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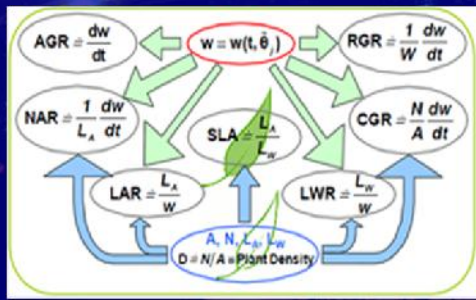
LECTURE 07:
CROP GROWTH ANALYSIS



Leaf area was the main factor determining differences in yield in several crops. Watson (1947)

LEARNING OUTCOMES

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

1. to apply general growth indices (RGR and NAR) to analyze the growth of plants in communities.
2. to explain and apply relative leaf growth rate (R_L), leaf area index (LAI) and leaf area duration (LAD).
3. to explain and apply Root/Shoot ration and Surplus biomass production.
4. to explain the ontogenetic drift of various indices in plants growing in communities for certain species

LECTURE OUTLINE

1. INTRODUCTION
2. RGR AND NAR
3. RELATIVE LEAF GROWTH RATE (R_L)
4. RELATIONSHIP BETWEEN R_L AND RGR
5. LEAF AREA INDEX (LAI)
6. LEAF AREA DURATION (LAD)
7. ROOT/SHOOT RATIO
8. BIOMASS PRODUCTION SURPLUS

Chapter 6:
Sitompul, S.M. (2016).

1. INTRODUCTION

1. All indices used for the analysis of plants growing individually (single plant), as discussed previously, can be used as well for plants in community.
2. It is important to assert that there is no theoretical reason why the concept of relative growth rate (RGR), unit leaf rate (NAR), leaf weight ratio (LWR) and other indices can not be used for the growth analysis of plants growing in communities.
3. Indeed in the agriculture field, population of plants is treated as a functional entity. Growth analysis concepts were derived from field experiments (Watson, 1947).
4. However, the performance of plants in community can be expressed per plant or per area (e.g. m^2).

5. The most simple index used in the analysis of plants growing in communities is **CGR** (Crop Growth Rate) which is equivalent to **AGR** for single plants.

$$\mathbf{CGR} = \frac{\mathbf{W_2 - W_1}}{\mathbf{T_2 - T_1}}$$

where W_1 and W_2 is the dry weight of plants per unit land area at time T_1 and T_2 respectively. Therefore, the unit of CGR is g m^{-2} that can be also expressed per plant.

6. The crop growth rate indicates the efficiency of the complete crop over a specific soil area in the production of biomass, and can be derived from the following equation.

$$\mathbf{CGR = NAR * LAI}$$

2. RGR AND NAR

- The equation used to estimate RGR for plants growing individually, as presented previously, is

$$\mathbf{RGR} = \frac{\mathbf{\ln W_2 - \ln W_1}}{\mathbf{T_2 - T_1}}$$

- This equation shows that plant dry weight (W) harvested at time T_1 and T_2 is transformed with natural logarithm (ln).
- For plants growing in a community (crops) as usual in field experiments, a W value is a mean of samples or replicates.
- Now a question arises as to the ln transformation; is it better done before or after taking the mean W.

- The

$$\overline{RGR} = \frac{\ln \overline{W}_2 - \ln \overline{W}_1}{T_2 - T_1}$$

$$\overline{RGR} = \frac{\overline{\ln W_2} - \overline{\ln W_1}}{T_2 - T_1}$$

- Hoffmaan & Pooter (2002) compared the two equations above and found that the second equation is better than the first one producing a high bias (over/under estima-tion).
- The bias increased as the RGR variation increased due to an increase in the interval of measurement. With the same reason, the following equation is better for NAR.

$$\overline{NAR} = \frac{\left(\overline{W}_2 - \overline{W}_1\right)}{\left(T_2 - T_1\right)} \frac{\left(\overline{\ln LA_2} - \overline{\ln LA_1}\right)}{\left(\overline{LA}_2 - \overline{LA}_1\right)}$$

3. RLGR

- As leaf is the plant organ (machinery) determining most plant biomass, the formation of leaves is highly important in the growth of plants.
- Plants producing more leaves would grow faster than those producing less leaves.
- Therefore, relative leaf growth rate (RLGR, R_L) is interesting to apply in the analysis of plant growth that can be used for plants growing individually and in a community. .
- The equation of RLGR, similar to RGR, is as follows;

$$R_L = \frac{\partial LA}{\partial t} \frac{1}{LA}$$

- If R_L is assumed constant over the period under study, the integration of the above equation results in the following equation.

$$LA_t = LA_0 e^{R_L T}$$

or

$$\ln LA_t = \ln LA_0 + R_L T$$

- The above equation applies to plants with leaf area increasing exponentially.
- If the growth of leaf area with time is not exponential, but quadratic for instance then

$$LA = a + bT + cT^2 \quad \text{and} \quad R_L = \frac{b + 2cT}{a + bT + cT^2}$$

4. RLGR AND RGR RELATION

- The relationship between R_L and RGR (R) is interesting to evaluate as this can offer information as to the strategi of plants in the utilization of plant capital (carbohydrate, biomass) to be invested in the productive parts of plants.
- If RL is constant over a certain period, often occuring during the initial phase of plant growth especially in the controlled environments, attention to the further step is focused on R during the period under study.
- In general, however, R is also constant when R_L is constant. In such conditions, the ratio of the two indices expressed as "N" in the following equation is interesting to see.

$$W = h + kLA^N$$

- Because if

$$R_L = \frac{\partial LA}{\partial t}\frac{1}{LA} \rightarrow LA_t = LA_0 e^{R_L T}$$

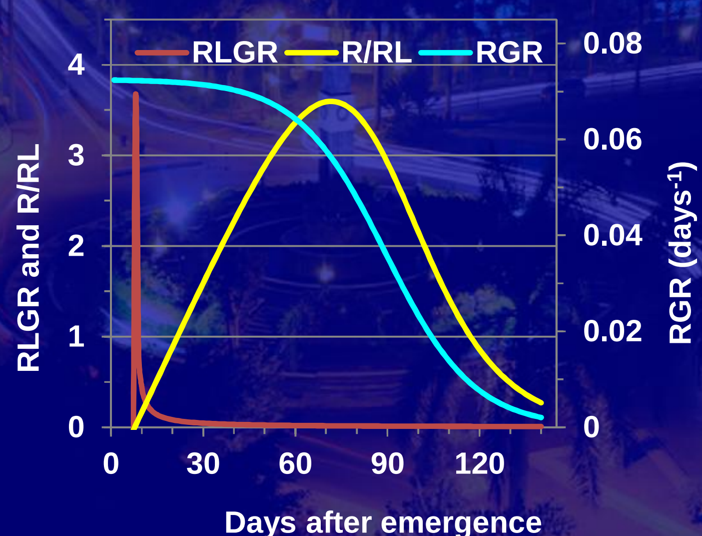
$$e^{R_L T} = \frac{LA_t}{LA_0} \rightarrow e^T = \left(\frac{LA_t}{LA_0}\right)^{1/R_L}$$

- From the previous discussion, it is known that

$$R = \frac{\partial W}{\partial t}\frac{1}{W} \rightarrow W_t = W_0 e^{RT}$$

- The substitution of eT from the previous equation into the above equation results in

$$W_t = W_0\left(\frac{LA_t}{LA_0}\right)^{R/R_L} \rightarrow N = R/R_L$$



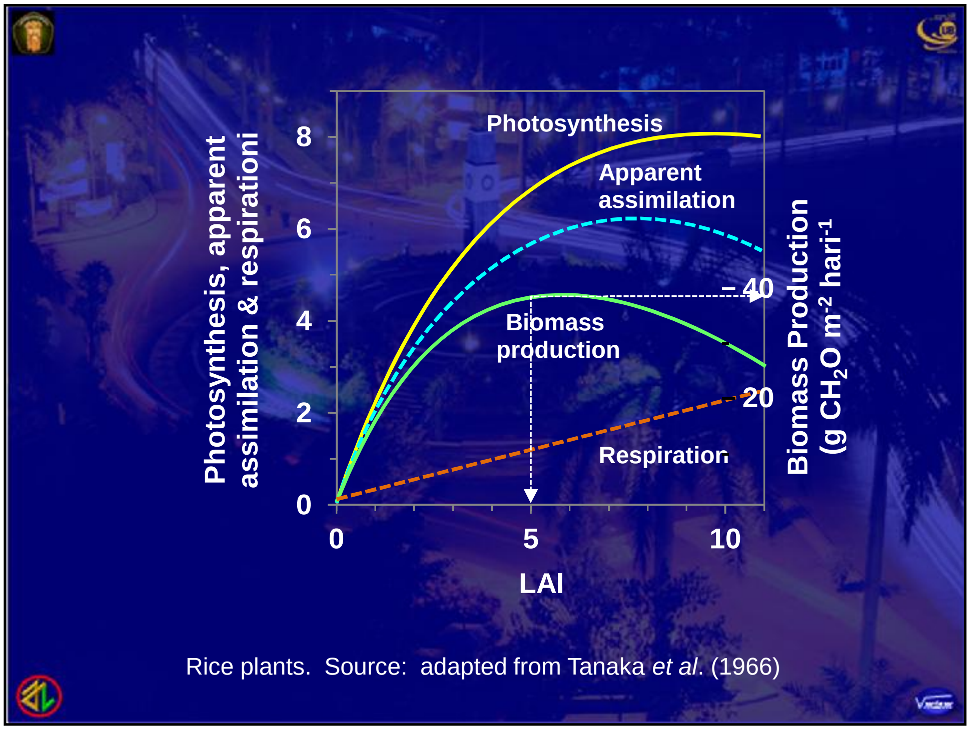
Rye plants (*Secale cereale L.).* Source: Estimated based on data from Pedó *et al*. (2015)

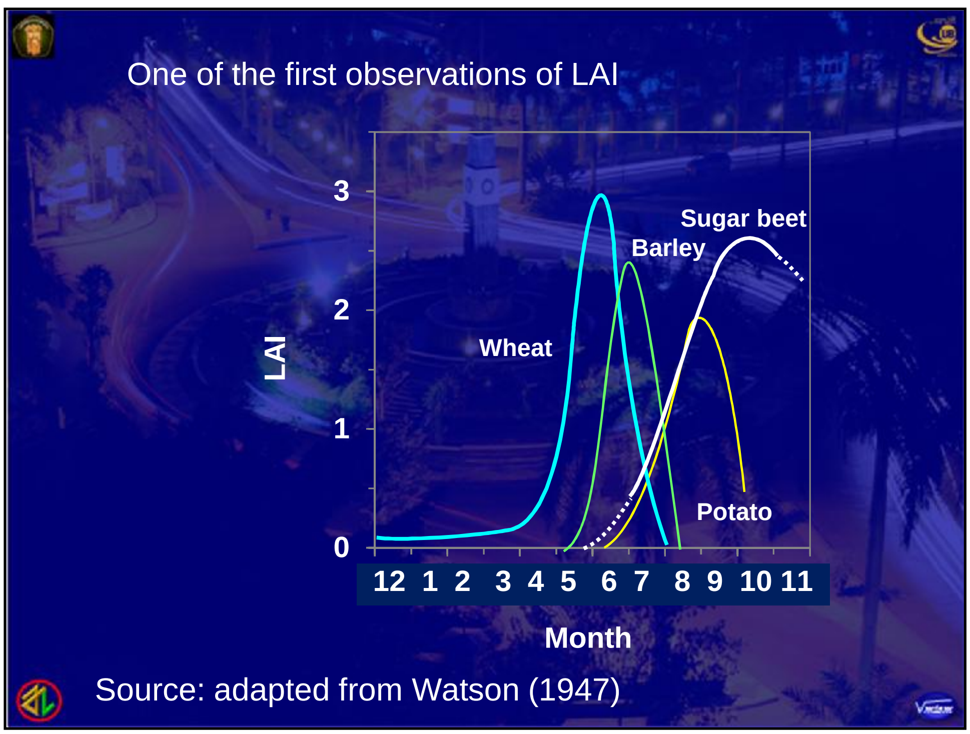
5. LAI

- NAR of plant community is not only determined by leaf characteristics and plant morphology, associated with light distribution, but also leaf density.
- Therefore, LA and LAR are not sufficient to elucidate a difference in NAR between plant communities.
- Leaf density is closely related to plany population or plants spacing. An increase in the leaf density will reduce the quantity of light intercepted by leaves on the lower layers of canopy.
- Watson (1947) introduced LAI (leaf area index) defined as "leaf area (LA, L) per unit area of land (A)“ as follows.

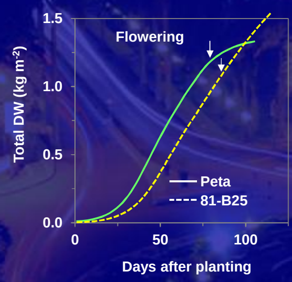
$$\mathrm{LAI} = \frac{\mathrm{L}}{\mathrm{A}}$$

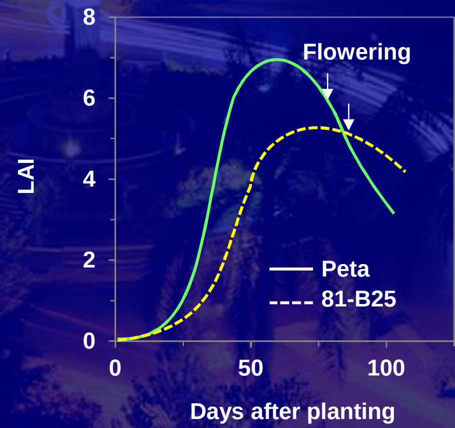
- Optimal LAI is defines as the level of LAI producing the highest biomass and estimated to be around 5 (Oldeman & Frere, 1982).
- This optimal LAI can be explained schematically, based on research results, with the effect of LAI on photosyn-thesis or CER (CO_2 exchange rate), apparent assimi-lation and respiration.
- The rate of CER increases as light quanta increases particularly at certain stages.
- The rate of CER, apparent assimilation and biomass production increase as LAI increases up to around 5, and the last two parameters decline with LAI>5.
- The rate of respiration increases continuously with an increase in LAI that elucidates the decrease in biomass production as LAI>5.


Photosynthesis, apparent assimilation & respirationi
8
6
4
2
0
Photosynthesis
Apparent assimilation
Biomass production
Respiration
40
20
Biomass Production (g CH_2O m^{-2} hari^{-1}
0
5
10
LAI
Rice plants. Source: adapted from Tanaka *et al.* (1966)


One of the first observations of LAI
LAI
3
2
1
0
Sugar beet
Barley
Wheat
Potato
12 1 2 3 4 5 6 7 8 9 10 11
Month
Source: adapted from Watson (1947)

Rice plants





Source: Adapted from Tanaka *et al*. (1966)

6. LAD

- Leaf area duration (LAD), proposed for the first time by Watson (1947), is an index of plant growth integrated leaf area (LA) active in photosynthesis over a period under consideration.
- Watson stated this index as "*a measure of the ability of the plant to produce and maintain leaf area, and hence of its whole opportunity for assimilation*' (Evans, 1972).
- The equation used to calculate leaf area duration is as follows.

$$\mathbf{LAD} = \frac{(\mathbf{L}_2 - \mathbf{L}_1)}{2}(\mathbf{T}_2 - \mathbf{T}_1)$$

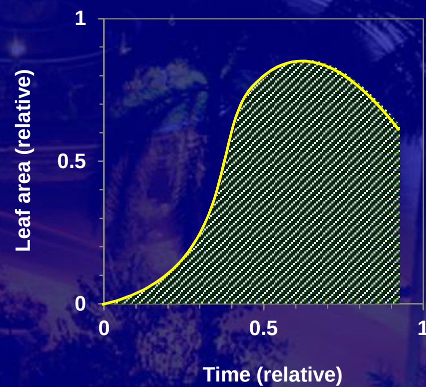
where L_2 and L_1 is LA at time T_1 and T_2 respectively

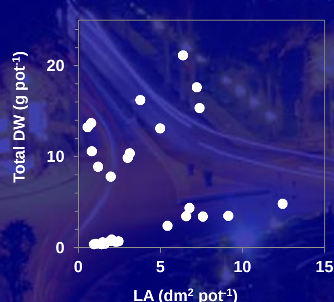
- If leaf area of plants is meaured several times during plant growth, and the development of leaf area with time can be mimiced by a particular model, then LAD is the integration of leaf area over a period under study.

$$\mathbf{LAD} = \int_{t_1}^{t_2} \mathbf{L}.\partial \mathbf{t} = \int_{t_1}^{t_2} \mathbf{LAI}.\partial \mathbf{t}$$

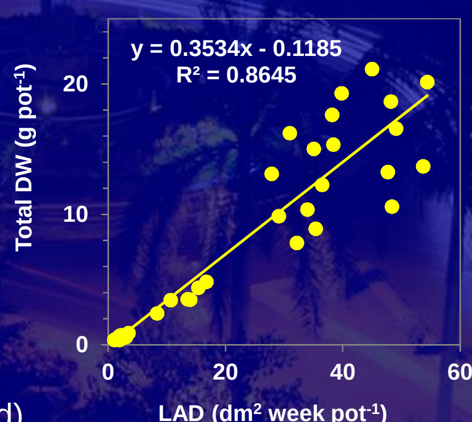
$$\mathbf{LAD} = \overline{\mathbf{L}} \int_{t_1}^{t_2} \partial \mathbf{t}$$

$$\mathbf{LAD} = \overline{\mathbf{L}}\left(\mathbf{T}_2 - \mathbf{T}_1\right)$$

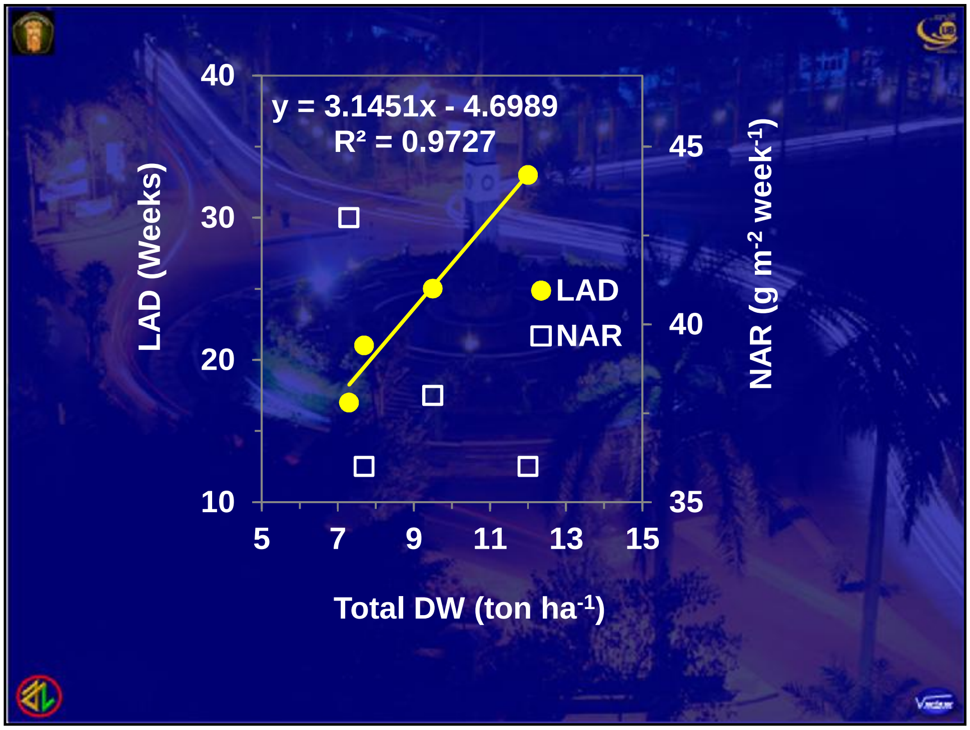




Soybean



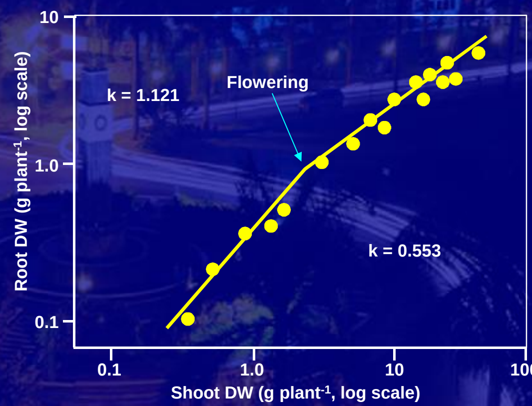
Source:
Sitompul (unpublished)



7. ROOT/SHOOT RATIO

- Roots, stems and leaves are functionally interdependent, and maintain a dynamic balance in biomass reflecting relative abundance of above-ground resources (light and CO_2) compared with root-zone resources (H_2O and nutrients) (Poorter *et al*. 2012).
- Whole-plant growth rate and summary measures such as root:shoot ratio are thus an outcome of developmental stage and of environmental influences.
- Change in root:shoot ratio during a plant's life cycle is part of an intrinsic ontogeny, but growth rates of roots and shoots continually adjust to resource availability with photoassimilate (hence biomass).

Root:shoot allometry in Italian reygrass (*Lolium multiflorum*) shows an abrupt change with flowering (log-log plot).



A change in allometric coefficient (*k*) for this species from 1.121 to 0.553 indicates a shift in biomass allocation from root growth towards shoot growth following emergence of inflorescences.

Based on Troughton (1956) J Brit Grassland Soc 11, 56-65

- In herbaceous plants, root:shoot ratios typically decrease with age (size) due to sustained investment of carbon in above-ground structures (root crops would be a notable exception).
- Developmental morphology is inherent, but expression of a given genotype will vary in response to growing conditions (hence phenotypic plasticity).
- Root:shoot ratios are thus indicative of plant response to growing conditions, but ratios are not a definitive measure because values change as plants grow.
- Trees in a plantation forest would show a progressive reduction in root:shoot ratio, and especially after canopy closure where a steady increase in stem biomass contrasts with biomass turnover of canopy and roots and thus predominates in determining root:shoot ratio.

8. SURPLUS BIOMASS

- The question of the growth of plants in term of the reproduction of identical units of form, which they call ”photosynthetic entities”.
- Whitehead and Myerscough (1962) introduced the notion of ”surplus production of dry weight”, over and above that used up in maintaining the proportion of the plants as a ”photosynthetic entities”..
- They pointed out that ’this ”surplus” dry weight is what is required to produce flowers, fruits, organs of vegetative reproduction and perennation, etc’.
- If the mean total plant dry weights at successive harvests are W_1, W_2, ..., W_x; and the corresponding leaf areas are LA_1, LA_2, ..., LA_x, they then computed α (equivalent to N), at the time of the xth harvest as

$$\mathbf{N_x = \frac{\overline{R}_x}{R_{L,x}}}$$

or

$$\mathbf{N_x = \frac{\ln W_x - \ln W_1}{\ln LA_x - \ln LA_1}}$$

where R_L is the relative growth (expansion) rate of leaf area, and R is the relative growth rate.

- The equation for the ”surplus” weight (**S**) proposed was

$$\mathbf{S = (N - 1)W}$$

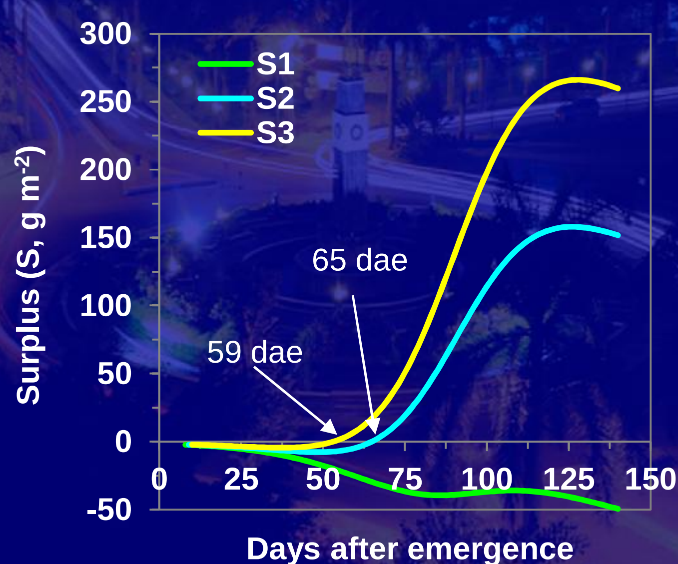
and at the xth harvest

$$\mathbf{S_x = (N_x - 1)W_x}$$

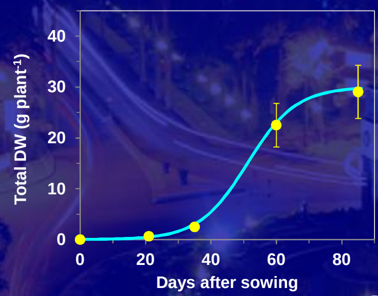
- The substitution of Nx from the previous equation into the above equation results in.

$$S_x = \left[\frac{\ln(W_x/W_1)}{\ln(LA_x/LA_1)} - 1\right] W_x$$

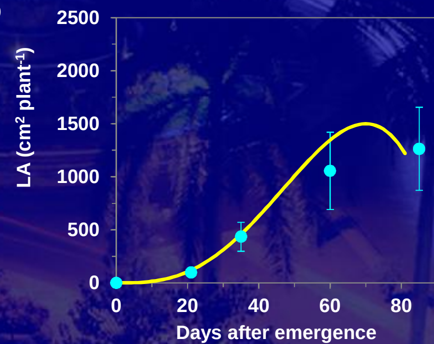
- It should be kept in mind that the equation applies after the formation of first fully expanded leaves.
- From the standpoint of calculation, the choice of time ”1” determines when plants to start flowering and the quantity of surplus biomass.
- However, it is clear on the basis of field evidence that plants producing excessive leaves cause retardation of reproductive development.
- Further detail research is required to study several aspects of the surplus biomass including the choice of time ”1” in relation to time of flowering and the relation between cumulative surlus biomass and yield.



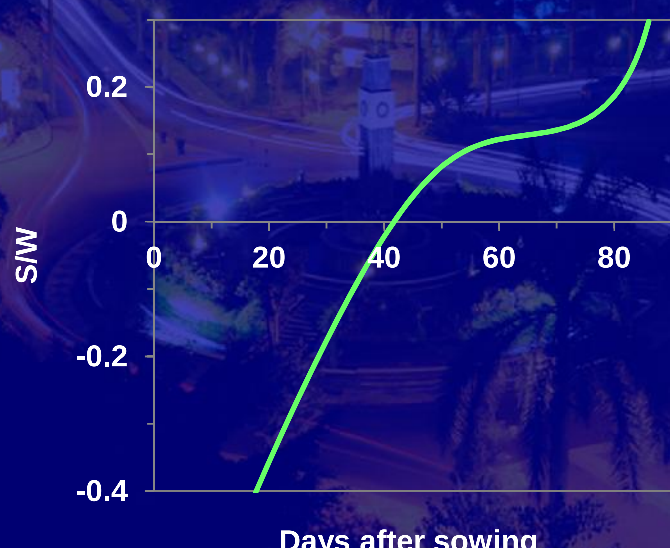
Rye plants (*Secale cereale L.).* Source: Estimated based on data from Pedó *et al*. (2015)



If the growth of soybean plants in total DW and LA follows the present patterns, how is Surplus biomass.



Soybean: Sitompul (*unpublished*)



WHAT HAVE YOU GOT?

1. What is the simplest index that can be used in the analysis of crop growth?
2. What is the result of NAR x LAI?
3. When should the ‘ln’ transformation of data be done in the case of RGR and NAR analysis?
4. What is the meaning of relative leaf growth rate (RLGR)?
5. How is the ontogenetic drift of R/R_L in Rye plants?
6. What is leaf area index (LAI)?
7. What is the meaning of LAD?
8. What is Root/Shoot ratio describe?
9. How is the relationship between W and LA compared to W as a function of LAD?
10. What is surplus biomass?