Octa Journal of Environmental Research
International Peer-Reviewed Journal
Oct. Jour. Env. Res. Vol. 10(1): 034-038
Available online http://www.sciencebeingjournal.com

Oct. – Dec., 2022
ISSN 2321 3655

Research Article

Octa Journal of Environmental Research
(Oct. Jour. Env. Res.) ISSN: 2321-3655
Journal Homepage: http://www.sciencebeingjournal.com

MODELLING BIOMASS PARTITIONING DATA IN *ARABIDOPSIS THALIANA* L.

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Received: 5th Dec. 2022 **Revised:** 24th Dec. 2022 **Accepted:** 27th Dec. 2022

Abstract: A three-parametric Gompertz function was applied to model biomass partitioning data in *Arabidopsis thaliana L.* Fitting and evaluation statistics of the model suggested that cumulative data of root biomass growth performed better than that of shoot growth while relative growth rate data demonstrated reverse trend. Both AGR and CGR peak was higher for shoot growth than root growth. Upper asymptotic values for both shoot and root growth came out to be 1.541 and 0.313 respectively at the end of growth cycle. Time- dependent analysis suggested that RGR declined exponentially over time and RGR-shoots (RGRs) was higher than that of RGR-roots (RGRr). Size-dependent RGR demonstrated that due to low rate of decline, RGRs was higher than that of RGRr.
Keywords: AGR, biomass partitioning, CGR, Gompertz, RGR, Upper asymptote
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INTRODUCTION

Growth is a complex process which can be explained and interpreted using sigmoid functions. The growth curve of the function has three distinct phases: initial phase which is the early accelerating phase, it is followed by a middle linear phase and finally the curve ends with a saturation phase. The three phases if combined together in synchronisation, forms a typical *S*- shaped curve whose absolute growth curve is bell- shaped. However, relative growth rate curve is reverse sigmoidal in nature due to the fact that there is always a universal decrease in RGR as the plant/organ size increases with time. Sigmoid functions operate on an assumption that there is always an upper limit of growth due to limited resources, intra and inter specific competition among individuals and environmental constrains. Sigmoid models consist of both response and independent variables along with model parameters having well- defined biological meaning. Biomass partitioning is the process by which plants divide the bio-energy among their leaves, shoots, roots and reproductive structures. It is an important trait for the process of characterization of plant physiological ecology (Mokany *et al*., 2006) and an important parameter that derive plant long term adaptation to different environmental conditions. Biomass partitioning data also informs about photosynthates allocation between above and belowground biomass which in turn affects plant growth as well as overall function of the ecosystem along with biogeochemical cycles. Therefore, the mechanism by which different plant species respond to variations in the availability of resources in their environment is a key exploring area in functional forestry.

Significant aspect of plant growth modeling is evaluating function-derived relative growth rates among plant species which helps in comparing growth efficiencies and resource allocation patterns in different plant functional groups. As RGR is an indirect quantification of the efficiency of plants to produce new material and regulates plant competitiveness, so interpreting RGR by incorporating both time and size dependent changes is a key to compare both inter and intraspecific growth efficiencies among plants. In this article *Arabidopsis thaliana L*. is taken as an example to analyse biomass partitioning data, applying a three- parametric Gompertz model. It is an annual, herbaceous, monocarpic and dicot plant belonging to family Brassicaceae. It has a simple genome organization and is widely used as model plant in growth modelling because it is easy to grow, has a ubiquitous presence and short life cycle of approximately 90- 120 days. Different aspects of the plant species have been studied and documented in the past, which are: phenology (Zang *et al*., 1994), growth characteristic according to ecotypic variations (Norton *et al*., 1995), growth rate (Li, *et al*., 1998) and physiology (Minorsky, 2001). In the present manuscript, biomass partitioning data was analysed and compared in terms of cumulative, absolute and relative growth rates using a Gompertz function. The author believes that results will throw light on the carbon economy of the plant in question and can be applied to study biomass allocation patterns of other similar species as well.

EXPERIMENTAL

Study area: The work was carried out at Ecophysiology Laboratory, Department of Functional Plant Biology, SSJ University (formerly called as Kumaun University, SSJ/Almora Campus), Almora, Uttarakhand, India. The coordinates are: 29°35’31’’ N 79°38’45’’ E/ 29.5919406°N 79.6458561°E.

Experimental Design: For growth of *Arabidopsis thaliana* seeds, alluvial soil was considered which is readily available in the terai region (at the foothills) of central Kumaun Himalaya. The soil was mixed with vermicompost in the ratio 3:1. The soil was autoclaved before the experiment and simultaneously cooled. Details of physio-chemical characteristic and nutrient composition of vermicompost used are: pH 7.9; EC (mS.cm^{-1}) 0.17; Moisture Content (g. Kg^{-1}) 529; WHC (g. Kg^{-1}) 1101; OC (%) 11.15; Nitrogen (%) 1.01; Phosphorus (%) 0.59; Potassium (%) 0.395; Calcium (%) 3.13; Magnesium (%) 0.321; Sodium (%) 0.086; Zinc (%) 0.058; Copper (%) 0.0029; Iron (%) 0.758; Manganese (%) 0.106. Eventually plastic pots (diameter 8.5 inches) were taken and soil was gradually put in the pots with constant layering. Seeds were planted by sprinkling them carefully over soil surface, trying to maintain the desired density. Single pot accommodated at least 12-15 plants. Planted seeds were not covered with additional soil as light was required for germination. All pots (12) were covered with clear plastic wrap with few perforations in order to maintain enough humidity for germination. Seeds were watered as and when required using sprinklers and saturation level of soil was maintained accordingly. Finally, pots were placed at 4°C in dark for two days just to eliminate any dormancy and ensure uniform and synchronized germination. After two days, plastic pots were transferred to growth chamber at 22°C and at 80% relative humidity. Seeds were further grown under white light, with 100% light intensity which was equivalent to approx. 120µ mols min^{-1}. The growing plants were kept under 8 hours light and 16 hours dark i.e., under short day conditions in order to prevent early flowering and simultaneously improving vegetative growth (leaf size and biomass). First harvesting was conducted on 21st day of the experiment set, which was followed by subsequent harvesting at every 7th day, till 91 days of life cycle. After every harvest, plants were separated from soil, cleaned and segregated into above and belowground biomass. Leaves, stem and raceme in combination was considered as aboveground biomass while roots as below ground biomass. Initially, fresh weights were taken before shade drying the plant parts for estimating dry weights. Above and belowground biomass was weighted separately till final i.e., 11th harvest.

Model Development and Fitting: Eventually, the biomass data (above and below ground) was modelled against time applying a three-parametric Gompertz model (Gompertz, 1825). Cumulative, absolute and relative growth rates were calculated and compared along with model parameters. CGR, AGR and time- dependent RGR was calculated by directly applying model functions. Gompertz model had the following functional form:

$\boldsymbol{y(t) = ae^\wedge - be^\wedge - ct}$ ....(I)

Its absolute growth rate function was:

$$y(t) = abce^{-ct}e^\wedge - be^\wedge - ct\text{.......} \quad \text{(II)}$$

Followed by relative growth rate function:

$$y(t) = bce^\wedge - ct \text{.....} \quad \text{(III)}$$

Here, *y(t)* is the value of y (biomass) at a given time t, a, b and c are model parameters, t represented independent variable i.e., time and *e,* is an exponential which is constant.

Size- dependent or size- standardized RGR (Turnbull *et al*., 2008; Rose *et al*., 2009; Rees *et al*., 2010) was calculated by modelling observed RGR against observed biomass. In this way, RGR was calculated at a common size.

Model Evaluation: Model performance was evaluated using three criteria *viz*. Adjusted R^2 (Chenge, 2021), Akaike Information Criterion (Akaike, 1974) and Bayesian Information Criterion (Schwarz, 1978). Models with least AIC/BIC and high Adj. R^2 was considered to perform the best. Statistical calculations were all implemented in Microsoft Excel 2021 using *Real Statistics Resource pack*. Nonlinear linear curve fitting was performed with Excel *Solver*. Both observed AGR and RGR was calculated from the actual biomass accumulation data using the formula: AGR = $(W_2 - W_1)/(T_2 - T_1)$ and RGR = $LN(W_2) - LN(W_1)/(T_2 - T_1)$, where W_2 and W_1 are final and initial dry weights respectively, T_2 and T_1 are time between harvest, W is the dry weight increment at a given time *t* and LN is the natural log.

RESULTS AND DISCUSSION

A three-parametric Gompertz function was used to model biomass partitioning data in *Arabidopsis thaliana L*. The model function was not symmetrical about the point of inflection and had the coordinates (T_i; a/*e*) i.e., the inflection point (T_i) of the model felled at approximately 37% of the asymptotic mass, a. Here, RGR function declined exponentially with time. The upper asymptotic values of cumulative biomass increment for shoots and roots came out to be 1.541 and 0.313 respectively (Fig 1a). AGR-peak for shoots exceeded to that of roots and was 2.2% more in magnitude than AGR-peak of roots (Fig 1b). Compared at 21st day, roots had 0.18% greater AGR than shoots but when compared at the final harvest, AGR- shoots was found to be greater than that of roots by 0.71% (Figure 1b).

Table 1. Parameter estimates and evaluation statistics of (a) cumulative biomass, and (b) relative biomass growth of shoots and roots in *Arabidopsis thaliana L.*

Model	**Model Parameters**	**Biomass**	
Gompertz	**(Cumulative growth)**	**Shoots**	**Roots**
	a	1.541	0.313
	b	16.033	9.885
	c	0.045	0.045
	Adj. R^2	0.994	0.996
	AIC	-72.043	-112.538
	BIC	-67.346	-107.841
	(Relative Growth)	**-**	**-**
	b	7.465	5.977
	c	0.025	0.027
	Adj. R^2	0.855	0.748
	AIC	-92.246	-91.493
	BIC	-89.243	-88.491

Time-dependent RGR study suggested that both the curves declined exponentially and almost had quite similar growth pattern in the order S > R i.e., shoot growth had higher RGR than that of roots throughout its lifetime (Fig 1c). In the middle of growth, time-dependent data depicted that, shoots had 1.04% greater RGR than roots. Comparing RGR on size basis corrects for variation in the initial size so that plant organs can be compared at a common size. In other words, replacement of time with size (biomass in this case) allowed evaluating size- standardized RGR (SSRGR). Here, at a common dry weight of 0.1 gm shoots had a greater RGR, which was 4.4% more in magnitude than that of roots. Size- standardized RGR (Fig 1d) suggested that due to low rate of decline, shoot growth curve had a superior RGR than that of root throughout the growing cycle, despite the fact its initial RGR was more or less similar to that of roots. The curve - shape of shoot and root growth was interestingly different in both time and size standardized RGR. Time standardized RGR displayed a rather similar trend of shoot and root growth with a smooth curve decrease. However, SSRGR showed a different trend altogether. Root growth data had the smallest final biomass and a sharp RGR decline during the study period of 91 days as compared to shoot growth. In fact, the concept of RGR is closely related to plant mortality i.e., low RGR for extended period of time are good indicators of imminent death (Pommerening *et al*., 2023). Thus, in this article plant growth modelling through function- derived growth rates were conducted on biomass partitioning data of *A. thaliana*. Results indicated that RGR declined exponentially with time and shoots had a greater RGR than roots throughout its life cycle. However, SSRGR depicted that due to low rate of decline, shoots had a superior RGR than that of roots.

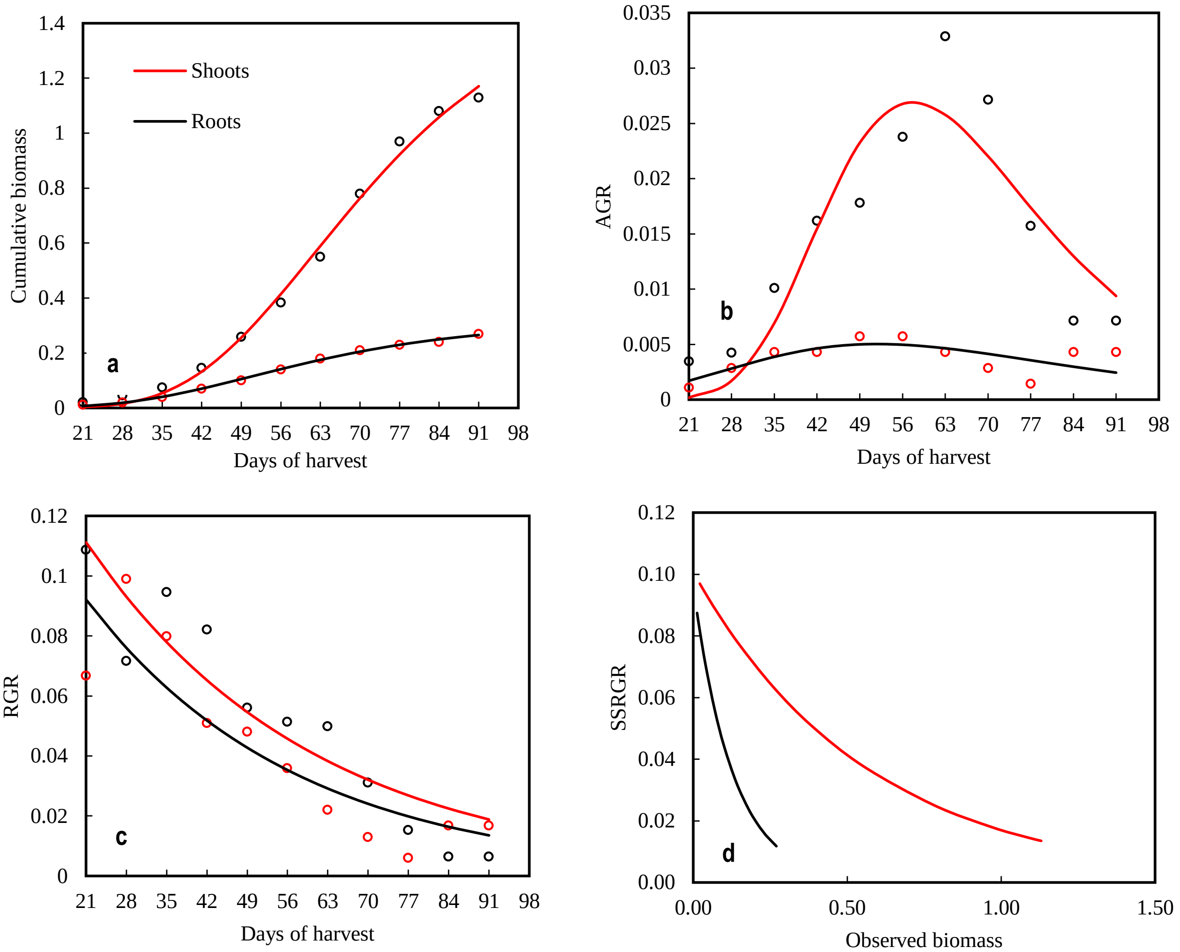

Figure 1. Fitted values from a 3- parametric Gompertz function for (a) Cumulative growth; (b) absolute growth; (c) relative growth on time basis and (d) relative growth on size basis of the biomass partitioning data in *Arabidopsis thaliana L.* * Circles are observed values

CONCLUSION

Quantifying and modelling of shoots and roots biomass growth data through function-derived growth rates served the ultimate purpose of improved analysis, in terms of growth performance and efficiency. Gompertz- model worked well to accommodate temporal dynamics of growth and was effectively used to simulate biomass partitioning data in *A. thaliana*. In this temporal analysis, cumulative, absolute, and relative growth rates were evaluated and compared at specific times during the complete life cycle of the plant. Moreover, SSRGR analysis had also proved to be useful in comparing growth efficiencies in plants species as well as plant parts.

Acknowledgements: Thanks to two anonymous reviewers for reviewing the manuscript.

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Source of Financial Support: Nil.
Conflict of Interest: None, Declared.