Review Paper:

GRC and pathway analysis: significance and applications in exploring RGR in plants

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Abstract

Utility of some modern methods (Growth Response Coefficient and Pathway Analysis) in analysing RGR and its components (NAR, SLA, LMF) has been depicted in the present study. Studies related to RGR are complex. Moreover, it is impractical for a researcher to study the entire spectrum of plant functional groups due to abundance and diversity of species in nature. RGR often varies between functional groups and in different environmental conditions as well. It is desirable to observe and identify characteristic patterns in plant growth models for better management practices.

To achieve this goal, a more holistic approach is adopted which scrutinizes experimental data from number of independent studies in order to establish overall trends in RGR. The method is called meta-analysis. The, above mentioned statistical methods can further assist evolutionary biologists in tracing the evolutionary and phylogenetic characteristics of plants, the knowledge of which can be applied for modelling RGRs in future.

Keywords: Growth Response Coefficient, Pathway Analysis, RGR, NAR, SLA, LMF, functional groups, meta – analysis.

Introduction

Three remarkable phases in the life cycle of plants are growth, survival and reproduction. Whole concept of "plant growth analysis" revolves around Relative Growth Rate (RGR) and its functional components as both survival and reproduction depend upon plant size i.e. on growth rate[4]. RGR is an important variable influencing plant growth models[2] and understanding its ecology is essential in analysing, comparing and improving such models.

Functional ecology is an advance branch of plant science which studies growth functions at both intraspecific and interspecific level in variety of environmental conditions. This branch is basically a combination of ecology and physiology, the knowledge of which is utilized to understand the complex relationships between the organism and its environment. Some legitimate questions which a researcher in this field seeks are: how plants perform ecological, morphological and physiological adjustments to its everchanging environmental conditions; strategies made by plants for resource allocation; to what extent external factors influence biomass synthesis on daily basis and how biomass is partitioned or allocated to different plant parts and many more.

RGR is an important function in plant growth modelling which fascinates researcher the most. RGR does not operate in isolation but is influenced by external environmental factors as well as other functional parameters forming an RGR- complex. Other functional parameters include Net Assimilation Rate (NAR), Specific Leaf Area (SLA) and Leaf Mass Fraction (LMF).

In plant growth models, as RGR is determined by differences in morphology, physiology and biomass partitioning[3] so the RGR complex can be factorized or decomposed into classical growth components NAR, SLA, LMF[7] which are functions of plant mass, leaf mass and leaf projected surface area[8].

Due to RGR complexity, the experimenter often finds it difficult to explain the relative contribution of each factor in influencing RGR. To overcome this problem, advanced tools are applied which are mainly Growth Response Coefficient (GRC) and Pathway Analysis (PA). Such tools assist in meta- analysis of the experimental data collected from independent studies in order to determine overall trends in RGR. Thus, the manuscript provides a brief description of the two statistical methods which are being utilized in studies related to RGR modelling in plants.

Growth Response Coefficient: Poorter and Werf[6] proposed the concept of Growth Response Coefficient (GRC) in order to compare relative contribution of each growth component in relation to RGR trajectory. The authors defined GRC as the proportional difference in a particular growth component "α" (NAR, SLA, LMF) scaled to the proportional difference in RGR (equation v), the value of which is denoted by the slope (β_1) of the linear regression. Thus, GRC values are scaling allometric slopes of the regression line where the natural log of each growth component is regressed on the natural log of RGR, so that the slope with respect to each growth component "α" (β_1, GRC) is independent of others.

GRC calculations:

$$RGR = NAR * LAR \quad (i)$$
$$\text{And } LAR = SLA * LMF \quad (ii)$$
$$\text{Therefore, } RGR = NAR*SLA*LMF \quad (iii)$$
$$\text{In (RGR)} = \text{In (NAR)} + \text{In (SLA)} + \text{In (LMF)} \quad (iv)$$
$$\text{In }(\alpha) = \beta_0 + \beta_1 \text{In (RGR)} \quad (v)$$

Now, GRC is a tool to investigate contribution of each factor in determining RGR.

Thus, $GRC_{NAR} + GRC_{SLA} + GRC_{LMF} = 1$ (vi)

GRC values basically indicate how a proportional difference in any of the growth component scales with the observed proportional difference in RGR. $GRC_{NAR}= 1$ indicates that a given proportional difference in RGR is accompanied by a proportional difference in NAR of the same magnitude and $GRC_{NAR} = 0$ indicates that a difference in RGR is not accompanied by any systematic difference in NAR. GRC values can be higher than one, if the increase in growth parameter is stronger than the increase in RGR and can be lower than zero, if an increase in growth parameter goes with a decrease in RGR.

Literature search on herbaceous plants using 57 experimental results[3] through meta- analysis revealed that average value for GRC_{NAR} was 0.26 and GRC_{LAR} was 0.74 indicating that LAR was by far the most important factor in explaining inherent variation in RGR. The difference in LAR was mainly due to variation in SLA ($GRC_{SLA}= 0.63$) and GRC_{LMF} being 0.11. GRC calculations can be applied to data sets of large number of species to investigate interspecific variations in RGR[6]. They can also be utilized to study effect of different treatments or resource levels[5] on RGR as well.

Pathway Analysis: Prof. Sewall Wright gets the credit of proposing the method of Pathway Analysis (PA) in the year 1921. Initially the work was only restricted to population genetics, but later was extended to plant biology as well. While dealing with plant functions, at times researcher is often confused in making conclusions at the level of regression analysis even when the model reports a reasonably good fit and a high R^2 value. The experimenter fails to explain any direct positive significant contribution from any of the casual variables with respect to its target variable. Thus, it is a decision support tool that helps researcher in determining both direct as well as indirect contributions of casual variables (NAR, SLA, LMF) in relation to RGR. PA is a natural extension of multiple regression analysis, only difference is that latter can just give closest prediction of the response variable (Y) based on the given independent variables by least square test, but PA goes a step further and provides probable interpretation of the relationships between and within the contributing causal factors (NAR, SLA, LMF) to the observed effects (RGR).

In nature, nothing works in isolation but multiple casual factors called as x- variables influence the primary characteristic of an organism called as response or target variable. Suppose X_1(NAR), X_2(SLA) and X_3 (LMF) are the casual factors which influence a variable "Y" (RGR). Now there could be six possibilities to this:

- Direct effect of X_1 on Y
- Direct effect of X_2 on Y
- Direct effect of X_3 on Y
- Indirect effect of X_1 on Y via X_2 and X_3
- Indirect effect of X_2 on Y via X_1 and X_3
- Indirect effect of X_3 on Y via X_1 and X_2

PA of data sets interprets the relationship between all six possibilities through (a) Partial Regression Coefficients also known as Direct Path Coefficients and (b) Indirect Path Coefficients. The method can be referred to as the process of splitting correlation coefficients into its component parts[1]. PA can be performed in Microsoft EXCEL[1] using statistical functions in "Data Analysis Tool Kit".

Thus, we see that GRC and PA have immense potential in exploring plant growth functions and are being gradually used worldwide for the aforesaid purpose. These advanced tools in modern biology have opened space for comprehensive plant grow modelling of individual plants and communities as well.

Conclusion

Relative Growth Rate (RGR) is an important characteristic of plants related to plant size, so understanding the concept of RGR is crucial. Plants survive in different types of environmental conditions utilizing different degree of resource limits. Due to this, RGR varies from species to species and maximum RGR can be attained by those species which can use the existing resources to its maximum. As the resources are exhausted temporally, the growth rate gradually decreases and almost ceases when maximum size of plant or plant part is achieved.

Many factors influence RGR in nature, few factors which directly influence RGR are: NAR, SLA and LMF. While investigating RGR, at times it becomes difficult to quantify relative contribution of each factor in determining RGR and its underlying components. GRC and PA assist the researcher in dealing with such complex issues. Effective utilization of the tools helps in exploring and understanding RGR in a much better way.

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