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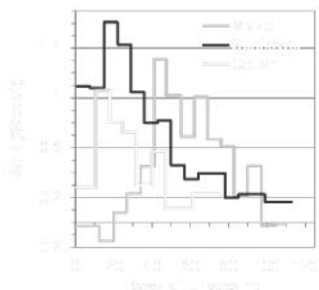
LECTURE 05: PLANT GROWTH ANALYSIS I: AGR & RGR



If we do not plant knowledge when young, it will give us no shade when we are old."~ Lord Chesterfield

LEARNING OUTCOMES

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

1. to explain the role of plant growth analysis to identify problems of plant growth in relation to crop yields
2. to explain and apply the index of AGR (absolute growth rate.
3. to explain RGR (relative growth rate) as a constant or not constant index.
4. to explain and apply the index of RGR (relative growth rate)
5. to explain the ontogeny of RGR in different species

LECTURE OUTLINE

1. INTRODUCTION
2. BIOMASS PRODUCTION
2.1 AGR
2.2 RGR
2.3 Ontogeny and Environment
2.4 Species Difference

Chapter 5:
Sitompul, S.M. (2016).

1. INTRODUCTION

What is it for?"

1. Plant growth analysis is aimed, among others, at disentangling the details of the mechanism of growth and at a precise knowledge of the factors limiting growth throughout its course.
2. Einstein stated that "*Know where to find the information and how to use it – That's the secret of success*". He also argued that "*we can't solve problems by using the same kind of thinking we used when we created them*".
3. Plant growth analysis put emphasis on analysis or finding problems; *what is the problem of plants to grow differently with time and environment*.

5. It is not few research with observation limited only to the “final yield” (seed yield) and its components (e.g. number of seeds and seed size or seed weight/100 seeds).

5. Such observation offers no explanation on yield variation between groups of plants or treatments from the standpoint of growth.
6. Plant growth analysis could offer ways to identify major growth factors controlling or limiting the yield of plants.
7. The information can be used for efforts to improve crop yields in certain environments or plant adaptation to particular environments.

$\frac{\partial W}{\partial t} = G$

2. BIOMASS PRODUCTION

1. AGR

- Simple methods for measuring plant growth were first introduced in the 1920s (Blackman 1919; West et al. 1920), leading to what is now termed “classical” growth analysis.
- The simplest measure of growth is the absolute growth rate (AGR or G) which is the absolute change in plant biomass over a given time interval.

$$\frac{\partial \mathbf{W}}{\partial \mathbf{t}} = \mathbf{G}$$

where ∂**W** is an increment in plant biomass per unit increment in time (∂**t**).

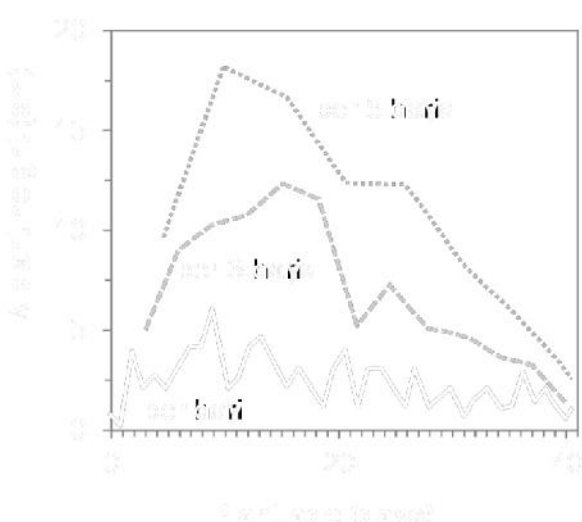
- The mean value over the interval T_1 to T_2 (time 1 to 2) is $\overline{\mathbf{G}} = (\mathbf{W}_2 - \mathbf{W}_1)/(\mathbf{T}_2 - \mathbf{T}_1)$

- The growth index can be used for resolving the nature of genotype x environment interactions on plant growth and development.
- The integration of the above equation results in the following equation.

$$\mathbf{W} = \mathbf{W}_0 + \mathbf{GT}$$

- The above equation shows that the cumulative production of biomass increases linearly with time.
- In most cases, an increase in growth per unit time is not constant during the growing cycle of plants.
- Growth in plant height, for instance, fluctuated in an interval of 1 day, 3 days or 5 days.

$$\frac{\partial W}{\partial t} = G$$



Increases (Δ) in plant height of *Scirpus lacustris* per day, 3 days and 5 days. Source: adapted from Sestak *et al*. (1971)

$\frac{\partial W}{\partial t} = G$

- When observation of plant growth is >1 day, and G may fluctuate with time, then average G should be used.

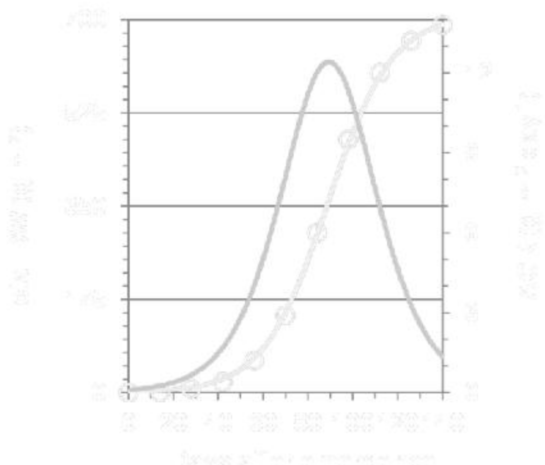
$$\overline{G} = \frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} G \partial t$$

- As G = ∂W/∂t,

$$\overline{G} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{\partial W}{\partial t} \partial t = \frac{W_2 - W_1}{t_2 - t_1}$$

- The basic concept of above equation (G.∂t) suggests as if the value of G could directly measured, but in fact is the result of calculation.
- Other approach that could be used to derive the value of G using ∂W/∂t = G which gives similar results to the above equation.

An example of growth deviating from a linear form that results in AGR varying with time

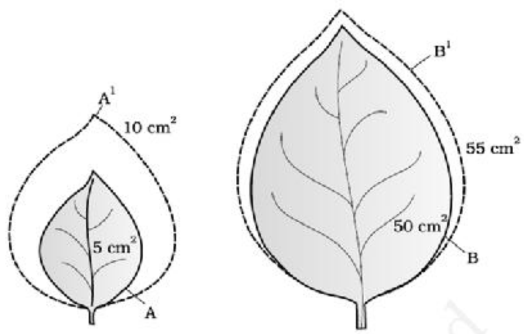


Growth and growth rate of Rye plants (*Secale cereale L.)*
Source: Pedó *et al*. (2015)

$\frac{\partial W}{\partial t} = G$

2. RGR

- The use of AGR index to compare different plants of different size (W), however, may not be fair. RGR was then developed as an efficiency index to produce new biomass per unit initial capital per unit time.



$\frac{\partial W}{\partial t} = G$

- Relative growth rate (RGR or r) is the index of plant growth the most attracting attention in the study of plant growth.
- This index can be derived from an assumption that the rate of plant growth or biomass production ($\partial w/\partial t$) is not constant, but dependent upon the initial capital (biomass) of the plant itself as shown in the following equation.

$$\frac{\partial \mathbf{W}}{\partial \mathbf{t}} = \mathbf{rW}$$

- The reposition of W from the right side to the left side results in an equation that can be expressed as an increment in the biomass of plants per unit time per unit initial capital (biomass) as shown in the following equation.

$$\frac{\partial \mathbf{W}}{\partial \mathbf{t}} \frac{1}{\mathbf{W}} = \mathbf{r}$$

- Further rearrangement of the above equation followed by integration results in

$$\frac{\partial \mathbf{W}}{\mathbf{W}} = \mathbf{r}.\partial \mathbf{t}$$

- The integration of above equation within the limit of $W_0 \rightarrow W_t$ for biomass and $0 \rightarrow t$ for time results in the following equation.

$$\int_{\mathbf{W}_1}^{\mathbf{W}_2} \frac{\partial \mathbf{W}}{\mathbf{W}} = \mathbf{r} \int_{\mathbf{t}_1}^{\mathbf{t}_2} \partial \mathbf{t}$$

- After integration, the above equation will result in the following equation.

$$\ln\left(\frac{\mathbf{W}_t}{\mathbf{W}_0}\right) = \mathbf{r}(\mathbf{t}_2 - \mathbf{t}_1)$$

$$\ln(\mathbf{W}_t) - \ln(\mathbf{W}_0) = \mathbf{r}(\mathbf{t}_2 - \mathbf{t}_1)$$

$$\mathbf{r} = \frac{\ln(\mathbf{W}_t) - \ln(\mathbf{W}_0)}{(\mathbf{t}_2 - \mathbf{t}_1)}$$

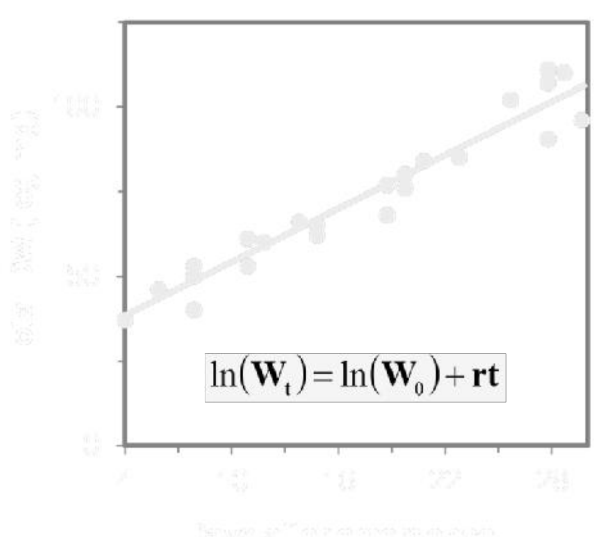
or

$$\mathbf{RGR} = \frac{\ln \mathbf{W}_2 - \ln \mathbf{W}_1}{\mathbf{T}_2 - \mathbf{T}_1}$$

- **RGR Constant.** The above approach inflicts a question on the nature of RGR whether it is constant or not.
- If RGR is regarded constant, the growth of plants will follow an exponential pattern as shown by the following equation derived from the integration of equation presented previously.

$$r\int_{0}^{t}\partial t=\int_{W0}^{W_t}\frac{\partial W}{W}\rightarrow rt=\ln\left(\frac{W_t}{W_0}\right)\rightarrow W_t=W_0e^{rt}$$

- The last equation above asserts that the initial concept of RGR applies to plants with an exponential pattern of growth.
- The exponential equation can be drawn directly or in a form of log transformation.



- In fact, it is rare to find the growth of plants in term of biomass follows the exponential pattern except at the initial stage of growth.
- Therefore, RGR considered to be constant prevails only in a short period at the initial phase of growth or other stages.

- **RGR not constant**. In a long term (whole growth cycle), RGR is not constant.
- Thereby the value of RGR for certain period (T_1-T_2) has to be the integration of each RGR value for each time increment (∂t) over the period under consideration which is expressed as R.

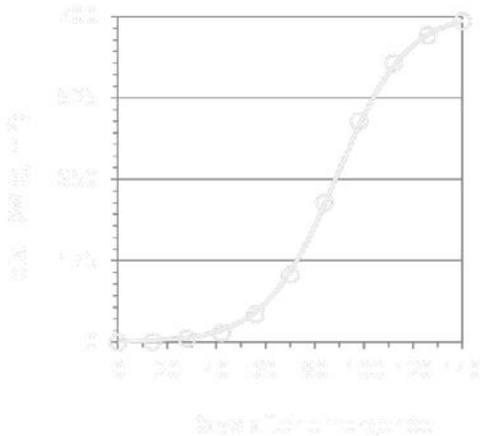
- The integrated RGR value is, of course, similar to the average value of RGR multiplied by the whole period under study as shown bellow.

$$\overline{\mathbf{R}}(\mathbf{T}_2 - \mathbf{T}_1) = \int_{\mathbf{T}_1}^{\mathbf{T}_2} \mathbf{R}\partial\mathbf{t} \quad \rightarrow \quad \overline{\mathbf{R}}(\mathbf{T}_2 - \mathbf{T}_1) = \int_{\mathbf{W}_1}^{\mathbf{W}_2} \frac{\partial\mathbf{W}}{\mathbf{W}}$$

$$\overline{\mathbf{R}}(\mathbf{T}_2 - \mathbf{T}_1) = \ln \mathbf{W}_2 - \ln \mathbf{W}_1$$

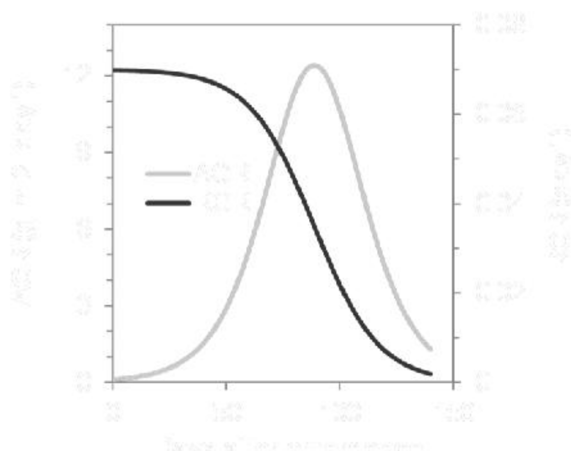
$$\overline{\mathbf{R}} = \frac{\ln \mathbf{W}_2 - \ln \mathbf{W}_1}{\mathbf{T}_2 - \mathbf{T}_1}$$

If the growth pattern of plants deviates from a linear pattern, how are their AGRs and RGRs?

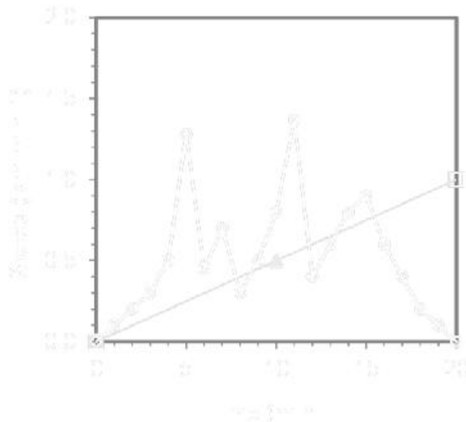


The progress with time of total dry matter in rye plants (*Secale cereale L.).* Source: Pedó *et al*. (2015)

Then AGR and RGR varied with time



- In fact, the assumption of RGR constant or not constant is not very important as both approaches give the same value of RGR as explained in the following figure.



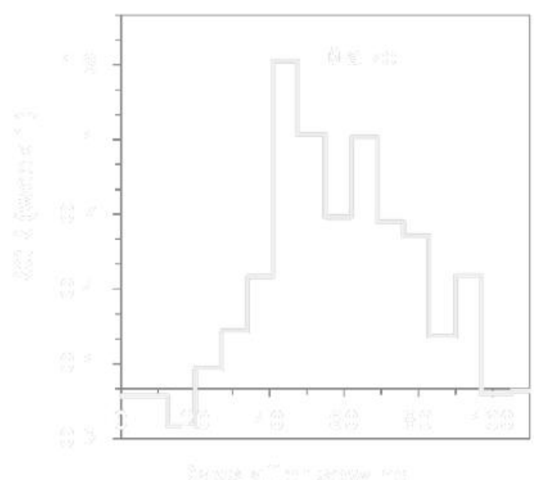
- Someone is driving a car from a place (A) to other (B) separated by a certain distance (D).
- The speed of car, which is hardly constant, can be recorded from time to time during the travel from A to B from speedometer.
- The average of traveling speed is obtained from the average of speedometer records. This is a difficult way to acquire the average speed of travel.
- The average speed can be easily obtained from the quotient of the distance between A and B (D) and traveling time (T).

$$\overline{\mathbf{V}}(\mathbf{T}_2 - \mathbf{T}_1) = \int_{\mathbf{T}_1}^{\mathbf{T}_2} \mathbf{V}\partial\mathbf{t}$$

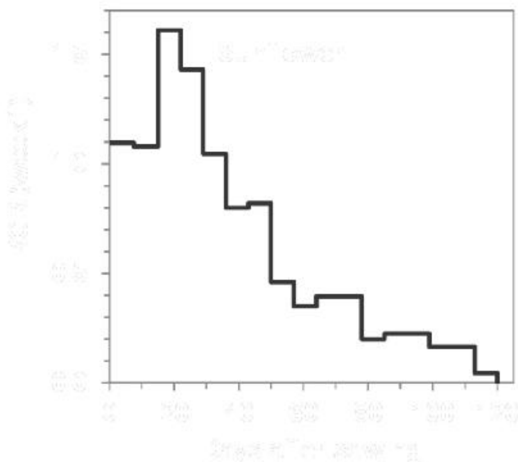
$$\overline{\mathbf{V}} = \frac{\mathbf{D(km)}}{\mathbf{T(hours)}}$$

3. Ontogeny and Environment

- The possibility of anxiety to use RGR to study the effect of environment may just arise. In this objective, RGR must free from the effect of ontogeny that is the effect coming from plant itself.
- For instance, the effect of ontogeny can be seen on results of a study in maize, sunflower (*Helianthus annuus*) and cotton (*Gossypium arboreum*).
- The RGR of the tree species showed patterns different with time which means that the ontogeny of RGR is specific for each species.
- In term of biosynthetic process, plants of high protein content per unit biomass such as legumes would form less biomass per unit substrate (carbohydrate) than other species do with a low protein content.

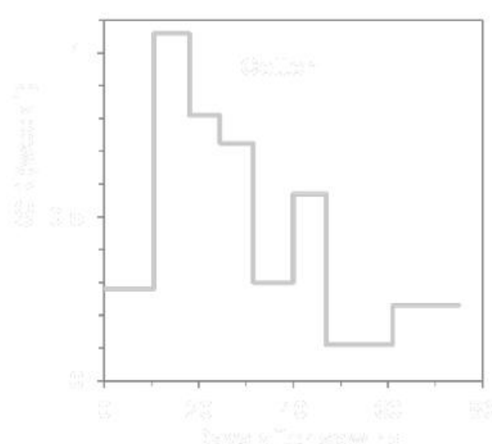


The progress with time of RGR in Maize. Source: Evans (1972)



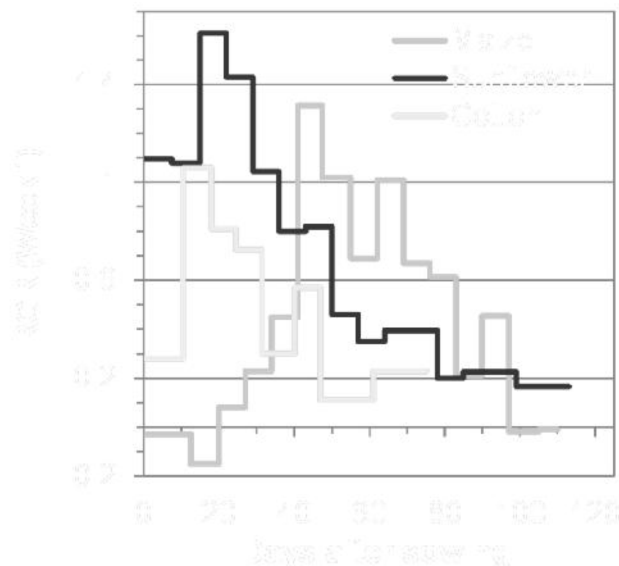
High
Very high
Declines drastically

The progress with time of RGR in Sunflower. Source: Evans (1972)



Low
Very high
Declines drastically

The progress with time of RGR in Cotton. Source: Evans (1972)



4. Species Difference

- RGR (relative growth rate) provides a valuable over-all index of plant growth, but the nature of the case its make-up is complex.
- This index almost inevitably involves a complex ontogenetic drift, with all the consequential problems of untangling the operation of the various determining factors.
- It is, therefore, not surprised that plants of different species show difference in RGR that could be partly related to difference in the rate in photosynthesis and efficiency of biomass synthesis.
- A simple example in this case is the rate of photo-synthesis generally higher in C4 plants than C3 plants which is related to the concentration of CO_2 surrounding Rubisco in chloroplast.

- The concentration of CO_2 in C3 plants is not sufficiently high to bind all Rubisco involving in the Calvin cycle in the chloroplasts thereby some binds O_2 resulting photorespiration.
- On the contrary, CO_2 concentration is high in the chloroplast of C4 plants so that no Rubisco is used to bind O_2. This nature is attributed to the cell structure of leaves and the presence of additional chemical pathway in C4 plants. Therefore, the rate of photosynthesis in C4 plants is not influenced directly by the concentration of CO_2 in the atmosphere.
- In the context of biosynthesis process, plants with a high protein content per unit biomass such as legumes would produce less biomass per unit substrate (carbohydrate) supply than plants with a low protein content.

- The energy requirement would increase with an increase in protein content, while the energy is acquired from the breakdown process (aerobic or anaerobic respiration) of substrate (carbohydrate) produced by photosynthesis.
- Effect of these factors can expressed in the following equation.

$$\mathbf{G} = \varepsilon\left(\mathbf{P_g} * 0{,}68 - \mathbf{mW}\right)$$

where G is growth or biomass production (kg CH_2O m^{-2} day^{-1}), ε is conversion efficiency of growth process (kg kg^{-1}), Pg is gross photosynthesis, 0.68 is conversion rate of CO_2 to carbohydrate such as glucose (kg.m^{-2} day^{-1}), m is maitenance cofficient (kg.kg^{-1} day^{-1}) and W is existed dry matter of plants.

- With the value of m around 0.02-0.015, ε dependent only on chemical composition of plant biomass which is around 0.7, then

$$\mathbf{G} = 0.48\mathbf{P_g} - 0.012\mathbf{W}$$

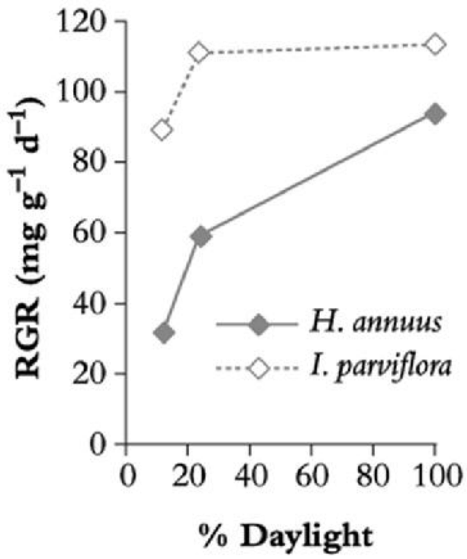
or

$$\mathbf{RGR} = 0.48\mathbf{P_g}(1/\mathbf{W}) - 0.012$$

- **Temperature**. Relative growth rate (RGR, d^{-1}) and rate of area expansion (RGR_A, d^{-1}) are both sensitive to temperature, but NAR is less so. Responses in RGR are therefore driven primarily by responses of area expansion. RGR and RGRA were higher in C4 than C3 species, especially under warm conditions.

Species		21/10ºC		32/21ºC		38/27ºC	
		RGR	RGR_A	RGR	RGR_A	RGR	RGR_A
Cotton	C_3	0.086	0.073	0.206	0.197	0.188	0.172
Soybean	C_3	0.108	0.124	0.202	0.199	0.165	0.168
Cocklebur	C_3	0.165	0.151	0.269	0.263	0.204	0.176
Maize	C_4	0.096	0.133	0.255	0.354	0.178	0.189
Pigweed	C_4	0.262	0.239	0.482	0.436	0.393	0.328
Johnson grass	C_4	0.156	0.139	0.391	0.370	0.359	0.324

Based on Potter and Jones (1977). Species listed are *Gossypium hirsutum, Glycine max, Xanthium pensylvanicum, Zea mays, Amaranthus retroflexus, Sorghum halepense*.



Based on Blackman and Wilson 1951b; Evans and Hughes 1961)

EXAMPLES

Problem

- Assume you did an experiment, 2 groups (A & B) of plants observed on day 20 and 25 respectively had:

  Group A: 15 g/plant (20 das) & 45 g/plant (25 das)

  Group B: 22 g (20 das) & 54 g (25 das)

Questions

- Which group of plants is more efficient in the production of biomass per unit initial biomass (capital).
- What is the factor responsible for the biomass difference between the two groups of plants.

Answer

- Based on the equation of RGR for plants growing exponentially as shown bellow:

  $$\mathbf{R} = \frac{\ln \mathbf{W}_2 - \ln \mathbf{W}_1}{\mathbf{T}_2 - \mathbf{T}_1}$$

  then,

  Plant A$\rightarrow$R = ln[(45)-ln(15)]/(25-20) = 0,22 g g^{-1} day^{-1}

  Plant B$\rightarrow$ R = ln[(54)-ln(22)]/(25-20) = 0,18 g g^{-1} day^{-1}

  Therefore, plant A is more efficient in the formation of biomass per unit biomass capital.

  But the biomass of plant B is higher than plant A that could be related to the initial biomass of plants.

WHAT HAVE YOU G0T?

1. What is one of the main purposes of plant growth analysis.
2. What is absolute growth rate (AGR) in term of plant biomass.
3. How can the yield of crops be increased
4. What is the nature of growth rate in term of plant height during the growing cycle of plants.
5. What is the consequence of growth deviating from linear on AGR
6. What is relative growth rate (RGR) in term of plant biomass
7. What is the nature of RGR during the growing cycle of plants.
8. How is the effect of species on growth rate.
9. What is a possible plant factor that causes a difference in RGR between plants
10. What is a possible environmental factor that causes a difference in RGR between plants


THANK YOU
http://leavingbio.net/TheStructureandFunctionsofFlowers%5B1%5D.htm
Спасибо
謝謝
شكراً