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# LINEAR FORECASTING NUTRIENT UPTAKE MODEL FOR TEAK (*TECTONA GRANDIS*) IN EARLY DEVELOPMENTAL STAGES (SEEDLING STAGES) UNDER FERTIGATION SYSTEM

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Teak (*Tectona grandis*) is a valuable timber yielding species in the world due to its exemplary quality and market value. Though teak plantations twirls natively, countries like India are mostly depending on total import of teak for domestic utility. Thus the need to adopt a precised planting technology for Teak productivity enhancement is highly relevent. In this context, a field experiment was conducted with nitrogen, phosphorus & pottasium (NPK) fertiliser under drip fertigation system to study the early (seedling) response of teak in relation to nutrient uptake and growth. All yield prediction models in teak were related to growth and age, but research towards yield related to nutrient is least available. The model developed helps to conclude that, in the current study, height, basal diameter and volume index is predominantly a function of phosphorus and potassium uptake during initial growth phase (4 months after treatment), while 8 months after treatment, basal diameter and volume index were expressed as a function of nitrogen and phosphorus uptake. Hence the model helps to optimise nutrient use efficiency (NUE) of teak at different growth stages with good growth rate.

Keywords: Nutrient uptake, growth, height, basal diameter, volume index, nutrient use efficiency, yield

## INTRODUCTION

Teak (*Tectona grandis*) belonging to the family Verbanaceae is known as 'King of Timber' and is one of the most valuable timber across the world (Cowan et al.1965, White 1991). Owing to its higher timber qualities, market demand, ease of domestication and cultivation, teak plantation has been widely established throughout the tropics since 1850s (FAO 1957, Parton et al. 1988). The total round wood demand in India is estimated to be 199 M $m^3$ and teak accounts to almost half of the total roundwood requirement (95 M $m^3$ ). India alone consumes 70 to 100 per cent of teak logs from Africa and Latin America and 90,000 $m^3$ of teak are imported annually (Shrivastava & Saxena 2017). Though teak is the most important and widely planted member in Verbanaceae family, successful teak plantations are only found in discontinuous regions within the tropical climate zones (Sands and Mulligan 1990, Kyaw et al. 2020).

In order to meet the rising demand for iwood in the global context, productive output should be supplied within a shorter rotation period (Mohan et al. 2022). Resource inputs like irrigation and fertilisers coupled with specific silvicultural prescriptions will improve the productivity with reduced rotation (Haynes 1985, Kant et al. 2005, Solaimalai et al. 2005). The uptake of nutrients like nitrogen, phosphorus and potassium (NPK) are important for tree growth and productivity (Marschner 1995, Borchardt 1996, Cakmak 2005). It is important to predict the nutrient influence on the yield of the tree, and the correlation between nutrient uptake and tree growth in order to assess the significant nutrient contributions to crop yield (Marschner 1995, Pretzsch et al. 1995). Growth and yield modelling is such an essential prerequisite for predicting the impact of a particular management action on the future development of trees (Pretzsch et al. 1995, Tewari 2006).

Growth model in forestry is generally referred to a system of equations which can predict the growth and yield of forest stand under variability of conditions (Tewari 2006). With the aid of suitable inventory and other resources data, growth models provide authentic methodology to examine the impacts of forest management like fertiliser application and harvesting on yield and productivity of the trees (Pretzsch & Kahn 1995, Sterba & Robert 1995, Balasubramanian et al. 2022, Tewari 2006). Many of the yield models developed in farm grown trees like *Azadirachta indica*, *Ailanthus excelsa* and *Ailanthus excelsa* were confined with age and yield, but were not correlated to nutrient uptake (Raviperumal et al. 2018, Ravi et al. 2018, Balasubramanian et al. 2019).

The various growth models related to tree nutrient uptake such as mechanistic nutrient uptake models in Red Spruce, soil nitrogen availability predictor (SNAP) model in *Pinus radiata*, 3-PG fertility model in *Eucalyptus*, soil organic matter model (Century model), NST 1.0 model, SSAND model, PCATS model and nutrient uptake model in *Pinus taeda* were confined to conifer trees (Parton et al. 1987, 1988, Kelly et al. 1992, Kelly et al. 1995, Landsberg & Waring 1997, Li & Comerford 2000, Kirschbaum & Paul 2002, Paul et al. 2002, Smethurst 2004, Stape et al. 2004, Lin &Webster 2012). However such models are very scanty in tropical trees like teak and the available yield model developed in teak by Balasubramanian (2019) and Laurie & Ram (1940) in India, Jean (2020) in West Africa, Bermejo et al (2004) in Costa Rica, Gonzales (1985) in Philippines, Laurie & Ram (1940) in Burma were also based only on age and yield relationship. However, growth model in relation to nutrient uptake in teak is yet to be addressed. Hence the current study formulated the nutrient uptake growth model in Teak through linear forecasting method of growth modelling by multiple linear regression analysis.

## MATERIALS AND METHODS

### Experimental layout

A teak research trial was established in a farmer's field at Pachapalayam village, Perur, Coimbatore district of Tamil Nadu, India (11.1477 N and 77·03955 E). The teak plantation was raised by seedlings in August 2020 with a spacing of 3 m × 3 m in an area of about 7.5 acres. The age of the plantation is 20 months. The experiment was carried out from January 2021 to till date. Within the plantation, an area of 5508 $m^2$, having homogenous plant population with uniformity was selected and demarcated to impose treatments in order to avoid edge effects and land fertility variation. The total number of trees chosen for the study was 180 numbers (15 trees per treatment). The experimental design followed was split plot design with 3 replications. In the split plot design, different levels of irrigation and fertilisers were assigned as the main plot and subplot treatments, respectively. The soil texture of the experimental field was sandy clay loam with a field capacity of 26.75%. During the study period, the mean maximum and minimum temperatures were 35.5 and 29.8 °C respectively. The amount of rainfall prevailed during the study period was 903.55 mm with 27 rainy days. The daily weather data was collected from Agro Climate Research Centre, Tamil Nadu Agricultural University, and Coimbatore.

### Treatment and observations

Fertiliser 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 schedule. The operating pressure for the drip fertigation system was 1.0 kg $cm^{-2}$.

### Computed water requirement (litre/plant)

Water is applied to the effective root zone of the tree in the drip irrigation system, and hence, it is necessary to calculate the water requirement of the tree intended to be grown so that the wastage of the input can be minimised and the required amount of water can be used for irrigating the tree. It can be computed using the formula as follows:

$$WR_c = CPE * K_p * K_c * W_p * A - ER$$

where $WR_t$ = computed water requirement for tree (litre/plant), CPE = cumulative pan evaporation (mm), $K_p$ = pan factor, $K_c$ = crop factor/plant factor (FAO 2015), $W_p$ = wetted percentage, ER = effective rainfall, A = spacing. $K_c$ is a factor that helps to correct water requirement, not all plants use water at the same rate under same conditions. The derived plant factor used in the present study was developed by the Food and Agriculture Organisation (FAO) which is regarded as 0.85 for medium size actively growing trees. The derived plant factors by FAO is re-evaluated by the formula:

Plant factor = canopy area / land area

## Irrigation duration

The duration of irrigation through drip irrigation system was estimated using the formula:

$$\text{Irrigation Duration} = \frac{\text{Volume of water required}}{\text{Emitter discharge} \times \text{No. of emitters}}$$

where numbers of drippers per tree = 2 and discharge rate (litres $hr^{-1}$) = 4

The treatments comprised of 4 levels of irrigation (50, 75, 100 and 125% PE) and 4 levels of fertilisers (75, 100, 125 and 150% RDF) by considering the recommended dose of fertiliser (RDF) for Teak in Indian condition as 150:100:100 kg $ha^{-1}$, as recommended by Balagopalan (2006). The treatment with conventional method of irrigation and 100 % RDF was taken as control.

The fertiliser response to teak was measured in terms of growth biometry by estimating the height (m) using tree telescope and the basal diameter (mm) by vernier calliper. The volume index ($m^3$) was worked out as per the standard prescribed by Hatchell (1985). The measurements were taken on a monthly basis (15 trees per treatment).

V.I = height (cm) X basal diameter$^2$ (cm$^2$)

The (NPK) levels and its uptake by teak was estimated as nitrogen uptake by Micro Kjedahl method, and phosphorus and potassium uptake by Triple acid digestion method (Humphries 1956, Jackson 1973). The Karl Pearson's correlation analysis procedure was adopted for estimating the relationship between the nutrient uptake and growth attributes of teak by means of IBM SPSS Statistics 21 software. Growth modelling was done by means of multiple linear regression analysis using IBM SPSS Statistics 21 software, where the equation was formulated by treating biometric parameters as dependent variables, and nutrient uptake as independent variables.

The multiple linear regression model is as below (Kocherginsky et al. 2005, Sellam & Poovammal 2006):

$$Y = a + b_1X_1 + b_2X_2 + \ldots\ldots\ldots b_nX_n \qquad (1)$$

where a = constant, $b_1$, $b_2$.....$b_n$ = regression coefficients, Y = dependent variable (height, basal diameter, volume index) and $X_1$, $X_2$...... $X_n$ = independent variables (nutrient uptake).

## RESULTS AND DISCUSSION

The Karl Pearson's correlation analysis between nutrient uptake and growth attributes of teak biometry observed during 4 months (Table 2) and 8 months (Table 3) after imposing treatment has led into the following finding. At 4 months after treatment (Table 4), nitrogen uptake of the tree in relation to height showed a weak positive correlation (0.405), however phosphorus uptake (0.561) and potassium uptake (0.563) with reference to the tree height showed positive correlations ($p < 0.05$). Similarly, weak to moderate level of correlations existed between height V/s nitrogen (0.473), phosphorus (0.481) and potassium (0.501) uptake at 8 months after imposing treatment (Table 5) ($p < 0.05$). The

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

| Treatments | | Sub plot (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 |

PE = potential evapotranspiration, RDF = recommended dose of fertilisers

**Table 2** Impact of fertigation on growth biometrics of teak at 4 months after fertigation

| Fertigation | | N uptake (%) | P uptake (%) | K uptake (%) | Height (m) | Diameter (cm) | Volume index (cubic cm) |
|---|---|---|---|---|---|---|---|
| Irrigation | Fertiliser | | | | | | |
| $I_1$ | $F_1$ | 1.25 | 0.09 | 0.35 | 4.9 | 165.7 | 13453.68 |
| | $F_2$ | 1.30 | 0.11 | 0.53 | 5.7 | 175.2 | 17496.17 |
| | $F_3$ | 1.89 | 0.13 | 0.74 | 6.1 | 183.3 | 20495.32 |
| | $F_4$ | 1.75 | 0.10 | 0.68 | 5.7 | 175.9 | 17636.26 |
| $I_2$ | $F_1$ | 1.23 | 0.07 | 0.31 | 5.8 | 168.8 | 16526.20 |
| | $F_2$ | 1.44 | 0.10 | 0.58 | 6.5 | 176.5 | 20248.96 |
| | $F_3$ | 1.95 | 0.13 | 0.78 | 6.9 | 185.3 | 23691.90 |
| | $F_4$ | 1.82 | 0.12 | 0.72 | 5.8 | 176.8 | 18129.78 |
| $I_3$ | $F_1$ | 1.21 | 0.08 | 0.32 | 5.8 | 184.1 | 19657.83 |
| | $F_2$ | 1.46 | 0.12 | 0.64 | 7.2 | 185.5 | 24775.38 |
| | $F_3$ | 1.97 | 0.14 | 0.79 | 7.8 | 190.1 | 28187.65 |
| | $F_4$ | 1.85 | 0.11 | 0.75 | 6.3 | 184.7 | 21491.88 |
| $I_4$ | $F_1$ | 1.11 | 0.08 | 0.40 | 6.6 | 174.3 | 20051.12 |
| | $F_2$ | 1.33 | 0.12 | 0.61 | 7.0 | 186.2 | 24269.31 |
| | $F_3$ | 1.93 | 0.12 | 0.77 | 7.2 | 188.9 | 25691.91 |
| | $F_4$ | 1.80 | 0.10 | 0.73 | 6.5 | 186.9 | 22705.55 |
| Mean | | 1.58 | 0.11 | 0.60 | 6.36 | 180.5 | 20906.81 |
| CD value | | 0.19 | 0.19 | 0.28 | 0.06 | 0.04 | 0.18 |

N = nitrogen, P = phosphorus, K = potassium, CD = coefficient of dispersion

**Table 3** Impact of fertigation on growth biometrics of Teak at 8 months after fertigation

| Fertigation | | N uptake (%) | P uptake (%) | K uptake (%) | Height (m) | Diameter (cm) | Volume index (cubic cm) |
|---|---|---|---|---|---|---|---|
| Irrigation | Fertiliser | | | | | | |
| $I_1$ | $F_1$ | 1.46 | 0.10 | 0.40 | 8.6 | 288.0 | 21467 |
| | $F_2$ | 1.68 | 0.12 | 0.70 | 8.8 | 295.3 | 22911 |
| | $F_3$ | 1.90 | 0.15 | 0.79 | 9.2 | 300.0 | 25609 |
| | $F_4$ | 1.85 | 0.13 | 0.73 | 9.0 | 298.7 | 22099 |
| $I_2$ | $F_1$ | 1.55 | 0.09 | 0.42 | 8.8 | 276.8 | 21627 |
| | $F_2$ | 1.62 | 0.13 | 0.62 | 9.4 | 343.0 | 29843 |
| | $F_3$ | 2.07 | 0.14 | 0.81 | 10.0 | 365.0 | 32231 |
| | $F_4$ | 1.95 | 0.14 | 0.76 | 9.2 | 350.8 | 27654 |
| $I_3$ | $F_1$ | 1.54 | 0.08 | 0.44 | 9.6 | 312.6 | 36921 |
| | $F_2$ | 1.67 | 0.13 | 0.69 | 9.9 | 362.5 | 37606 |
| | $F_3$ | 2.11 | 0.15 | 0.82 | 10.4 | 382.1 | 39907 |
| | $F_4$ | 1.98 | 0.15 | 0.78 | 9.6 | 370.0 | 35098 |
| $I_4$ | $F_1$ | 1.44 | 0.11 | 0.46 | 9.5 | 355.6 | 29014 |
| | $F_2$ | 1.64 | 0.13 | 0.69 | 10.2 | 362.1 | 33876 |
| | $F_3$ | 2.08 | 0.15 | 0.82 | 9.9 | 352.0 | 41471 |
| | $F_4$ | 1.91 | 0.14 | 0.76 | 9.7 | 350.1 | 31098 |
| Mean | | 1.79 | 0.13 | 0.67 | 9.49 | 335.3 | 30527 |
| CD value | | 0.13 | 0.17 | 0.23 | 0.06 | 0.10 | 0.21 |

N = nitrogen, P = phosphorus, K = potassium, CD = coefficient of dispersion

**Table 4** Correlation between nitrogen, phosphorus & potassium (NPK) uptake and growth (4 months after treatment)

| Parameters | Height | Diameter | Volume index | N uptake | P uptake | K uptake |
|---|---|---|---|---|---|---|
| Height | 1 | | | | | |
| Diameter | $0.787^{**}$ | 1 | | | | |
| Volume index | $0.967^{**}$ | $0.913^{**}$ | 1 | | | |
| N uptake | 0.405 | $0.606^{*}$ | $0.517^{*}$ | 1 | | |
| P uptake | $0.561^{*}$ | $0.651^{**}$ | $0.641^{**}$ | $0.765^{**}$ | 1 | |
| K uptake | $0.563^{*}$ | $0.698^{**}$ | $0.649^{**}$ | $0.923^{**}$ | $0.862^{**}$ | 1 |

**Correlation is significant at the 0.01 level (2-tailed), *correlation is significant at the 0.05 level (2-tailed), N=nitrogen, P=phosphorus, K=potassium

**Table 5** Correlation between (NPK) uptake and growth (8 months after treatment)

| Parameters | Height | Diameter | Volume index | N uptake | P uptake | K uptake |
|---|---|---|---|---|---|---|
| Height | 1 | | | | | |
| Diameter | $0.867^{**}$ | 1 | | | | |
| Volume index | $0.886^{**}$ | $0.779^{**}$ | 1 | | | |
| N uptake | 0.473 | 0.489 | 0.428 | 1 | | |
| P uptake | 0.481 | $0.598^{*}$ | 0.360 | $0.855^{**}$ | 1 | |
| K uptake | $0.501^{*}$ | $0.537^{*}$ | 0.398 | $0.907^{**}$ | $0.944^{**}$ | 1 |

**Correlation is significant at the 0.01 level (2-tailed), *correlation is significant at the 0.05 level (2-tailed), N=nitrogen, P=phosphorus, K=potassium

scattered plot between nitrogen (N), potassium (K) and phosphorus (P) uptake with height (Figure 2 & 5 ) also depicted maximum points at the matrix of P and K uptake.

Linear regression growth modelling between the height and NPK uptake also converge to a similar correlation between the parameters; the model equation is as follows ($R^2 = 0.904$):

$$\text{Height (H)} = 5.502 - 1.718 \text{ N uptake} + 7.768 \text{ P uptake} + 4.528 \text{ K uptake}$$

while at 8 months after treatment, the regression growth model ($R^2 = 0.914$) is:

$$\text{Height (H)} = 8.037 + 0.253 \text{ N uptake} + 1.964 \text{ P uptake} + 1.125 \text{ K uptake}$$

The basal diameter of the crop showed positive correlation (0.606) with N uptake ($p < 0.05$) and a strong positive correlation with P uptake (0.651) and K uptake (0.698) ($p < 0.01$) at 4 months after imposing treatments. While at 8 months after treatment, basal diameter showed weak positive correlation (0.489) with N uptake and positive correlation (0.598) with P uptake and K uptake (0.537), which were significant at 5% level of significance ($p < 0.05$). While comparing the relationship between basal diameter and NPK uptake at 4 and 8 months after treatment, the regression model developed is explained below. The scattered plot between NPK uptake with basal diameter (Figure 3 & 6) also depicted maximum points at the matrix of P and K uptake.

At 4 months after treatment ($R^2$=0.817):

Basal diameter = 162.807 - 5.222 N uptake + 60.502 P uptake + 32.143 K uptake

At 8 months after treatment ($R^2$ = 0.829):

Basal diameter = 204.750 + 1.573 N uptake + 1309.934 P uptake - 56.946 K uptake

With respect to the volume index, which is a function of height and basal diameter, 4 months after imposing treatments, showed positive correlation of 0.517 with N uptake at ($p < 0.05$), and a strong positive correlation with P uptake (0.641) and K uptake (0.649) at ($p < 0.01$). The scattered plot between NPK uptake with volume index (Figure 4 & 7) also depicted maximum points at the matrix of P and K uptake. At 8 months after treatment, the correlation between N uptake (0.428), P uptake (0.360) and K uptake

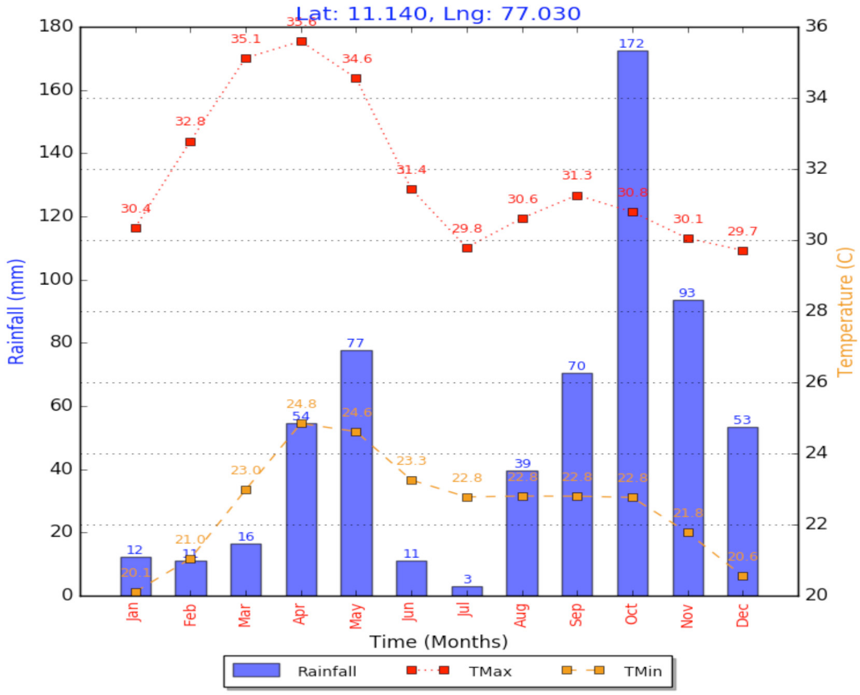

**Figure 1** Average weather data (projected) of the study area (Model-NoeESM1-M 2022)

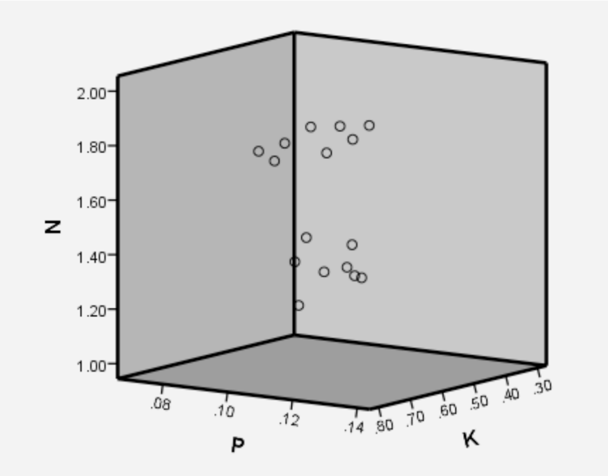

**Figure 2** Scatter plot between nitrogen, phosphorus & potassium (NPK) uptake and height (4 MAT)

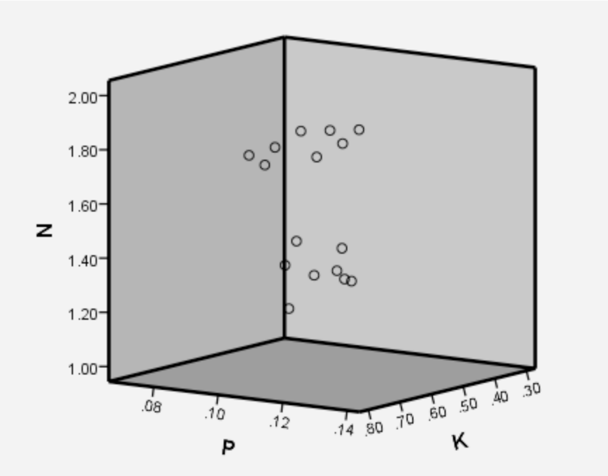

**Figure 3** Scatter plot between nitrogen, phosphorus & potassium (NPK) uptake and basal diameter (4 MAT)

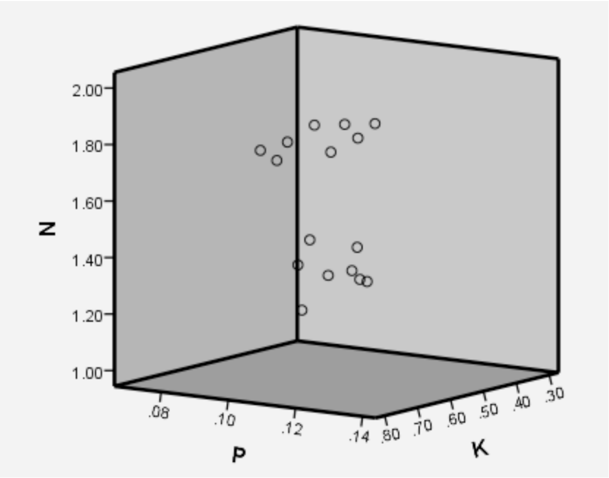

**Figure 4** Scatter plot between nitrogen, phosphorus & potassium (NPK) uptake and volume index (4 MAT)

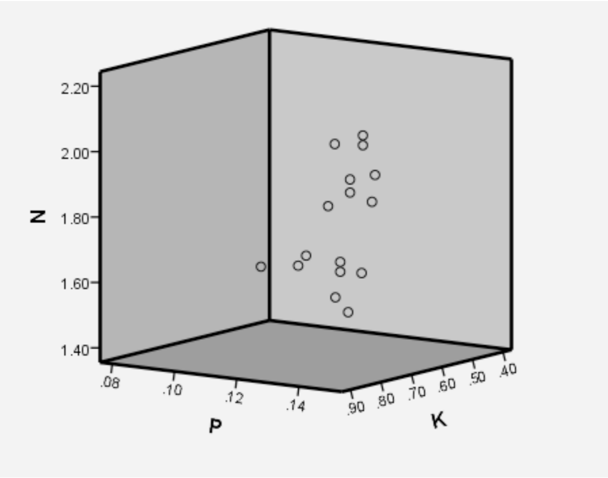

**Figure 5** Scatter plot between nitrogen, phosphorus & potassium (NPK) uptake and height (8 MAT)

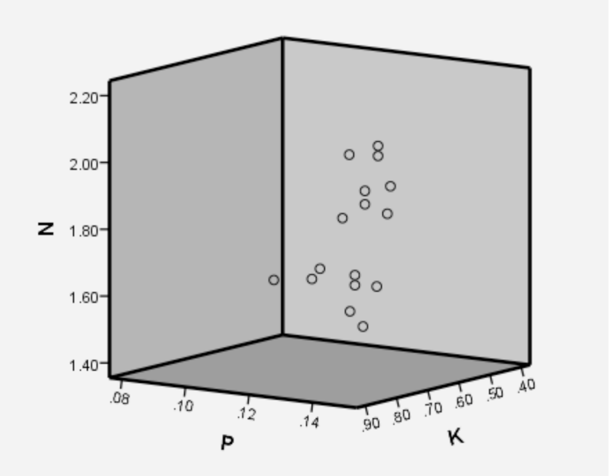

**Figure 6** Scatter plot between nitrogen, phosphorus & potassium (NPK) uptake and basal diameter (8 MAT)

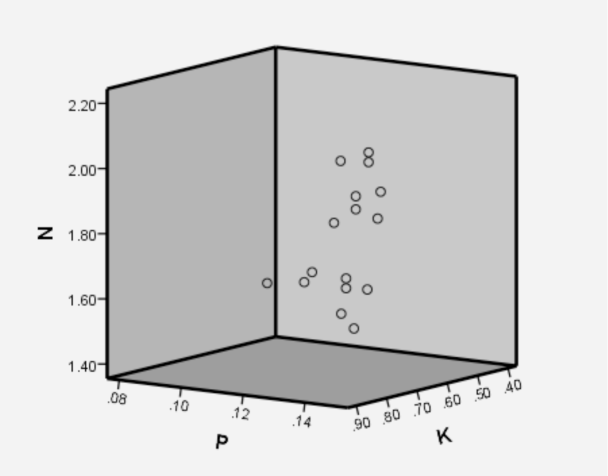

**Figure 7** Scatter plot between nitrogen, phosphorus & potassium (NPK) uptake and volume index (8 MAT)

(0.398) showed a weak positive correlation ($p > 0.05$). While comparing the volume index based growth modelling at 4 and 8 months after treatment, the multiple linear equation developed is explained below,

At 4 months after treatment ($R^2 = 0.875$):
Volume index (VI) = 13281.720 – 6082.444 N uptake + 49756.101 P uptake + 19654.014 K uptake

At 8 months after treatment ($R^2 = 0.912$):
Volume index (VI) = 10891.244+11072.492 N uptake – 41457.427 P uptake + 7774.647K uptake

The growth function study in teak helped to conclude that, in height based growth modelling, height is expressed as a function of nutrient uptake at different growth stages. Comparing 4 and 8 months after treatment, height expression was predominantly influenced as a function of P uptake at 4 months after treatment, while at 8 months after treatment, height expression was influenced as a function of NPK uptake, which is represented in the growth model. Similar to height, basal diameter and volume index were predominantly a function of P and K uptake during initial growth phase (4 months after imposing treatment), while 8 months after treatment, basal diameter and volume index were expressed as a function of N and P uptake.

The linear growth modelling was expressed as a function of the nutrients that influence the biometrics as the dependent variable at early growth stage (4 months after treatment), and later at 8 months after treatment. According to Harper (1974), the early stages of crop growth are primarily correlated to the elemental NPK uptake dynamics. The trial also concluded that NPK dynamics was more positive with biometric attributes at very early stages (4 months after treatment) than at 8 months after treatment, indicating that teak shows early response to fertiliser application. Factors that influence nutrient uptake of trees include age, yields, tree vigor, type of nutrient and specific crop characteristics (Sands & Mulligan 1990).

The partitioning of the nutrient uptake within tree organs depends on the relative growth and specific nutrient needs (Tagliavini & Scandellari 2012). This indicates that unbalanced nutrient supply results in excess uptake causing internal stoichiometric imbalance against other elements, thus suppressing tree growth (Gusewell 2005, Venterink et al. 2010, Yuan & Chen 2015). Hence, constructing growth model helps to provide a balanced formula between nutrient uptake with respect to tree growth.

The linear forecasting growth model for teak in the present study helps to explain the basis for simulating nutrient uptake under different soil- teak interaction scenarios, including multiple soil compartments, net mineralisation inputs, changing root growth, changing soil water content and multiple fertiliser events (Gusewell 2005, Comerford et al. 2006, Venterink et al. 2010, Yuan & Chen 2015). It incorporates root uptake by considering soil nutrient bioavailability as explained in soil supply and nutrient demand (SSAND) model, which is a general nutrient uptake model developed by Comerford et al. (2006) in forest crops. It is well understood that under different fertigation regimes in teak, simulation model predicts the dynamic development of the nutrient flux density, indicating large differences in the time required to reach saturation (optimum nutrition) and maximum production (Takenaka 1994). It should, therefore, be of the utmost interest to study further the conditions for efficient fertilisation, minimum losses of fertilisers and the long-term development of increased nutrient flux densities, as explained by Ingestad et al. (1981) through nutrient flux density model of mineral nutrition in conifers. The nutrient uptake model used to study the nutrient uptake by trees (Kelly et al. 1992) concluded that tree uptake of P and N indicate substantial overestimate of uptake. In order to avoid such a problem, it is suggested that an alternative model be used to calculate, theoretically, the $I_{max}$ values based on observed uptake to optimise the growth v/s annual uptake of nutrients more closely. Generally the nutrient uptake depends on the concentration of a particular nutrient in the soil solution, for instance Kelly et al. (2011) proved that N uptake depends on the concentration of nutrients in the soil solution, temperature and the ability of soil solid phase to buffer using NST3.0 model in spruce trees. Hence the dynamics of nutrients in the soil and its physio-chemical environment is derived as potent growth regulating mechanisms responsible for growth and development in trees. Fertiliser placement in a plantation considers uptake efficiency and the relative value of placement options (Smethurst 2007). Like other cropping systems, the emphasis of most forest fertilisation research has been on diagnosis of nutrient limitations in specific contexts (i.e. combinations of soils, climate, species and management) using soil and plant analyses, and the refinement of fertiliser rate, timing, form and placement options (Smethurst et al. 2004). Hence, more cognitive approach on the identification of the fertigation dynamics under farm forestry conditions must be promoted for sustainable harvesting of trees within a short rotation period.

## CONCLUSION

The growth model was developed based on nutrient uptake and its allocation to different plant parts which were correlated with growth biometry of teak. According to the model devloped, height, basal diameter and volume index are primarily a function of P and K uptake during the first phase of growth (4 months after treatment is imposed), while basal diameter and volume index were expressed as a function of N and P uptake at 8 months after treatment. Further development of a comprehensive growth model is essential to incorporate soil factors, so that the fertigation can be planned with advantage of not only wasting fertilisers but also to identify optimal levels to boost growth without nutritional toxicity.

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