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Individual-Based Modelling for Predicting Dry Matter Accumulation in Juveniles of Indian Olive Raised under Different Soil Treatments

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Dry matter accumulation data for juvenile Indian Olive saplings was modelled using linear and non-linear regression models. The data was gathered bimonthly and for two years i.e., twelve readings. Linear, Quadratic, Power, Sigmoid, and Exponential models performed quite well for cumulative growth data (Adj. $R^2 > 0.93$). The Sigmoid model (Chapman- Richard) demonstrated upper asymptotic values ranged between 179.96- 334.49 grams for all treatments ($T_0 – T_4$) suggesting that olive saplings responded positively to different soil treatments. Both, age and size dependent relative growth rates (RGRs) manifested low values and decrease in RGR curve. Age- dependent RGR displayed a smooth decline in function, indicating extended longevity. Low RGR (along with low Specific Leaf Area), is a characteristic feature of slow growing and evergreen species and this trait was observed in Indian Olive growth too. Size- standardized RGR revealed that due to the low rate of decline, T_4 had the superior RGR (and maximum dry matter accumulation) followed by other treatments. Moreover, T_0 had the sharpest decrease and the lowest dry matter accumulation. Cross- validation of model parameters exhibited statistical stability.

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Keywords: Indian olive; regression models; Chapman-Richard; upper asymptote; relative growth rates; specific leaf area.

1. INTRODUCTION

Plant simulation modelling is a robust and advance technique which is applied too often to model growth patterns of individual plant species as well as populations. The modelling system consists of a large number of mathematical functions which are mostly nonlinear in nature and with or without an upper asymptote. The upper stable value signifies that the growth of an organism is always restricted due to competition between individuals, limited resources and environmental constrains. The growth curves of large number of organisms including plant groups forms a sigmoid curve where initially the growth is exponential; in the middle part the growth takes a linear trajectory and eventually in the final phase it levels off or straightens thus imitating an *S*- shaped curve. Generally, nonlinear and asymptotic models are used to simulate growth patterns of plants. The cumulative growth is represented by a typical sigmoid curve, and absolute growth by a bell-shaped curve, however, relative growth curve is generally negative exponential or reverse sigmoidal in shape due to the fact that relative growth gradually decreases as the plant or organ size increases with age.

The tree species selected for the present investigation is an Indian Olive (*Olea ferruginea Royle*; syn. *O. cuspidate* Wall. Ex G. Don). It is a wild and indigenous species and has a wide distribution in the Himalayas from Kashmir to Kumaun, up to an altitude of 2400 m. It is one of the six species of *Olea* found in India. It is also noticed in the neighboring countries of Nepal, Pakistan and Afghanistan. It thrives well in wastelands where the soil is not suitable for other plants, that is why this species has been utilized as stock in grafting experiments along with *Olea europaea* (an exotic species from Europe).

Indian olive is a medium-sized, slow growing, broad- leaved and evergreen tree with an average height of approximately 10.5 m and an average diameter of 0.45 m. The trees constitute important communities of lesser Himalayas and provide wide variety of economic and ecological services to local people in their vicinity. Other fascinating characteristic includes: it is a zero-waste, multipurpose tree which provides construction wood, food, firewood, fodder and medicinal products to different ethnic groups since decades. Leaves are used as an antiperiodic in fever and debility [1], in mouth ulcer, toothache, sour throat, gonorrhea, hoarse voice, as an astringent, antiseptic and a mild digestive aid [2,3]. Timber is heavy and resilient and is utilized for manufacturing agricultural tools [1]. Fruits are edible and are used as antidiabetics, appetizers, and a rich source of Oleic acid (from Olive oil). The oil is extensively used in jaundice, scabies, typhoid, burning of eyes, caries of the teeth and tooth ache [3,4]. The olive oil is further used in joint pains, malaria, rheumatism, gonorrhea, skin disease, cosmetics and for cooking as well [4,5]. Root is used in rheumatism, headache, asthma and scorpion sting [6].

Due to its zero waste and multipurpose qualities, the Indian Olive growth pattern was investigated in an experimental plot at Almora applying different soil treatments. Healthy and disease-free saplings were selected and the dry matter accumulation data was recorded bimonthly for almost two years i.e., 24 months (12 readings). The cumulative data obtained from treatment T_0 for juvenile trees was initially screened using seven different regression models (both linear and nonlinear). Out of seven models tested, a sigmoid model (Chapman-Richard's curve) was applied to simulate cumulative and relative growth of trees for remaining treatments (T_1-T_4) Results of the modelling are being interpreted in the present manuscript.

2. MATERIAL AND METHODS

2.1 Site Details, Experimental Plot and Data Collection

The aim of this investigation was to model dry matter accumulation data over time during the initial developmental stages of Indian olive saplings. The present study was conducted at the experimental plots in Chausar village at Almora. Site coordinates were: 29.5892° N, 79.6467° E and it was situated at an elevation of 1642 m from sea level.

The experimental material consisted of 180 healthy, uniform and disease- free saplings of Indian Olive (*Olea ferruginea Royle*), procured from the Indo- Italian Government Demonstration farm, Dhakrani (Dehradun) and replanted in the experimental plots at village Chausar.

Table 1. Mean dry matter accumulation (gm/sapling) for Indian Olive at all sampling stages i.e., Aug 2021 to June 2023 under different soil treatments (n=3, ±SE)

Harvest (months)	T0	T1	T2	T3	T4
2	3.64±0.22	5.92±0.52	6.84±0.44	7.37±1.01	8.46±1.11
4	3.88±0.16	6.92±1.07	7.44±1.31	7.96±1.41	9.06±0.87
6	4.22±0.35	7.26±1.18	7.82±0.81	8.33±1.59	9.75±1.27
8	4.7±0.34	7.73±1.04	8.24±1.01	8.73±1.36	10.48±1.73
10	5.13±0.41	8.51±0.84	9.09±1.44	9.69±0.97	11.3±1.45
12	5.54±0.56	9.21±0.72	9.73±1.81	10.27±1.36	12.25±0.75
14	6.07±0.78	9.7±0.98	10.32±1.52	10.89±1.65	13.09±1.27
16	6.63±0.25	10.41±1.21	11.02±0.98	11.64±1.36	14.05±1.18
18	7±0.36	10.99±0.89	11.62±0.87	12.42±1.47	15.18±1.41
20	7.51±0.58	11.78±1.39	12.58±1.44	13.35±0.95	16.28±1.04
22	7.93±0.83	13.33±1.56	13.84±1.85	14.66±1.53	17.51±1.05
24	8.37±0.97	14.27±0.95	15.07±0.58	15.95±2.17	18.42±1.53

Table 2. Details of the treatments namely FYM (Tons/ha) and N, P and K (Kg/ha) on Indian olive saplings at experimental plot at Almora

Treatments	FYM (F) and N, P, K
T_0	$F_0 + N_0 + P_0 + K_0$
T_1	$F_{15} + N_{100} + P_{80} + K_{50}$
T_2	$F_{15} + N_{150} + P_{120} + K_{75}$
T_3	$F_{30} + N_0 + P_0 + K_0$
T_4	$F_{30} + N_{150} + P_{120} + K_{75}$

Table 3. Chapman- Richard's model [7] describing absolute and relative growth rate functions

Model	Absolute Growth Rate	Relative Growth Rate
Chapman- Richard's	$y = \alpha\beta\delta\, e^{-\beta t} (1-e^{-\beta t})^{\delta-1}$	$y = \beta\delta(1-e^{-\beta t})^{-1}$

The experiment was laid down in a randomized block design with thirty- six (36) saplings in each design and the data were analyzed accordingly. A total of 180 saplings were sacrificed to obtain the dry matter accumulation data of two years. Data was collected bimonthly that is, every sixty days interval. The experiment was conducted with three levels of Farm Yard Manure (FYM) viz. 0, 15 and 30 tons/ha and different combinations of N, P and K (Table 2) during 2021-23 at the experimental plots. Each of the combination was termed as treatment from T_0 to T_4.

The details of the physio-chemical characteristic of the soil used for the purpose was as follows: Texture (sandy loam), Sand (67.16%), Silt (22.29%), Clay (10.55%), Bulk Density (1.36 gram/cc), Water Holding Capacity (40.65%), pH (6.8), Organic Carbon (0.48%), Organic Matter (0.83%), Total Nitrogen (0.08%), Available Nitrogen (138.3 Kg/ha) and Available Potassium (198.4 Kg/ha).

2.2 Modelling Dry Matter Accumulation Over Time (24 Months)

Initially the dry matter accumulation data over time for treatment T_0 was screened using seven (7) regression models. The cumulative growth function and performance statistics for all models is depicted in Table 4. In the subsequent step, a 3- parametric Chapman- Richard's function (C-R) (Table 3) was selected to calculate relative growth rate (RGR) for treatment T_0 along with cumulative growth rates and RGR for remaining four treatments i.e., T_1-T_4. C-R function was applied to simulate the above data as all classical sigmoidal growth functions have two smooth transitions in a single formula and are quite flexible, versatile and reliable in nature.
The function is frequently used to model growth of individual trees and populations. Here, α is the upper asymptote, β is the growth rate or scale parameter and δ is the shape parameter and

inflection point. Cumulative growth was calculated for all treatments. Eventually relative growth was also calculated by using absolute growth values (Table 3).

2.3 Model Fitting, Evaluation and Validation

Nonlinear curve fitting was performed with Excel Solver which is an add-in function in Microsoft Excel, 2021. Three criteria were applied for model evaluation which were: Adjusted- R^2 [8], Akaike Information Criterion [9], and Bayesian Information Criterion [10]. Model with maximum Adjusted- R^2 and minimum AIC and BIC values were considered to perform the best. Cross-validation of model parameters was conducted through Jackknife resampling technique [11].

3. RESULTS AND DISCUSSION

Table 4 describes fitting and evaluation statistics of cumulative growth for treatment T_0. Though, linear quadratic and exponential models were slightly better than Chapman- Richard's model but the latter was considered to further evaluate CGR and RGR values for remaining treatments due to the fact that it a sigmoid function which responded quite well to dry matter accumulation growth of juvenile olive saplings and was a combination of linear, power and exponential functions. The function was quite flexible, accurate and had an upper asymptote. Model parameters had biological meaning too. The upper asymptotic values for all treatments were in the range 179.96- 334.49 grams. The highest dry matter was estimated for treatment T_4 and lowest for treatment T_0. The dry matter production had a wide range suggesting that olive saplings responded differently to different soil treatments. T_0 treatment, that is, normal soil (no FYM and NPK) displayed least value which confirmed that different treatments of NPK and FYM had a positive impact on dry matter accumulation in early stages of sapling growth. All the treatments followed the order: $T_4 > T_1 > T_3 > T_2 > T_0$. Model parameters were statistically stable.

RGR functions are unique in capturing both age and size dependent changes in growth patterns. As RGR itself is size- dependent and declines as individual tree grows so size- correction or size- standardization is always a better option when species are compared at a common size. Both age and size dependent RGR demonstrated a decrease in RGR curve, which is commonly referred to as ontogenetic drift, however, the former displayed a smooth decline for all treatments indicating extended longevity (Fig. 2g). Self- shading of leaves, decrease in local concentration of soil nutrients and accumulation of non- photosynthetic biomass in the form of stem and roots could be the possible reasons for universal decrease in RGR as the tree grows in nature. The initial values for age-dependent RGR were low and ranged between (0.151- 0.172). Low RGR is a characteristic feature of trees with a slow growing nature and evergreen habit.

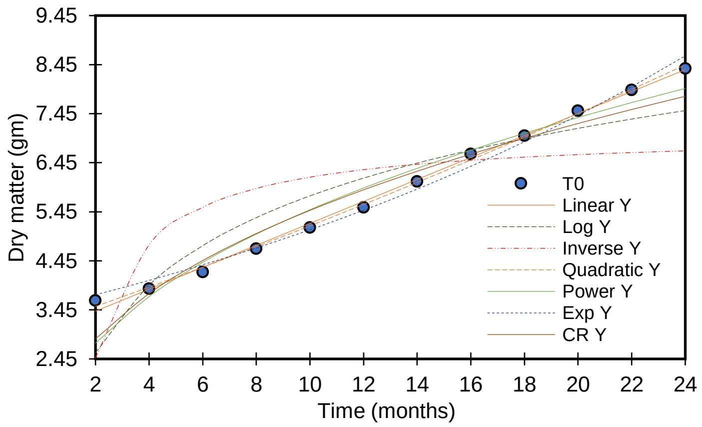

Fig. 1. Cumulative growth curves of juvenile Indian olive applying seven regression models
***Circles are observed values**

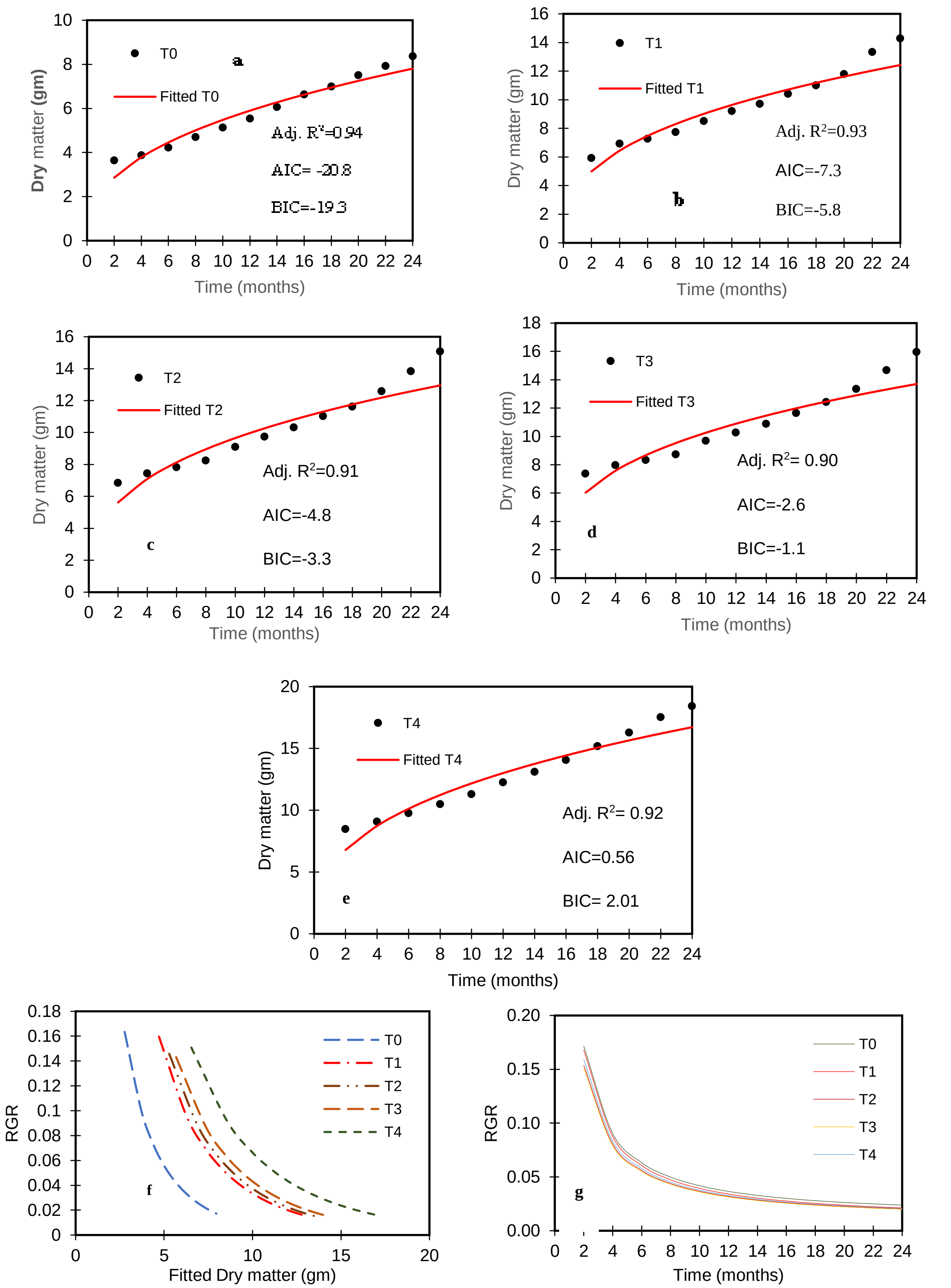

Fig. 2. Fitted values from a 3- parametric Chapman- Richard's function for (i) dry matter accumulation (a-e); (ii) relative growth rate on size basis (f) and (iii) relative growth rate on time basis (g) of juvenile Indian Olive (*circles are observed values)

Table 4. Model performance of the dry matter accumulation data of juvenile Indian olive saplings for treatment T_0, α, β and δ are model parameters and "t" denotes time of harvest in months

		Performance criteria		
Models	**Functional Form**	**Adj. R^2**	**AIC**	**BIC**
Linear	$y = \alpha + \beta t$	0.996	-54.204	-53.234
Logarithmic	$y = \alpha + \beta \log(t)$	0.832	-9.323	-8.354
Inverse	$y = \alpha + \beta/t$	0.601	1.068	2.038
Quadratic	$y = \alpha + \beta t + \delta t^2$	0.997	-58.178	-56.724
Power	$y = \alpha t^{\beta}$	0.936	-20.815	-19.845
Sigmoidal (C-R)	$y = \alpha(1-e^{-\beta t})^{\delta}$	0.938	-20.777	-19.322
Exponential	$y=\alpha e^{\beta t}$	0.989	-42.206	-41.236

Table 5. Model fitting and validation statistics for all treatments (T_0-T_4) using a 3- parametric Chapman- Richard's function (* ±SE in parenthesis); above values are the parameters for cumulative growth function and below for the relative growth function

	Model Parameters		
Treatments	**α**	**β**	**δ**
T_0	179.96 (6.27)	0.000033 (0.000008)	0.425 (0.006)
T_1	254.15 (9.95)	0.00003 (0.000003)	0.407 (0.007)
T_2	215.69 (8.41)	0.00003 (0.000004)	0.379(0.007)
T_3	213.62 (5.47)	0.000031 (0.000003)	0.373 (0.007)
T_4	334.49 (9.94)	0.000024 (0.000005)	0.391 (0.006)
	-	**β**	**δ**
T_0	-	-0.357 (0.002)	0.777 (0.005)
T_1	-	-0.239 (0.001)	1.389 (0.011)
T_2	-	-0.239 (0.0003)	1.551 (0.0023)
T_3	-	-0.229 (0.0009)	1.671 (0.0087)
T_4	-	-0.184 (0.0068)	1.912 (0.0073)

Size- standardization displayed the trend: $T_4 > T_3 > T_2 > T_1 > T_0$ i.e., due to low rate of decline T_4 had the superior RGR followed by other treatments (Fig. 2f). Moreover, T_0 had the sharpest RGR decline and the lowest dry matter accumulation (Fig. 2f). T_0 started with the highest RGR value but finished with lowest dry matter accumulation. At a common biomass value of 6.5 gm, T_4 had a superior RGR (0.15) than that of T_0 (0.02). The RGR for treatment T_4 was 13% more in magnitude than RGR for treatment T_0.

Evaluating growth rates is an important aspect of functional forestry. Relative growth rate (RGR) is a remarkable trait identifying plant growing strategy [12]. Species with high RGR are much more competitive in acquiring resources whereas slow growing species are more conservative with the limited resources they have obtained [13,14] or they are able to combat natural disturbances by allowing resources to storage rather than to grow [15]. In slow growing, evergreen trees low RGR is associated with a low SLA is a common feature. The present study also demonstrated low RGR for all treatments (T_0-T_4). Mean SLA was also calculated for 24 months (data not shown) and was also found to be consistently low with every harvest. As Indian Olive is an evergreen slow growing tree so low RGR (and SLA) values are not surprising at all. Ecological advantage of low RGR in slow growing evergreen trees has been discussed in the past. Generally, evergreen trees thrive in a temperate and subtropical areas with less fertile soil. Some possible explanations for low RGR in slow growing and evergreen species could be: having low RGR, the plant functions close to its optimum growth rate in harsh conditions; the plants have lower rates of accumulation of minerals and photosynthates into a structural material. Finally, slow growing species retain (hold) the resources for longer durations due to their low demands. Moreover, high leaf construction cost in evergreen trees could also be the reason for low SLA and RGR values.

Evergreen species are widely thought to have low RGR (slow- growing) and low SLA due to the need to produce thick leaves that sustain longer life spans [16]. For extended longevity and evergreen habit, the olive sapling needed to develop a mechanism which protects it from a large number of biotic and abiotic stresses viz. nutrient leakage, drought, cold, herbivory, and fungal infections to name a few. In order to maintain leaf longevity such species had to put extra investment in secondary compounds such as lignin and phenolics that eventually forms cell membranes. Moreover, leaf hairs and cuticle-waxes also increase the construction cost of leaves. Number of studies on different plant functional groups suggested that low RGR along with low SLA is an important feature linked with evergreen habits.

4. CONCLUSION

To conclude, growth modelling techniques are an important aspect of functional forestry where growth data can be collected over time, modelled and eventually interpreted to get the final outcome. In the present investigation, juveniles of Indian olive saplings were treated with five different soil treatments (T_0- T_4) and the dry matter accumulation data of two years was analyzed. T_4 came out with the best treatment with a smooth decline in RGR curve and maximum dry matter accumulation in two years duration. Here, low RGR (for all treatments) was found to be associated with low SLA which is a key feature in evergreen and slow growing trees. Species with low SLA and RGR values are naturally conditioned for the conservation of acquired resources due to their large dry matter content, high concentration of cell walls and increased production of secondary metabolites as a part of defense infrastructure. Moreover, evergreen species with low SLA/RGR has high leaf and root longevity too. All such traits were observed in Indian olive species which naturally grows in wastelands and unfertile soils. Such characters are developed due to harsh micro-climatic conditions. As olive saplings responded positively to different soil treatments, so more combinations of FYM and NPK should be screened in the future to come out with better growth, adaptation, and survival models for the species.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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