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LECTURE 04: ANALYSIS APPROACH

The best way of comparing the activity in dry weight production of two plants *was to compare the rate at which the material already present could produce new material*. V.H. Blackman (1920)

LEARNING OUTCOMES

After the completion of this lecture and mastering the lecture materials, students should be able

1. to explain the initial approach used to study plant growth.
2. to explain several facts that should be taken into account in the analysis of plant growth.
3. to explain the general pattern of plant growth for annual species.
4. to explain “compound interest law” in relation to quantitative plant growth analysis.
5. to apply RGR in the quantitative analysis of plant growth.

LECTURE OUTLINE

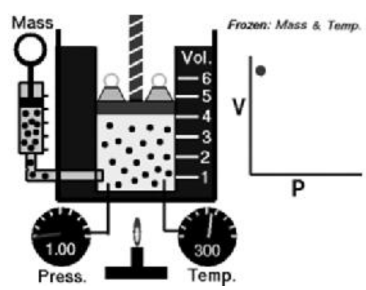
Chapter 4:
Sitompul, S.M. (2016).

1. INTRODUCTION

How to analyze?

- An important part of the whole process of scientific advance lies in the discovery of empirical generaliza-tions such as Boyle's and Ohm's Law.

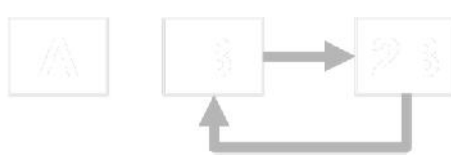
An animation showing the relationship between pressure and volume (P = 1/V) when amount and temperature are held constant.



- These generalizations epitomize masses of individual observations, and which at the same time, within recognized limits, can be used for predictions.

- The early investigators of the quantitative relationship involved in the growth of plants were thus following the classical pathway when they try to find simple empirical relationships which would in similar fashion sum up many individual measurements of attributes of growing plants.
- Bearing in mind the complex organization of higher plants it is not surprising that these attempts should have failed.
- It was important, however, that they should have been made as a stage in the overall advance of knowledge,
- The ideas underlying some of these attempts proved to be of such limited application that they are now almost forgotten.

- An example is afforded by the attempts of Brailsford Robertson in 1908s to demonstrate that plant growth follows the time course of an autocatalytic chemical reaction in a closed system.
  - Autocatalytic reactions are those in which at least one of the products is a reactant.



- He had an initial success in fitting an autocatalytic curve to the latter part of the growth of an organ of limited growth (a fruit of *Cucurbita pepo*), but even here there were large deviations in the early part of the fruit’s development.

2. BASIC CONCEPT

- The following facts should be taken into account in the analysis of plants growth.
- The first fact is that the performance of living organisms (plants), as the target of quantitative growth analysis, is the resultant of numerous factors either from the inside or the outside of the organisms.
- The second fact is that all the factors work through a complex mechanism (processes) in the system of plants.
- The third fact is that the mechanism changes with time to suit with the growth and development of plants under the influence of environment changing with time that results in changes in the performance of plants with time. The changes may even occur in a short term within a day.

1. Patterns of Plant Growth

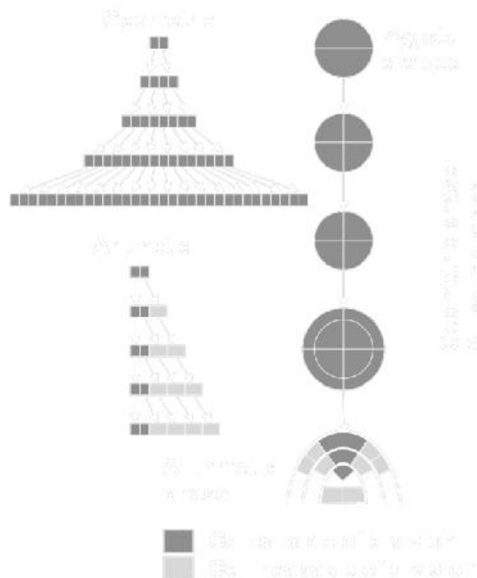
- The pattern of plant growth is a subject of biology where quantitative analysis has been applied for a long time.
- The growth of plants in term of biomass and other parameters such as leaf area shows in general a sigmoid pattern (S form) for annual species. The sigmoid pattern can be divided into 3 or 4 phases;
  - (i) Lag phase at the beginning of plant growth.
  - (ii) Exponential (log) phase when the maximum rate of growth is achieved.
  - (iii) Diminishing phase due to senescence following by loss of some biomass.
  - (iv) Stationary phase when plants show no growth which is often unified with phase III.

General pattern of growth for annual plants

2. Unicelluler Analogy

- Increase in biomass or plant growth is the product of cell division and growth (increase in cell mass and irreversible size).
- The role of cell number increase, taking place in meristematic tissue including cambium, is dominant in plant growth as the increase of cell size is limited.
- Leaf epidermal cell counts showed that the increased or decreased transgenic plant and organ size was due to changes in cell number, not cell size (Guo *et al*., 2010).
- It is, therefore, cell dimensions such as cell number, which is under control of genetic program such as *CNR* (*Cell Number Regulator*) genes in maize, may be used as a parameter of plant growth.

- The application of this parameter, however, is limited to the meristematic tissues.
- Cell division in the meristematic tissues proceeds in a arithmetic fashion, and geometric fashion occurs only after zygotic cell division.



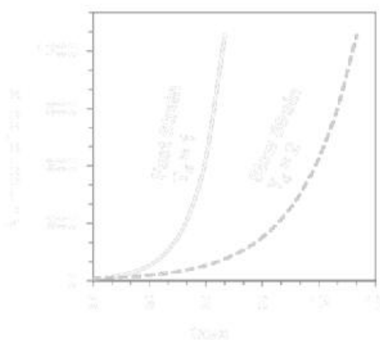
- The rate of growth is the number of cells produced per unit time. If the cell division is synchronized until the substrate is limited, increases in cell number will follow a geometric fashion.
- The growth of a bacterial population is a simple example with the initial population of N_0. At optimal conditions, each cell will divide into two daughter cells after a certain period, known as generation time, and the number of cells produced after "t" period is

0.	At the beginning	$N = N_0$	**$= N_0 . 2^0$**
1.	one generation	$N = N_0 \times 2$	**$= N_0 . 2^1$**
2.	two generations	$N = N_0 \times 2 \times 2$	**$= N_0 . 2^2$**
3.	three generations	$N = N_0 \times 2 \times 2 \times 2$	**$= N_0 . 2^3$**
n	n generations	$N = N_0 \times 2 \times 2 \times .... \times 2$	**$= N_0 . 2^n$**

- The number of cells after time ‘t’ can be expressed as follows.

$$N_t = N_0 e^{rt}$$

where ‘r’ = the growth rate of cells, and ‘e’ = 2,7182 is the base of normal logarithm.



A hypothetical growth of unicellular organism
T_d = doubling time

3. GROWTH PROCESS

1. Autocatalysis

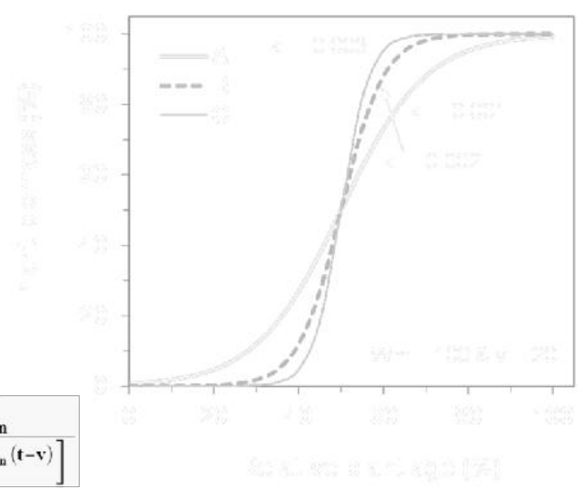
- As the biomass of plants can be regarded as the products of metabolism using substrates produced by leaves and roots, then a plant seems to be a self-propagating system like autocatalytic reactions.
- Brailsford Robertson (1908), as mentioned previously, was one of earliest researchers who approached plant growth with autocatalytic chemical reaction in a closed system.
- The rate of substrate converted to product is proportional to the quantity of substrate and the quantity of product which can be represented by the following figure.

- The rate of reaction above or the rate of product formation per unit time is

$$\frac{\partial \mathbf{P}}{\partial \mathbf{t}} = \mathbf{k.S.P}$$

where S = substrate, P = product, k = constant and $\partial P/\partial t$ = the rate of product produced (∂P) per unit time (∂t). The integration of the above equation with some arrangement results in the following equation.

$$\mathbf{W} = \frac{\mathbf{W_m}}{\left[1 + \mathbf{e}^{-q\mathbf{W_m}(\mathbf{t}-\mathbf{v})}\right]}$$



$$\mathbf{W} = \frac{\mathbf{W_m}}{\left[1 + \mathbf{e}^{-k\mathbf{W_m}(\mathbf{t}-\mathbf{v})}\right]}$$

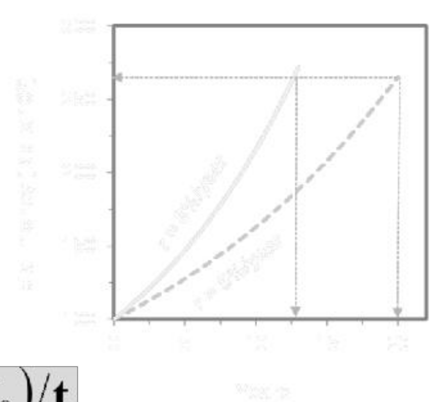
The hypothetical growth of plants based on autocatalytic assumption

- Other interesting statement from Blackman (1920) was "… *clearly the efficiency of the plant is greatest at first and then falls somewhat, but the fall is only slight until the formation of the inflorenscence when there is a marked diminution in the efficiency index*
  - The Compound Interest Law can be illustrated as follows. We save some money (M_0) in a Bank with an interest rate of '**k**', and the interest is never taken but saved in the Bank. After several year 1, 2 … and t is calculated as follows.

Time	The amount of money	
0.	$\mathbf{M_0}$	
1.	$M_0 + kM_0$	$= M_0(1+k)$
2.	$M_0(1+k) + kM_0(1+k)$	$= M_0(1 + k)^2$
3.	$M_0(1 + k)^2 + kM_0(1 + k)^2$	$= M_0(1 + k)^3$
t		$= M_0(1 + k)^t$

- After year '**t**', the total amount of money in the Bank (M_t) with the concept of compound interest can be formulated based on the initial amount of money put in the Bank ($\mathbf{M_0}$) and the interest rate (**k**) as follows.

$$\mathbf{M_t} = \mathbf{M}_0(1+\mathbf{k})^{\mathbf{t}}$$



- The above equation is similar to the one presented previously ($N_t = N_0e^{rt}$) that can be written as $W_t = W_0e^{rt}$, and

$$\mathbf{r} = \mathbf{R} = \mathbf{ln}(\mathbf{W_t}/\mathbf{W}_0)/\mathbf{t}$$

2. Efficiency Index

- The rate of interest (r or R) is clearly a very important physiological constant.
  - It represents the efficiency of the plant as a producer of new material.
  - It may be termed the **efficiency index** of dry weight production.
- As data accumulated and were examined it soon became apparent that the idea of "**R**" being a constant must be abandoned.
- The term 'efficiency index', with its overtones of constancy, was replaced by the neutral term 'relative growth rate (RGR)' used by West, Briggs and Kidd (1920).

- However, Blackman's paper marked a notable advance in the arithmetic treatment of growth data.
- The paper added weight to the growing feeling of the importance of what is now called relative growth rate (**RGR**) as an overall measure, a summation or integration of all the processes bringing about increase in dry weight of the plant.
- R or RGR proposed by Blackman is based on an assumption that the production of biomass is dependent upon the initial size (biomass) of plant as shown by the following equation.

$$\frac{\partial \mathbf{W}}{\partial \mathbf{t}} = \mathbf{RW} \Rightarrow \frac{\partial \mathbf{W}}{\mathbf{W}} = \mathbf{R}\partial \mathbf{t}$$

- Integration of the above equation results in

$$\int_{W_1}^{W_2} \frac{\delta W}{W} = R \int_{T_1}^{T_2} \delta t$$

$$\ln\left(\frac{W_2}{W_1}\right) = R(T_2 - T_1) \Rightarrow R = \frac{\ln W_2 - \ln W_1}{T_2 - T_1}$$

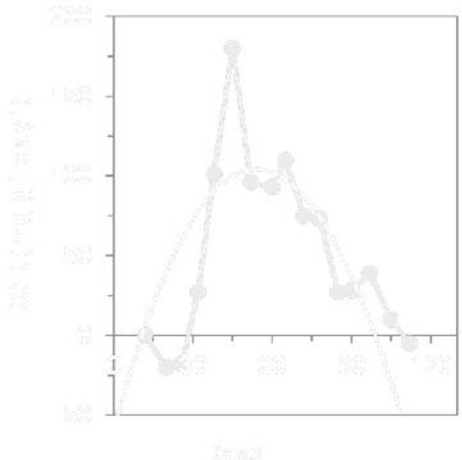
$$\Downarrow$$

$$W_2 = W_1 e^{R(T_2 - T_1)} \Rightarrow W = W_0 e^{rt}$$

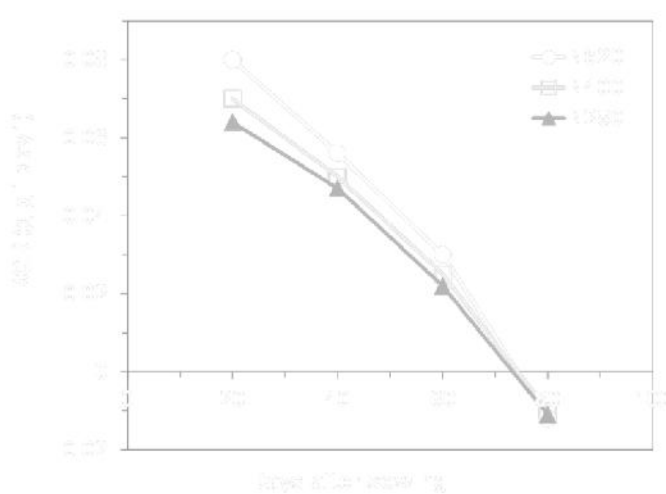
- Therefore, the above equation of RGR applies to plants with an exponential pattern of growth.

3. Plant RGR

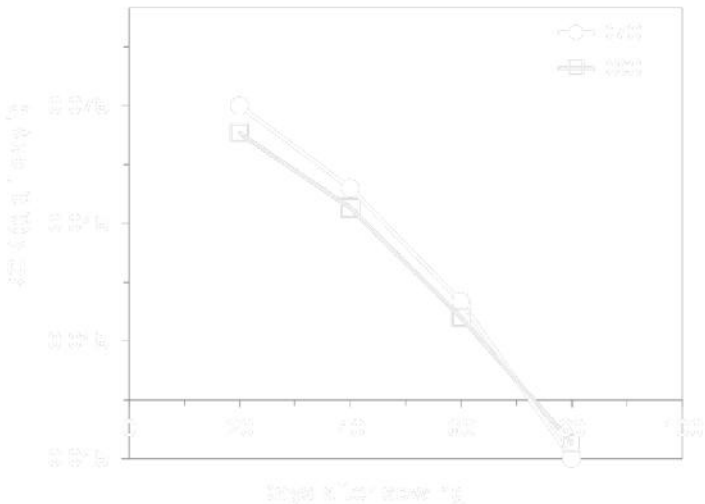
- The application of RGR equation above to several species in different environments affirmed that RGR is not a constant index of plant growth during the growth cycle of plants or even in a short period.
- It was also found that plant species and environment have a strong influence on RGR which is characterized by fluctuations at a stage or several periods of plant growth.
- In maize for instance, RGR was very low or even negative at the initial growth (≤30 days), then increased rapidly and reached a maximum followed by a rapid decrease at the final stage of growth. This is different from results of other maize experiments with a high RGR at the initial stage of growth.



The progress of RGR with time in maize. Source: adapted from Pooter (1989) originated from Kreusler *et al*. (1879)



The progress of RGR with time in maize with different rates of nitrogen fertilizer (urea): N520, 400 & 280 = 520, 400 & 280 kg Urea/ha. Source: adapted from Valadabadi & Farahani (2010)



The progress of RGR with time in maize of different population.
D70 & D90 = 70.000 & 90.000 plants/ha

- The results of several studies lead to a tentative conclusion that RGR is not a growth index easy to use.
- It is not only related to RGR changes with time and RGR sensitivity to the size of plants at measurements, but also related to the calculation of this index.
- As the RGR is derived from the ratio of newly produced biomass and previously produced biomass [$\partial W/(W x \partial t)$], caution should be taken in the interpretation of RGR.
- A high value of RGR does always mean good, but a low value of RGR is clearly not good.
- This can be explained by a simple example with two sphere representing leaf area or biomass of plants.

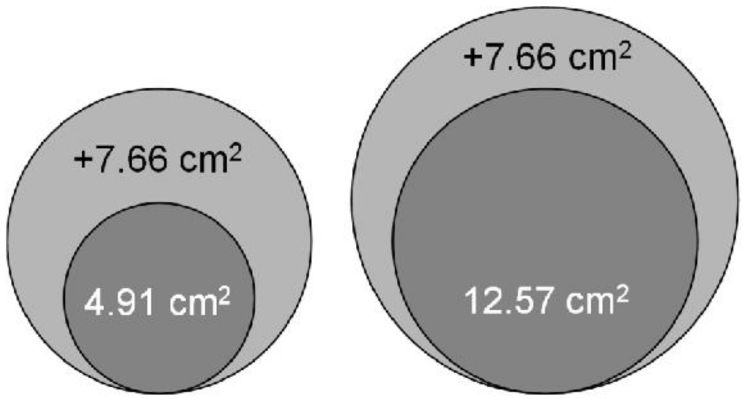


Illustration of RGR on leaf A and B. The ratio of (7.66+4.91) /4.91 = **2.56** >> (7.66+12.57)/12.57 = **1.91,** but B (7.66+12.57 = **20.23**) >>A(7.66+4.91 = **12.57**)

4. APPLICATION

1. Benefit of Plant Growth Analysis

- There is no doubt that quantitative plant growth analysis is important in the effort to understand plant growth.
- It is clear that quantitative feature of plant growth and phenomena supporting plant growth processes can be better understood with the quantitative analysis of plant growth.
- A better understanding of plant growth would be a valuable capital in the effort to manage plants and their environments to obtain a high yield of crops.
- This means that plant growth would give benefit more significant if it is not seen as separate process, but as a part of whole plant system.

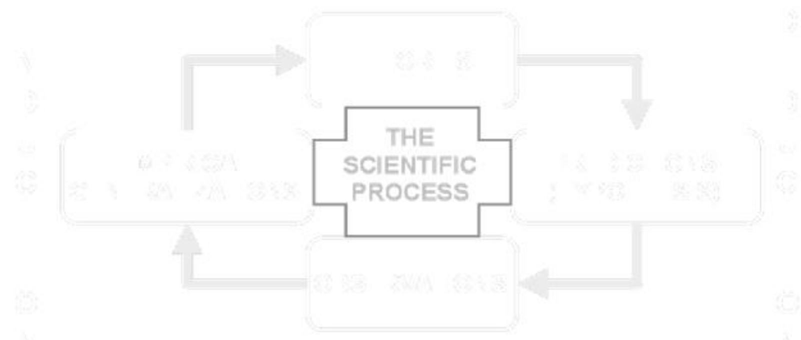
2. Growth Complexity

- Plant growth is a complex process as a manifestation of many processes including the supply of substrates such as carbohydrate, derived from the process of photosynthesis, and nutrients taken up by the roots.
- The substrates are then used in the metabolic reactions for the formation of compounds, plant biomass and plant organs.
- All processes are integrated under the control of genetic program that is subject to the influence of environment. A change in one processes may lead, of course, to changes in other processes.
- This can be illustrated by results of an experiment that showed the rate of photosynthate use in plants may influence the rate of photosynthesis.

- The rate of photosynthesis declined when photosynthate accumulates in the leaves and is not used in the process of plant growth or the formation of new plant biomass (Maggs, 1964; King *et al*., 1967).
- This can be interpreted as the result of feed-back control; a slow plant growth would inhibit the rate of photosynthesis which is the opposite of slow plant growth phenomenon due to a low rate of photosynthesis.

WHAT HAVE YOU G0T?

1. What is the approach used by the early investigators of quantitative plant growth analysis?
2. What is an example of earlier attempts in the study of plant growth?
3. What are autocatalytic reactions?
4. What are the facts that should be taken into account in the analysis of plant growth?
5. What is the plant growth pattern of annual plants?
6. What is lag phase of plant growth?
7. What is plant growth at cellular level?
8. What is "compound interest law" in the growth of plant?
9. What is efficiency index posed by V.H. Blackman?
10. Why does RGR decline with time after plants to reach certain size?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