increase growth. When soil water and nutrients limit tree growth, productivity may be improved by increasing the amount of uptake of water and nutrients, or by increasing the efficiency by which they are used in growth (Coyle and Coleman, 2005; Li and Liu, 2011). Resource inputs like water and nutrients along with the specific silvicultural practices will improve the productivity of the tree species (Zafari and Mohammadi, 2019; Dobrowolski et al., 2017). The shrinking availability of resources, increasing fertilizer prices, energy crisis, widespread pollution and fast degradation of natural resources put forwarded the need for improving water and fertilizer use efficiency (Solaimalai et al., 2005). The critical intensive silvicultural practice followed in plantations to boost up the biomass production is fertilization techniques. But it is heavily associated with environmental risk of leaching with excessive application of chemical fertilizer under conventional method of application (Wang et al., 2015). This scenario necessitated to push tree cultivation beyond the natural boundaries of forest, which is popularly attenuated as “trees outside forest” (Kleinn et al., 1999; Kleinn, 2000; Chauhan, 2006; Ellison et al., 2017) in order to meet the local wood demand as well as to reduce the import burden of the country. The basic challenge to promote commercial cultivation of teak includes the development of precision silviculture techniques, water and nutrient scheduling, reduction of rotation period and ensuring good quality of timber.

Therefore, in order to accomplish the sustainable use of fertilizer and improved fertilizer use efficiency and concurrently to increase the biomass production of plantations, the high effectual fertilization techniques must be espoused (Silva et al., 2012; Shirazi et al., 2014; Balasubramanian et al., 2019). One such modern innovation with high water and fertilizer use-efficiency is drip irrigation technology. The change in the fertigation levels under drip irrigation alters the soil nutrient dynamics which in turn affects the yield of the plantations (Zafari and Mohammadi, 2019; Kaleeswari and Balasubramanian, 2020). Thus, the nutrient additions and effective nutrient makeup of soil under fertigation need to be monitored (Dobrowolski et al., 2017). In this context, the major objective of the research focusses to address the “Effect of fertigation on soil nutrients, physio-chemical properties and yield of teak at early growth stages”.

Materials and methods

A teak research trial was established on August 2020 in farmer’s field at Pachapalayam village (*Plate 1*), Perur, Coimbatore district of Tamil Nadu, India (11°14” N and 77°03” E). The teak plantation was raised with a spacing of 3 m × 3 m for an area of about 7.5 acres. The treatments were imposed on the selected homogenous sampling plot of 5508 m^2 (108 m × 51 m). The experimental design followed was split plot design with 3 replications. In the split plot design different levels of irrigation and fertilizers were assigned as the main plot and subplot treatments respectively. The total number of trees chosen for the study was 180 numbers (15 trees per treatment).

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Plate 1. *Farmers field at Pachapalayam, Perur, Tamil Nadu (age: 2 years)*

Fertilizers treatments were imposed through pre-installed drip irrigation systems. Irrigation was applied based on the pan evaporation (PE) values from an open pan evaporimeter. Irrigation was scheduled once every three days using the formula stated below and applied according to the schedule. The operating pressure for the drip fertigation system was at 1.0 kg cm^{-2}.

Computed water requirement (lit/plant)

The water requirement of the tree is calculated according to FAO (1998) using the formula as follows:

$$WR_t = CPE \times K_p \times K_c \times W_p \times A - ER \qquad \text{(Eq.1)}$$

where: WR_t = computed water requirement for tree (L/plant); CPE = cumulative pan evaporation (mm); K_p = pan factor, K_c = crop factor/plant factor (as per Allen et al., 1998); W_p = wetted percentage, ER = effective rainfall; A = spacing.

K_c is a factor that helps to correct water requirement, because the fact that not all plants use water at the same rate under same conditions. The derived plant factor used in the present study was developed by Allen et al. (1998) which is regarded as 0.85 for medium size actively growing trees. The derived plant factors by FAO is reevaluated by the formula:

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$$\text{Plant factor} = \text{Canopy area} / \text{Land area} \qquad \text{(Eq.2)}$$

Irrigation duration

The duration of irrigation through drip irrigation system will be estimate using the formula:

$$\text{Irrigation duration} = \frac{\text{Volume of water required}}{\text{Emitter discharge} \times \text{No. of emitters}} \qquad \text{(Eq.3)}$$

Number of drippers per tree: 2; discharge rate (L h^{-1}): 4.

The treatments comprised of 4 levels of irrigation (50% PE, 75% PE, 100% PE, and 125% PE) and 4 levels of fertilizers (75% RDF, 100% RDF, 125% RDF, and 150% RDF) by considering the Recommended Dose of Fertilizer (RDF) for teak in Indian condition as 150:100:100 kg/ha as recommended by Geetha and Balagopalan (2009). The fertilizer is applied as one split dose for every month and irrigation is applied once in three days based on the factor of rainfall distribution. The irrigation durations were calculated as 21 min (I_1), 26 min (I_2), 32 min (I_3) and 39 min (I_4), the discharge rate of dripper is 4 L h^{-1} (*Table 1*).

Table 1. *Layout of the irrigation (main plot) and fertilizer (sub plot) treatments*

Treatments		Subplot (fertigation levels)			
		F_1	**F_2**	**F_3**	**F_4**
Main plot (irrigation levels)	I_1	50% PE 75% RDF	50% PE 100% RDF	50% PE 125% RDF	50% PE 150% RDF
	I_2	75% PE 75% RDF	75% PE 100% RDF	75% PE 125% RDF	75% PE 150% RDF
	I_3	100% PE 75% RDF	100% PE 100% RDF	100% PE 125% RDF	100% PE 150% RDF
	I_4	125% PE 75% RDF	125% PE 100% RDF	125% PE 125% RDF	125% PE 150% RDF
Control		Conventional method of irrigation (surface) and fertigation (soil application of 100% of recommended dose of fertilizer)			

PE – potential evapotranspiration; RDF – recommended dose of fertilizers

Soil properties of the experimental site

The initial soil profile characteristics of the study area were presented in *Table 2*. The soil field capacity (%) is 26.75% and the permanent wilting point (%) is 14.25%. The soil samples were collected from 0-30 cm depth in both seasons (9 MAT and 18 MAT) and the soil physio-chemical properties were analyzed as per the standard procedure.

Table 2. *The experimental field's initial soil profile characteristics*

Soil parameters	Magnitude	Methodology
Soil bulk density (g cc^{-1})	1.32	Dakshinamurthy and Gupta (1968)
Soil texture	Sandy clay loam	Piper (1966)
Soil pH	7.55	Jackson (1973)
Soil EC (dSm^{-1})	0.78	Jackson (1973)
Soil organic carbon (%)	0.51	Walkley and Black (1934)
Available nitrogen (Kg ha^{-1})	142.5	Subbiah and Asija (1956)
Available phosphorus (Kg ha^{-1})	8.55	Olsen et al. (1954)
Available potassium (Kg ha^{-1})	157.2	Stanford and English (1949)

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The average weather conditions of the experimental site are represented in *Figures 1* and *2*.

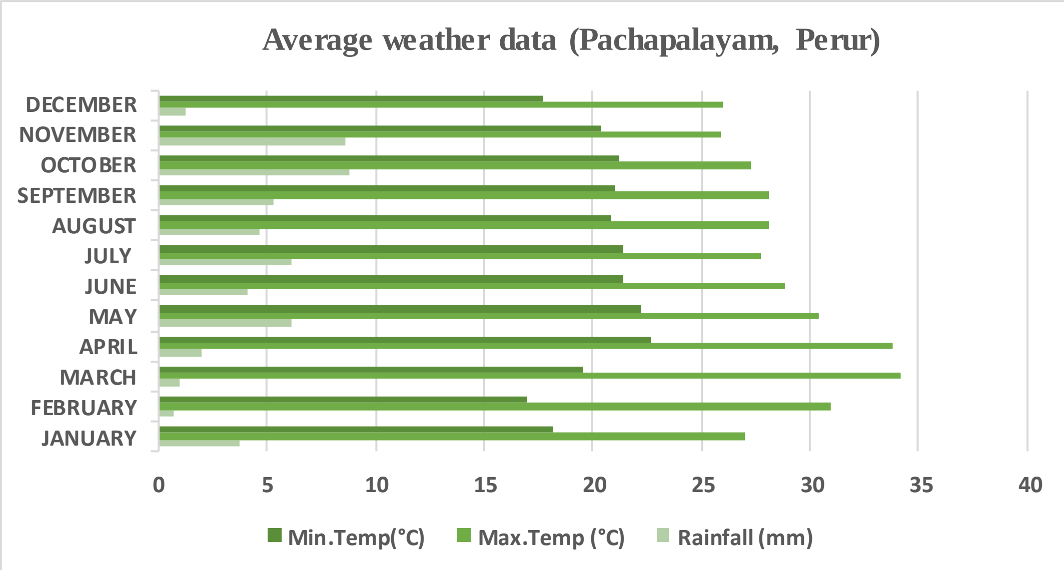

Figure 1. *Average weather data of the study area (2021). (Source: Agro Climate Research Centre, Tamil Nadu Agricultural University)*

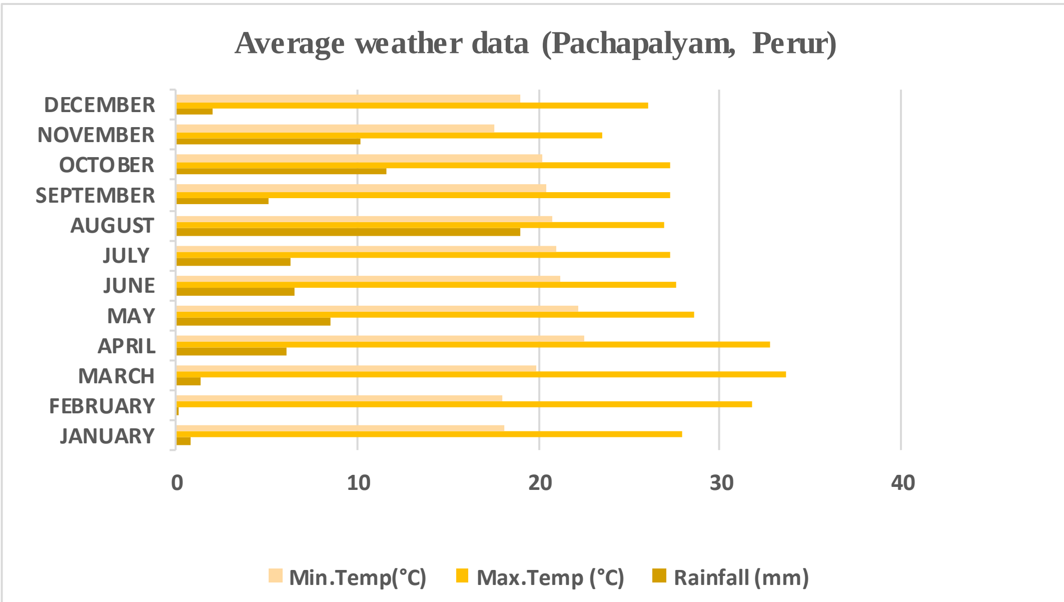

Figure 2. *Average weather data of the study area (2022). (Source: Agro Climate Research Centre, Tamil Nadu Agricultural University)*

Growth biometrics

The fertilizer response of teak was measured in terms of growth biometry by estimating height (m) using Laser Distance Meter (Leica DISTO ^{TM} S910), Basal

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diameter (mm) by Vernier Caliper and the volume index (m^3) was worked out as per the standard prescribed by Hatchell (1985). The form factor was ignored, while taking the measurement in laser distance meter as the diameter is taken at every 2 m interval of height, so that the destructive sampling of the tree was ignored.

$$V.I = \text{Height (cm)} \times \text{Basal diameter}^2\ (cm^3)$$

Statistical analysis

The experimental databases collected were statistically analyzed under split plot design. Wherever the treatments were significant, the critical differences were worked out at five per cent probability level by means of DMRT (Duncan's Multiple Range Test) for the post-hoc test under R environment (R Core Team, 2012). The relationship between the parameters is estimated by means of Karl Pearson's correlation analysis by means of IBM SPSS Statistics 21 Software.

Results

Soil pH and nutrients status in collected samples from field survey

The soil physiochemical parameters were analyzed at two different phases of the treatment viz., 9 months after treatment (MAT) and 18 months after treatment (MAT). The soil physio-chemical parameters is represented in term of soil pH, electrical conductivity, available nitrogen, available phosphorus and available potassium (*Table 3*).

At 9MAT, the soil samples collected fromI_2F_1 (75% PE 75% RDF) registered the maximum pH (7.28) and minimum (6.44) at I_4F_3 (125% PE 125% RDF), where electrical conductivity is maximum (0.42dSm^{-1}) at I_1F_4 (50% PE 150% RDF) and minimum (0.23dSm^{-1}) for I_4F_2 (125% PE 100% RDF). On considering available nitrogen, available phosphorus and available potassium, the maximum value for available potassium (202.5 Kg ha^{-1}) and available phosphorus (15.00 Kg ha^{-1}) is obtained for I_3F_3(100% PE 125% RDF) while maximum value for available nitrogen (199.5 Kg ha^{-1}) is under treatment combinations of I_4F_3 (125% PE 125% RDF), where the minimum value for available nitrogen (166.00 Kg ha^{-1}) and available potassium (162.00 Kg ha^{-1}) is registered in I_1F_1(50% PE 75% RDF) where the minimum value for available phosphorus (9.50 Kg ha^{-1}) is registered under I_4F_1 (125% PE 75% RDF), the values are significant at 5% level of significance.

On considering the soil physiochemical parameters taken at 18 months after treatment (*Table 4*), with respect to soil pH, the maximum (7.61) value is registered under I_1F_1 (50% PE 75% RDF) and minimum value (6.43) at I_3F_1 (100% PE 75% RDF), where electrical conductivity is maximum (0.344 dSm^{-1}) at I_1F_4 (50% PE 150% RDF) and minimum (0.267 dSm^{-1}) at I_2F_4 (75% PE 150% RDF). The maximum value for available nitrogen (204.30 Kg ha^{-1}), available phosphorus (15.94 Kg ha^{-1}) and available potassium (213.51 Kg ha^{-1}) is registered in I_3F_4(100% PE 150% RDF), I_2F_3(75% PE 125% RDF) and I_1F_3(50% PE 125% RDF) respectively, where the minimum value for available nitrogen (147.00 Kg ha^{-1}) is recorded at I_2F_1(75% PE 75% RDF), for available phosphorus (10.46 Kg ha^{-1}) and available potassium (145.17 Kg ha^{-1}) is recorded in I_4F_1(125% PE 75% RDF), the values are significant at 5% level of significance.

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Table 3. *Impact of fertigation on soil physio-chemical properties 9 months after treatment (MAT)*

Main plot	Subplot	pH	Electrical conductivity (dSm^{-1})	Available nitrogen ($Kg\ ha^{-1}$)	Available phosphorus ($Kg\ ha^{-1}$)	Available potassium ($Kg\ ha^{-1}$)
I_1	F_1	7.21^{ab}	0.36^{b}	166.0^{k}	10.50^{b}	162.0^{l}
	F_2	7.10^{bc}	0.36^{b}	178.5^{j}	12.00^{d}	177.7^{j}
	F_3	6.88^{c}	0.38^{ab}	190.0^{e}	13.80^{e}	199.2^{f}
	F_4	6.75^{d}	0.42^{a}	188.2^{g}	13.62^{g}	192.7^{h}
I_2	F_1	7.28^{a}	0.30^{cd}	168.0^{jk}	9.50^{a}	161.5^{l}
	F_2	7.13^{b}	0.29^{d}	179.5^{j}	11.50^{c}	175.0^{k}
	F_3	6.70^{d}	0.30^{cd}	191.8^{c}	14.50^{h}	201.0^{b}
	F_4	6.68^{de}	0.34^{ab}	189.6^{f}	14.00^{i}	198.3^{g}
I_3	F_1	7.10^{bc}	0.28^{d}	167.8^{k}	11.00^{d}	162.0^{l}
	F_2	6.77^{d}	0.30^{cd}	180.2^{i}	12.50^{f}	178.0^{i}
	F_3	6.65^{de}	0.32^{b}	191.8^{c}	15.00^{j}	202.5^{a}
	F_4	6.60^{e}	0.35^{b}	192.3^{b}	14.53^{h}	200.2^{c}
I_4	F_1	6.62^{e}	0.24^{e}	167.0^{jk}	9.50^{a}	161.5^{l}
	F_2	6.55^{f}	0.23^{e}	182.4^{h}	12.80^{d}	174.4^{kl}
	F_3	6.44^{g}	0.26^{de}	199.5^{a}	14.80^{h}	200.0^{d}
	F_4	6.55^{f}	0.29^{d}	190.6^{d}	14.29^{gh}	199.7^{e}
Grand mean		6.81	0.31	182.7	12.74	184.1
SE (d)		0.0112	0.01266	0.24181	0.10926	0.53898
CD (0.01)		0.0443	0.02916	0.66498	0.30048	1.48220

Table 4. *Impact of fertigation on soil physio-chemical properties 18 months after treatment (MAT)*

Main plot	Subplot	pH	Electrical conductivity (dSm^{-1})	Available nitrogen ($Kg\ ha^{-1}$)	Available phosphorus ($Kg\ ha^{-1}$)	Available potassium ($Kg\ ha^{-1}$)
I_1	F_1	7.61^{a}	0.33^{abc}	159.83^{kl}	11.70^{k}	176.00^{i}
	F_2	7.60^{a}	0.29^{ef}	157.50^{kl}	13.20^{g}	191.70^{c}
	F_3	7.49^{ab}	0.30^{cdef}	169.00^{j}	15.00^{c}	213.20^{a}
	F_4	7.38^{abc}	0.34^{ab}	167.15^{k}	14.82^{d}	206.73^{b}
I_2	F_1	7.34^{bc}	0.31^{cde}	147.00^{m}	10.70^{l}	175.50^{i}
	F_2	7.38^{abc}	0.27^{ef}	158.50^{kl}	12.90^{h}	189.00^{d}
	F_3	7.39^{abc}	0.35^{a}	172.80^{h}	15.90^{a}	184.00^{fg}
	F_4	7.45^{ab}	0.26^{f}	170.56^{i}	15.40^{b}	181.29^{h}
I_3	F_1	6.43^{e}	0.32^{bc}	148.80^{lm}	12.40^{i}	145.00^{l}
	F_2	6.88^{d}	0.29^{def}	192.20^{c}	13.40^{g}	161.00^{j}
	F_3	7.19^{c}	0.33^{abc}	203.80^{b}	15.90^{a}	185.50^{e}
	F_4	7.49^{ab}	0.31^{cdef}	204.25^{a}	15.43^{bc}	183.15^{g}
I_4	F_1	7.43^{abc}	0.29^{def}	179.00^{f}	10.40^{l}	144.50^{l}
	F_2	7.42^{abc}	0.29^{def}	173.40^{g}	12.10^{j}	157.40^{k}
	F_3	7.40^{abc}	0.28^{ef}	190.50^{d}	14.10^{e}	183.00^{fg}
	F_4	7.30^{bc}	0.31^{cd}	181.56^{e}	13.59^{f}	182.65^{f}
Grand mean		7.3262	0.3093	173.5021	13.6527	179.7490
SE (d)		0.12418	0.01166	0.24181	0.10926	0.53898
CD (0.01)		0.34148	0.03206	0.66498	0.30048	1.48220

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Effect of fertigation on growth biometry of teak

The effect of fertigation in growth biometrics is represented as the function of height increment, basal diameter increment and calculated volume index. The variation in the growth attributes of teak under fertigation are present in *Table 5*. With respect to the height, at 9 months after treatment (MAT), the maximum height (3.12 m) was recorded for the irrigation and fertilizer combination at I_3F_3 (100% PE 125% RDF) and minimum (1.98 m) under I_1F_2 (50% PE, 100% RDF) ($F = 3.6331$, $P < 0.01$). On comparing the main plot (irrigation) effects, the maximum (2.94 m) is obtained for I_4 (125% PE) and minimum at I_1 (2.20 m) ($F = 56.24$, $P < 0.01$) where at subplot (fertilizer levels), the maximum (2.89 m) is obtained for F_3 (125% RDF) and minimum (2.35 m) is obtained for F_1 (75% RDF), the values varies significantly among different treatment levels ($F = 23.21$, $P < 0.01$). On comparing the basal diameter, at 9 MAT, the values varies among the treatments, while the interaction effects are not significant ($F = 0.273$, $P > 0.05$) where the maximum basal diameter (9.74 cm) was recorded for the irrigation and fertilizer combination at I_3F_3 (100% PE 125% RDF) and minimum (7.42 cm) under I_1F_1 (50% PE, 75% RDF). On comparing the main effects, under different irrigation regimes, the maximum (9.48 cm) is obtained for I_3 (100% PE) and minimum at I_1 (7.9 cm) ($F = 30.16$, $P < 0.01$) where at different fertilizer levels, the maximum (9.14 cm) is obtained for F_3 (125% RDF) and minimum (8.47 cm) is obtained for F_1 (75% RDF), the values varies significantly among different treatment levels ($F = 4.35$, $P < 0.05$). With respect to the calculated volume index, at 9 MAT, the maximum value (2903.28 m^3) is registered for the treatment combinations at I_3F_3 (100% PE 125% RDF) and minimum (1087.98 m^3) under I_1F_1 (50% PE, 75% RDF) ($F = 0.9917$, $P > 0.05$). On comparing the main effects, under different irrigation regimes, the maximum (2547.80 m^3) is obtained for I_4 (125% PE) and minimum at I_1 (1372.87 m^3) ($F = 62.28$, $P < 0.01$) where at different fertilizer levels, the maximum (2421.71 m^3) is obtained for F_3 (125% RDF) and minimum (1741.99 m^3) is obtained for F_1 (75% RDF), the values varies significantly among different treatment levels ($F = 0.99$, $P < 0.01$).

Where at 18 MAT (*Table 6*), on comparing the height, the maximum value (4.45 m) is registered under treatment combinations of I_4F_3(125% PE 125% RDF), the values are significant at 5% level of significance ($F = 2.17$, $P < 0.05$). On considering the main plot (irrigation), the maximum height (4.27 m) is procured under I_4(125% PE) and minimum at I_1 (50% PE) ($F = 32.38$, $P < 0.01$), while at sub plot level (fertilizer), the maximum height (4.15 m) is registered for F_3 (125% RDF) and minimum at F_1 (75% RDF) ($F = 14.45$, $P < 0.01$). Regarding the basal diameter taken at 18 MAT, the maximum value (13.12 cm) is registered under treatment combinations of I_3F_2(100% PE 100% RDF) and minimum (11.00 cm) at I_1F_1(50% PE 75% RDF) ($F = 0.33$, $P > 0.05$). On considering the main plot (irrigation), the maximum (12.77 cm) is under I_4(125% PE) and minimum (11.19 cm) at I_1 (50% PE) ($F = 32.38$, $P < 0.01$), while at sub plot level (fertilizer), the maximum value (12.31 cm) is registered for F_2 (100% RDF) and minimum (11.89 cm) at F_1 (75% RDF) ($F = 1.21$, $P > 0.05$). On comparing the calculated volume index for values taken at 18 MAT, the maximum value (7072.62 m^3) is registered under treatment combinations of I_4F_3(125% PE 125% RDF) and minimum (4214.97 m^3) at I_1F_1(50% PE 75% RDF) ($F = 086$, $P > 0.05$). On considering the main plot (irrigation), the maximum (6872.41 m^3) is procured under I_4 (125% PE) and minimum (4367.19 m^3) at I_1 (50% PE) ($F = 41.09$, $P < 0.01$), while at sub plot level (fertilizer), the maximum value (6139.71 m^3) is registered for F_3 (125% RDF) and minimum (5153.87 m^3) at F_1 (75% RDF) ($F = 0.86$, $P > 0.05$).

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Table 5. *Effect of fertigation on growth biometry of teak at 9 months after treatment (9 MAT)*

Main plot	Subplot	Height (m)	Diameter at breast height (cm)	Volume index (cm^3)
I_1	F_1	2.06^{f}	7.42^{a}	1087.98^{a}
	F_2	1.98^{f}	7.81^{a}	1252.33^{a}
	F_3	2.65^{cde}	8.41^{a}	1830.69^{a}
	F_4	2.11^{f}	7.98^{a}	1318.59^{a}
I_2	F_1	2.09^{f}	8.26^{a}	1386.33^{a}
	F_2	2.61^{de}	8.77^{a}	1968.15^{a}
	F_3	2.86^{bcd}	8.79^{a}	2175.24^{a}
	F_4	2.82^{bcde}	8.75^{a}	2137.25^{a}
I_3	F_1	2.58^{e}	9.11^{a}	2098.56^{a}
	F_2	2.91^{abc}	9.50^{a}	2561.14^{a}
	F_3	3.12^{a}	9.74^{a}	2903.28^{a}
	F_4	2.92^{ab}	9.57^{a}	2613.11^{a}
I_4	F_1	2.88^{abcd}	9.26^{a}	2403.19^{a}
	F_2	2.89^{abc}	9.33^{a}	2451.42^{a}
	F_3	3.01^{ab}	9.72^{a}	2778.67^{a}
	F_4	2.96^{ab}	9.36^{a}	2553.98^{a}
Grand mean		2.66	8.86	2094.94
SE (d)		0.364	0.129	203.9
CD (0.01)		1.023	0.351	559.8

Table 6. *Effect of fertigation on growth biometry of teak at 18 months after treatment (18 MAT)*

Main plot	Subplot	Height (m)	Diameter at breast height (cm)	Volume index (cm^3)
I_1	F_1	3.54^{f}	11.00^{a}	4214.97^{a}
	F_2	3.48^{ef}	11.23^{a}	4340.88^{a}
	F_3	3.69^{f}	11.41^{a}	4675.41^{a}
	F_4	3.51^{ef}	11.17^{a}	4240.96^{a}
I_2	F_1	3.30^{def}	11.72^{a}	4456.66^{a}
	F_2	3.96^{f}	12.03^{a}	5639.54^{a}
	F_3	4.18^{abc}	12.11^{a}	6037.38^{a}
	F_4	4.03^{bcd}	11.82^{a}	5554.11^{a}
I_3	F_1	3.72^{de}	12.23^{a}	5383.30^{a}
	F_2	4.11^{bc}	13.12^{a}	6933.97^{a}
	F_3	4.30^{ab}	12.61^{a}	6769.59^{a}
	F_4	4.16^{abc}	12.82^{a}	6666.17^{a}
I_4	F_1	4.10^{bc}	12.81^{a}	6562.35^{a}
	F_2	4.22^{abc}	12.92^{a}	6940.33^{a}
	F_3	4.45^{a}	12.71^{a}	7072.62^{a}
	F_4	4.31^{ab}	12.82^{a}	6910.31^{a}
Grand mean		3.97	12.32	5774.99
SE (d)		0.155	0.445	494.0
CD (0.01)		0.427	0.907	1336.9

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Correlation analysis between soil pH on nutrient dynamics under fertigation system

Karl Pearson's correlation analysis correlation analysis was conducted in order to relate soil pH with soil nutrient dynamics, at initial stages of measurement (*Table 7; Fig. 3*), pH is positively correlated (0.281) with electrical conductivity ($P > 0.05$), while negatively correlated with available nitrogen (-0.708), available phosphorus (-0.688) and available potassium (-0.647) ($P < 0.01$). On contrary to these observations, at 18 MAT (*Table 8; Fig. 4*), pH is negatively correlated (-0.088) with electrical conductivity ($P > 0.05$), while positively correlated with available nitrogen (0.063, $P > 0.05$), available phosphorus (0.076, $P > 0.05$) and available potassium (0.480, $P < 0.01$).

Table 7. *Karl Pearson's correlation analysis between soil nutrient content and growth of teak under fertigation system (9 MAT)*

Correlations								
Pearson correlation	**pH**	**EC**	**N**	**P**	**K**	**Height**	**DBH**	**Volume index**
pH	1							
EC	.281	1						
N	-.708**	.176	1					
P	-.688**	.231	.964**	1				
K	-.647**	.314*	.964**	.963**	1			
Height	-.750**	-.504**	.524**	.530**	.485**	1		
Basal diameter	-.629**	-.541**	.389**	.381**	.314*	.763**	1	
Volume index	-.732**	-.540**	.481**	.486**	.421**	.920**	.949**	1

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed)

Table 8. *Karl Pearson's correlation analysis between soil nutrient content and growth of teak under fertigation system (18 MAT)*

Correlations								
Pearson correlation	**pH**	**EC**	**N**	**P**	**K**	**Height**	**DBH**	**Volume index**
pH	1							
EC	-.088	1						
N	.063	-.032	1					
P	.076	.174	.514**	1				
K	.480**	.166	.035	.613**	1			
Height	-.104	-.205	.688**	.323	-.197**	1		
DBH	-.233	-.272	.563**	.001	-.458**	.644**	1	.
Volume index	-.178	-.254	.684**	.146	-.371**	.872**	.933**	1

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed)

Correlation analysis between nutrient dynamics on growth attributes of teak under fertigation system

In order to correlate the relation between soil nutrient dynamics with growth, Karl Pearson's correlation analysis was conducted for observations taken at 9 months and

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18 months after treatment. At 9 MAT, the growth attributes viz., height, basal diameter and volume index is negatively correlated (*Table7; Fig. 3*) with soil pH (-0.750, -0.629, -0.732) and electrical conductivity (-0.504, -0.541, -0.540), while positively correlated with available nitrogen (0.524, 0.389, 0.481), available phosphorus (0.530, 0.381, 0.481) and available potassium (0.485, 0.314, 0.421) ($P < 0.01$). At 18 MAT, the growth attributes viz., height, basal diameter and volume index is negatively correlated (*Table 8; Fig. 4*) with soil pH ($P > 0.05$) (-0.104, -0.233, -0.178), electrical conductivity ($P > 0.05$) (-0.504, -0.541, -0.540) and available potassium ($P < 0.05$) (-0.197, -0.458, -0.371) while positively correlated with available nitrogen ($P < 0.01$) (0.688, 0.563, 0.684) and available phosphorus ($P > 0.05$) (0.530, 0.381, 0.481).

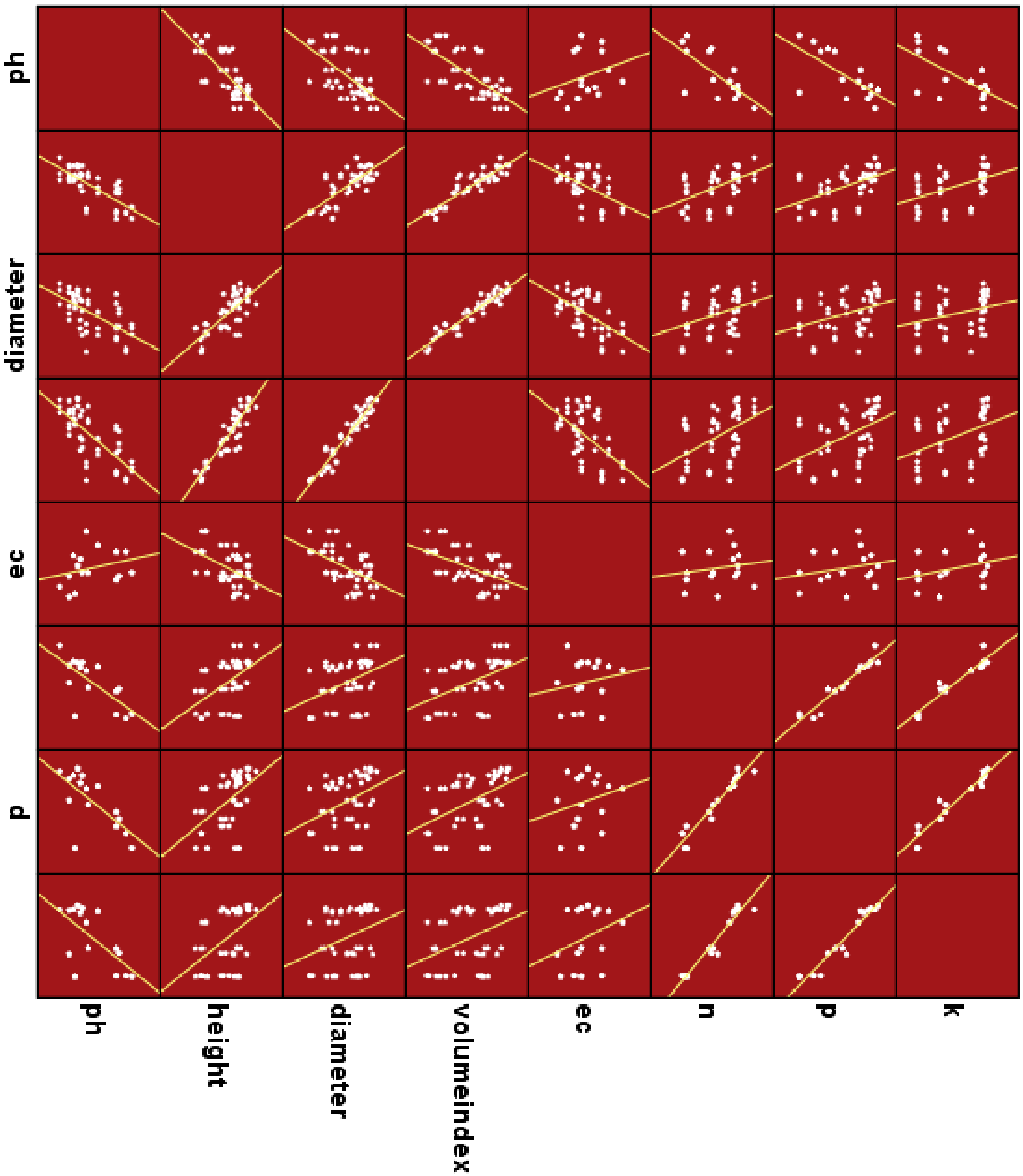

Figure 3. *Matrix scatter plot between soil physiochemical parameters with growth biometrics (9 MAT)*

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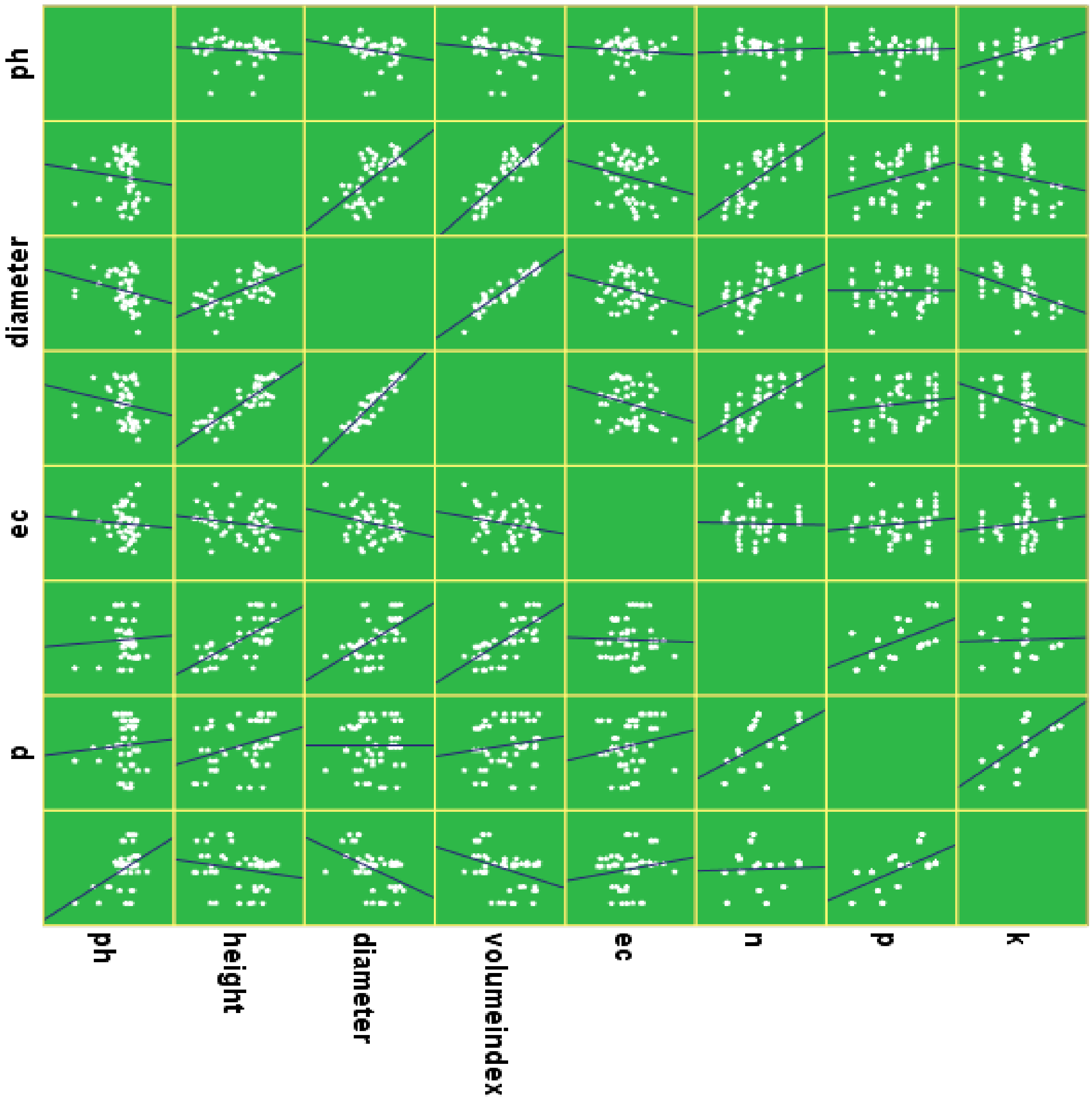

***Figure 4.** Matrix scatter plot between soil physiochemical parameters with growth biometrics (18 MAT)*

Discussion

The nutrient dynamics under different fertigation regimes has an impact on growth biometry of teak at early stages. The observed soil parameters at both phases of observation were registered improved value than the initial soil characteristics of the experimental site mentioned in *Table 2*. The study result was observed to be similar with the findings of Bhat et al. (2007) that the amount of nutrient concentration was strongly dependent on the input rate i.e., dosage of fertilizer and the frequency of the fertilizer and Singh and Mishra (2012) reported negative relationship between soil pH and nutrient availability. With the increase on soil pH, primary nutrients decreases gradually and vice-versa. On the other hand, with the increase on soil pH, secondary nutrient increases consequently and vice-versa. Thus, the soil pH can control the availability of macronutrients such as nitrogen, potassium and phosphorus at different stages of crop growth. The soil nutrient status represented in terms of available nitrogen,

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available potassium and available phosphorus is negatively correlated to soil pH and electrical conductivity at early stages the results and positively correlated at later stages. Similar significant negative correlation is obtained for Similar significant negative correlation is obtained for Singh and Mishra (2012); Khadka et al. (2016) and positive correlation for Ghosh and Mukhopadhya (1996); Sharma et al. (2008); Athokpam et al. (2013). The macronutrients are positively correlated to available nitrogen, phosphorus at both stages and to available potassium at early stages substantiating the increased growth at the plots where the nutrient availability is maximum, similar observations were registered by Binkley and Hart (1989); Ogidi et al. (2018); Soong et al. (2020). It is difficult, however, to rationalize the negative signs of the coefficients for potassium, these may be attributed to the increased potassium availability in most forest soils (Pritchett and Fisher, 1987), possibly explaining its weak role in multi-nutrient tree growth models, similar results are also reported by Sheppard et al. (2001). The growth increased at the increase in nutrient dosage may be attributed towards the increased macronutrient concentration with increased fertilizer dosage. The study result was in concordance with the findings of Mutanal et al. (2000) in teak; Coleman et al. (2004) in Sycamore; Samuelson et al. (2009) in loblolly pine; Mona (2013) in woody trees; and Yan et al. (2018) in poplar species**.** In the present study, the irrigation treatment with 100% PE at 9 MAT and 125% PE and 18 MAT water application has recorded to produce maximum tree height and tree basal girth. At 18 MAT, increased irrigation rate (125% PE) has increased growth than 100% PE at 9 MAT, this may be attributed towards the lower monthly rainfall (11 mm) observed in the study area at 18 MAT, than at 9 MAT (72 mm) (*Figs 1* and *2*) attributed to increased water requirement at the observation period. Similar observations are registered by Xi et al. (2017) and Yang et al. (2019) in Poplar trees. The minimum dimensions were elucidated at low level of irrigation of 50% PE regime. The growth increased at the increase in nutrient dosage may be attributed towards the increased macronutrient concentration with increased fertilizer dosage. The study result was in concordance with the findings of Mutanal et al. (2000) in teak; Coleman et al. (2004b) in sycamore; Samuelson et al. (2009) in loblolly pine; Mona (2013) in woody trees; and Yan et al. (2018) in poplar species.

Conclusion

The nutrient status of the soil is an essential parameter for growth and productivity. Therefore, in the present study, on envisaging different fertigation treatments, the nutrient status of the soil varies favorably correlating towards the growth and productivity of tree plantation. The study concludes that an increased growth biometrics and productivity under 100% PE and 100%RDF at 9 MAT and 125% PE and 100% RDF at 18 MAT. The average rainfall variations during the period of observations contributed towards the differences in irrigation regimes for growth and productivity. Hence, it is recommended that the standardization of the treatment applications based on the crop nutrient and water requirements can improve the crop growth at early stages of teak plantation with highest efficiency.

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