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Growth analysis and carbon economy of *Olea europaea L.* raised at foothills of central Kumaon Himalaya

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Abstract

In the present investigation, growth performance of Olea europaea L. was evaluated under natural conditions of day and night. Relative growth rate and other functional traits were evaluated in order to gain a more comprehensive knowledge about the morphological and physiological adjustments made by olive tree in response to a given set of natural environmental conditions at foothills of central Kumaon Himalaya. The experimental plot was set in an experimental farm at Halduchaur, Haldwani. Growth analysis was performed for 2 years (24 months) and data was recorded bimonthly (i.e. 12 readings) under natural conditions. Low values of RGR, NAR, SLA, LAR and LMF were depicted while RMF was high. Linear regression revealed that NAR contributed to strong and positive correlation with RGR but SLA and LMF were never functionally correlated. Interestingly NAR had a positive correlation with SLA. Evergreen leaves (low SLA, thick leaves) has high construction cost per unit leaf area in an unproductive environment and a low NAR. Further analysis also revealed that low SLA species could be an adaptive feature in dry and evergreen habitats. Temporal variation in RGR was mainly due to NAR. Biomass allocation analysis revealed much of the biomass was invested into roots (RMF) during the study period. The dissection of underlying functional components revealed that NAR can be considered as the best indicator in determining RGR in O. europaea L. under natural conditions.

Keywords: RGR, NAR, LAR LMF, SLA, biomass allocation, RMF, SMF.

Introduction

Green plants shares a unique relationship with their environment as only they are capable of converting light energy from sun into chemical energy i.e. bio-energy. Any specie in order to grow, survive and reproduce has to make a wide array of adjustments which is reflected in its resource allocation strategy and subsequent carbon economy. The more effectively the resources are managed, the more the size will increase.

Plants has a peculiar ability to synthesize food i.e. biomass through a process called photosynthesis where atmospheric carbon- di- oxide is reduced to form sugars using NADPH and ATP from light reaction and oxygen is released as bi-product during photolysis of water[1]. Majority of the acquired carbon is used up by the plant to grow and compete with other plant communities in a given set of environmental conditions. Much of the biomass is utilized to form structural material for plants. Photosynthetic process provides us an opportunity to explore the physiological basis of plant growth and has been thoroughly studied from time to time and in different plant groups. But other aspects like translocation of acquired carbon to other organs and factors controlling plant respiration has been studied less[2].

The environment is a complex cocktail of biotic and abiotic factors which influences the growth and life cycle of plants. The key to adaptation and survival is to effectively capture and utilize maximum resources within the vicinity for plant growth in order to increase biomass in quick span of time. In this context, Relative growth rate (RGR) is an important indicator of plant performance in the field of functional ecology which explores the ability of different plant groups to grow, survive and establish in different environment. Two pertinent questions always fascinate the scientific fraternity regarding RGR, one is the biomass synthesizing ability of different plant groups on daily basis and the second is the biomass allocation patterns in each functional group.

Though RGR has great importance in analyzing growth rates between and within species, yet RGR is a complex phenomenon that is governed by differences in physiology, morphology and biomass partitioning[3]. To find the relative contribution of all associated factors, RGR can be classically decomposed into Net Assimilation Rate (NAR) and Leaf Area Ratio (LAR). LAR can further be split into Specific Leaf Area (SLA) and Leaf Mass Fraction (LMF). All the above functional traits in plants influence RGR in some way or the other. These functional traits also get influenced by changing environment, water and nutrient supply from soil, root morphology, leaf economics, irradiance and CO_2 availability.

RGR is the log transformed values of increase in biomass in unit time and per unit of growing material. NAR gives the information regarding the increase in biomass per unit leaf area and per unit time which also reflects the average photosynthetic efficiency of leaves. SLA is the ratio of leaf area to leaf mass and strongly correlates with leaf thickness and biomass distribution pattern of plants. LAR is the ratio of total leaf area to total plant dry weight and provides the information about the leaf area constructed per unit biomass. Lastly, Root Mass Fraction (RMF), Shoot Mass Fraction (SMR) and LMF inform about the biomass allocation to roots, shoots and leaves with respect to the whole plant.

RGR vary both between and within species when the plant groups are raised under optimum conditions. The most extensive investigation on interspecific variations in RGR was conducted by Grim and Hunt[4] in which they compared 130 wild species from a local flora and found large number of variations between species. Much more scientific data was later added to this where different plant functional groups namely evergreen, deciduous, herbs, shrubs, trees, dicots, monocots, shade loving and sun loving were investigated for RGR variations. Till date, we have paucity of database regarding temporal variations in RGR in different plant species.

Olea europaea L. (*Oleaceae)* is a genus of evergreen- slow growing shrubs and trees which are distributed in sub tropical and warm temperate regions. It is a native to Europe, China, Africa and India. It grows in wild but also commercially cultivated for olive oil in different parts of the world. It can survive high summers and water deficit conditions and is adapted to a wide range of soils from heavy and clay to light and sandy soils[5]. It can successfully survive soil-nutrients and water limiting conditions by means of morphological, physiological and biochemical adjustments thus are easily established in dry ecosystems. The tree has a relatively shallow root system and consequently only requires 1.0-1.5m deep soil profile. Moreover, it can grow well on almost any well drained and aerated soil.

Olive shows higher production, greater adaptability to different environmental conditions (including wider pH and climatic variations) and therefore it has a potential for wider geographical expansion. Because of its high price value, it is mostly imported from European countries is a very costly affair; therefore it prompted the author to evaluate growth performance of *Olea* trees at foothills of Kumaon Himalaya in Uttrakhand state.

In India, small piece of work has been done on various attributes of olive tree. Presently, many scientists and co- workers studied the phenology, biochemical characteristic of olive oil, harvesting methodologies and other related fields[6-8] but no major work has been done so far on functional parameters of the plant. Since the olive varieties are very specific to microclimatic conditions, ecomorphological and ecophysiological studies are required before they can be recommended for commercial cultivation in any area of the state.

Author firmly believes that complex growth studies involving RGR and its associated parameters should be carried out under natural conditions and not under controlled or artificial condition (as hydroponics system and growth chambers). The latter may reduce complexity but it would not be wise to extend the findings to natural conditions as there will always be a question mark if such results will hold over time. Moreover, monitoring of growth parameters should be for a considerably longer durations so as to get a full understanding of the functional changes acquired by the plant with respect to its given environment.

This manuscript thus deals with the growth characteristic of olive tree raised in an experimental plot at foothills of Kumaon Himalaya under natural conditions of day and night. The author analyzed the significance of growth factors namely NAR, SLA and LMF in evaluating temporal variations in RGR and correlated the results with olive's performance. Moreover, biomass partitioning was also tracked during the experimental period of 24 months in order to get an insight of the carbon economy of the given species under natural environment.

Material and methods

Study area: The experimental plot in Halduchaur was situated in Haldwani and consisted an area of 0.1 acre, on an altitude of 424m and lied in 29.2183°N latitude and 79.5130° East longitude. Haldwani is located in bhabhar region in the Himalayan foothills on banks of Gaula river. Bhabhar soils are highly porous, sandy to gravelly, coarse-textured and largely infertile[9].

Climate: Average maximum and minimum temperature during the study period was 31.2°C and 16.8°C respectively. Average daily mean temperature was 22.8°C. Average annual rainfall was 2095mm (82.6 inches). The city gets much of its rainfall in the month of July (649mm) and August, (587mm). Annual average quantum input (irradiance) was 27.81 mol m^{-2} day^{-1}.

Physiochemical characteristic of soil used for experiment: The texture of soil used for the experiment was sandy loam. The composition of sand, silt and clay was 67.16%, 22.90% and 10.55% respectively. Bulk density (g/cc) and Water Holding Capacity (5) was calculated as 1.36 and 40.65 respectively. pH of soil came out to be 6.8. Organic carbon calculated was 0.48%, Organic matter was 0.83% and total nitrogen was 0.08%.

Experimental Procedure: For the experiment, *Olea* cultivator namely- *O. europaea* was selected. The specie was woody, evergreen and had C_3 type of photosynthesis. The study was carried out between August 2016 to June 2018 in an experimental plot prepared in a Halduchaur, Haldwani. The experimental material consisted of uniform, healthy and disease free saplings of the exotic cultivated variety- *Olea europaea* from the Government Demonstration Farm, Dhakarani, Dehradun and replanted at Halduchaur, Haldwani.

Data on dry matter of root, stem, leaves and total biomass of the species were noted bimonthly for two years (data not shown). For biomass calculations three saplings were harvested, washed and separated into component parts (stem, root and leaves), dried at 60°C for 72 hours and weighted. Initial fresh weights of the component parts were also noted. Moreover, functional growth traits as RGR[10] NAR[11], SLA[12], LAR[13], LMF, SMF and RMF[14] were calculated separately for a period of 24 months. Eventually, RGR was decomposed into its classical components viz. NAR, SLA and LMF and regression data was generated. RGR was treated as a dependent variable and all other components as independent or predictor variables. The values for all the components were standardized before performing regression analysis. The data was subjected to regression function using Microsoft EXCEL 2007. Other statistical analysis was also performed in Microsoft EXCEL, 2007 version using *Data Analysis* tool kit.

Results and discussion

Correlation between different variables: RGR was strongly and positively correlated to NAR (r=0.80, $p<0.01$) but was never functionally correlated with either SLA (p=0.18) or LMF (p= 0.51). Interestingly, NAR was positively correlated to SLA (r= 0.68, $p<0.05$). SLA was strongly and positively correlated to LAR (r= 0.99, $p<0.01$) but not correlated with LMF (p= 0.10). Regarding biomass partitioning, total plant mass (TPM) was strongly and negatively correlated to both LMF ($p<0.05$) and SMF ($p<0.01$) but was positively correlated to RMF (p=0.01).

Table-1: Values of mean RGR (g g^{-1} d^{-1}), NAR (g cm^{-2} d^{-1}), SLA (cm^2 g^{-1}), LMF (g g^{-1}), SMF (g g^{-1}) and RMF (g g^{-1}) in *O. europaea* taken bimonthly for two years

Months	RGR	NAR	SLA	LAR	LMF	SMF	RMF
2016-Aug	_	_	9.900	3.079	0.311	0.223	0.466
Oct	0.006	0.012	9.070	2.404	0.265	0.216	0.518
Dec	0.004	0.007	2.950	0.743	0.252	0.203	0.544
2017-Feb	0.001	0.004	3.350	0.858	0.256	0.206	0.538
Apr	0.005	0.007	3.410	0.835	0.245	0.210	0.545
Jun	0.001	0.004	4.040	1.010	0.250	0.209	0.541
Aug	0.004	0.008	4.110	0.974	0.237	0.202	0.561
Oct	0.001	0.005	4.540	1.081	0.238	0.197	0.565
Dec	0.001	0.004	4.230	1.024	0.242	0.203	0.556
2018-Feb	0.001	0.003	4.110	1.032	0.251	0.196	0.553
Apr	0.005	0.006	4.540	1.108	0.244	0.198	0.558
Jun	0.004	0.004	4.680	1.161	0.248	0.205	0.548

Table-2: Regression Coefficients (b), Pearson Correlation Coefficient (r) and *p- values* between different growth components in *Olea europaea* during the study period (α= 0.05, 5% significant level).

Components	b	r	*p- value*
RGR*NAR	0.63	0.80	0.003
RGR*SLA	0.0005	0.44	0.18
RGR* LMF	0.05	0.22	0.51
NAR* SLA	0.001	0.68	0.02
NAR* LMF	0.10	0.33	0.32
SLA*LMF	103.65	0.52	0.10
SLA*LAR	3.63	0.99	2.6E-11
LMF*RMF	-1.33	0.98	8.2E-09
LMF*SMF	0.33	0.82	0.001
SMF*RMF	-3.04	0.91	5.2E-05

Table-3: Mean RGR ($gg^{-1}d^{-1}$) of component parts (leaves, shoot, root) during the study period.

Months	RGRL	RGRS	RGRR
2016- Aug	-	-	-
Oct	0.00071	0.0029	0.0051
Dec	0.00083	0.00065	0.0025
2017-Feb	0.0013	0.0013	0.00086
Apr	0.0011	0.002	0.002
Jun	0.0013	0.00094	0.00084
Aug	0.0011	0.0015	0.0028
Oct	0.0012	0.00063	0.0011
Dec	0.0013	0.0015	0.00084
2018-Feb	0.0014	0.00023	0.00061
Apr	0.0011	0.0016	0.0017
Jun	0.0013	0.0016	0.0007

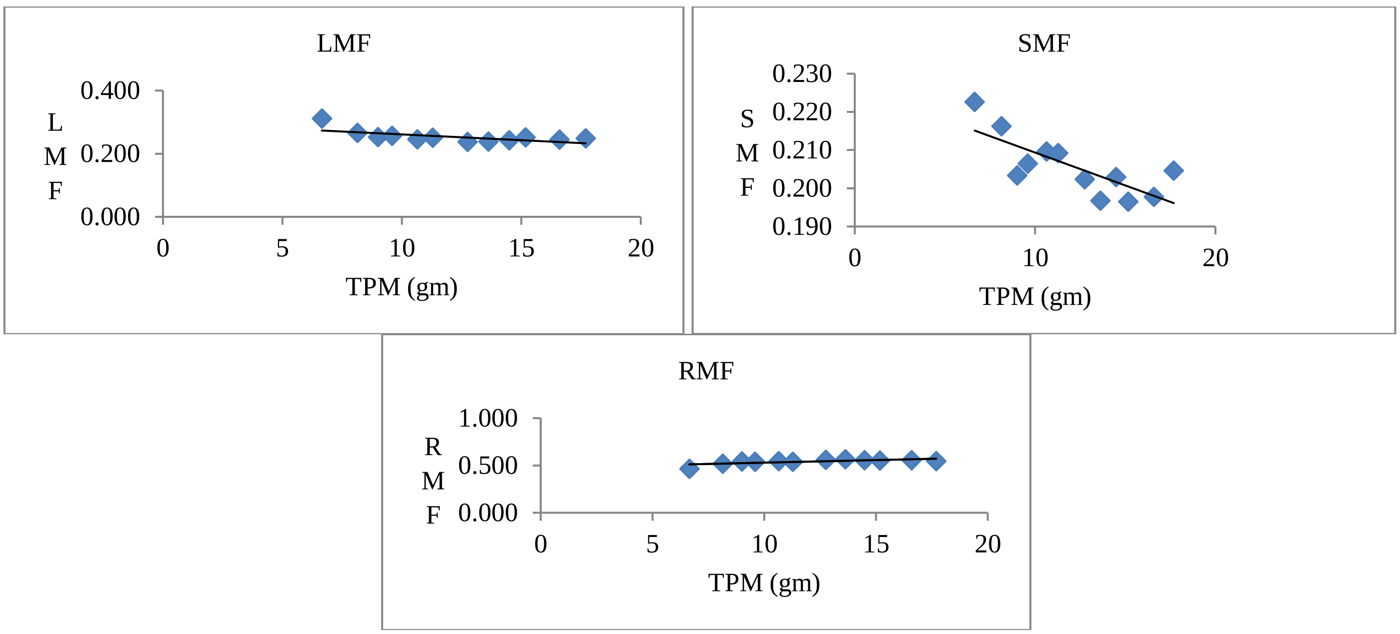

Figure-1: Biomass allocation in *Olea europaea* with respect to Total Plant Mass using 3- compartment model. *LMF= Leaf Mass Fraction, SMF= Shoot Mass Fraction, RMF= Root Mass Fraction

Temporal variations in RGR: Low values of RGR, NAR, SLA and LMF and relatively high values of RMF were observed during the study period. Ecological advantage of low RGR in slow growing evergreen species has been discussed earlier. In temperate and sub-tropical climate, slow growers are found in less fertile soil. Both Grime and Hunt[4] and Chapin[15] attempted to find out explanations for low RGR in slow growing evergreen tree species. Potential reasons according to them could be: Low RGR species functions close to its optimum growth rate under adverse environment; slow growers has high leaf construction cost and lower rates of accumulation of minerals and photosynthates into structural material, thus forming the reserve for later growth; and finally slow growing evergreen species does not exhaust the available resources too rapidly due to their low demands. The author found that temporal change in RGR was mainly caused by variations in NAR which is a physiological parameter and not by SLA/LAR which is a morphological parameter. This could be due to more physiologically plastic nature of NAR than SLA or LAR.

Allocation of sugars and carbon economy: *Olea europaea* is a slow growing and evergreen tree which grows in infertile soils with water and nutrients limiting conditions. Plant growing in such an environment often has low Total Leaf Area (TLA) and low LMF and relatively high RMF. In this condition, light competition for the plant becomes less significant, and root competition gain importance[16] and shift in the biomass allocation from above to below ground i.e. root is expected. This type of behavior by the plant can be explained through “functional equilibrium” theory which states that plants shift their allocation pattern in response to above and below ground resources that are limiting. In case of less availability of CO_2 and light, more biomass will be allocated to leaves and in case where water and nutrients in soil are limiting, biomass is allocated more towards roots. The shift is basically an adaptive measure which permits the plant to capture more of those resources that most strongly limit plant growth[14]. Bhabhar soil is characterized by a superficial absence of water on the surface due to porous substratum where most of the water disappears underground. This creates a condition of water deficit which weakens the nutrient flow from soil to root- surface and eventually to leaves which is the active site for photosynthesis. The obvious reason could be a weak transpiration pull. The overall effect reflects a decrease in total leaf area and leaf mass faction followed by a decrease in NAR and RGR as well. Though, in the experiment, *Olea* was grown under optimal conditions but as morphological plasticity of slow growing evergreen trees is low[17], hence even under congenial conditions slow growing species allocates relatively more biomass to roots than shoots and leaves.

Low SLA is an important characteristic of evergreen species which is influenced by physiological, morphological and biochemical traits of the plant. Evergreen leaves has a high construction cost per unit leaf area i.e. the amount of sugar required to construct 1gm of biomass[2]. There seems to be a clear connection between high construction cost and extended leaf longevity in evergreen species. For extended leaf longevity (evergreen habit), the plant needs to develop a mechanism to protect itself from large number of abiotic and biotic stresses as nutrient leakage, fungal infections, herbivory, drought, cold etc. For this the plant will have to do extra investment in secondary compounds such as phenolics, lignins probably in cell membranes, leaf hairs and cuticular waxes which would increase construction cost, lowers SLA and extends leaf longevity. Both young and mature leaves *of O. europaea* contain very high level of alkaloids apart from saponins and total phenolic content[18] which put more weight to the above interpretation. Ample studies on different plant groups revealed that low SLA is an important feature linked with infertile soils and evergreen habits. Large number of studies confirms that evergreen habit relates much with SLA than RGR and thus it can be concluded that SLA could have an adaptive value where SLA seems to be the target variable for selection and not RGR. These findings fall in line with Poorter's hypothesis[19]. According to him, variable such as SLA could be more important for plants in adapting infertile land and dry ecological systems.

Moreover, low SLA species is also linked to low protein concentrations in plant tissues[20] which is strongly correlated to its plant- nitrogen status which in turn reflects in low photosynthetic rates and low NAR in slow growing, evergreen species. Evergreen species has initial high construction cost of leaves which is gradually amortized over a period of time thus maintaining leaf longevity. Several findings support this hypothesis[21,22]. The present results also support this notion as NAR of olive trees was found to be low. This explains the relationship between evergreen habit-low SLA and extended leaf longevity. Further, it has been analyzed that in dry ecosystems plants has the ability to acquire new minerals and simultaneously conserves previously captured ones too[23].

Further, leaf thickness is caused by high leaf weight per unit leaf area which eventually relates to low SLA[24]. Native evergreen species has several layers of lignified epidermal cells and a thick cuticle[25] which reduces transpiration and thus conserves water in dry habitats. In fact, nutrient poor soil has high presence of evergreen species[26]. Hence, it can be concluded that feature of low SLA in evergreen species could be more effective and useful in acquiring infertile habitats.

Conclusion

Olea europaea is a slow growing evergreen tree. Evergreen habit is closely related to low SLA as to maintain leaf longevity high construction cost per unit leaf area is required. Slow growing evergreen trees mostly grow in an infertile habitat with water stress conditions so there is a reduction in TLA and LMF but an increase of RMF. This falls in accordance with the functional equilibrium theory. Low TLA and LMF further are interlinked to low RGR and NAR. Low SLA could be an adaptive feature in an evergreen habitat which influences other related functional traits as well.

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