HORT 604
Applied Physiology of Horticultural Crops

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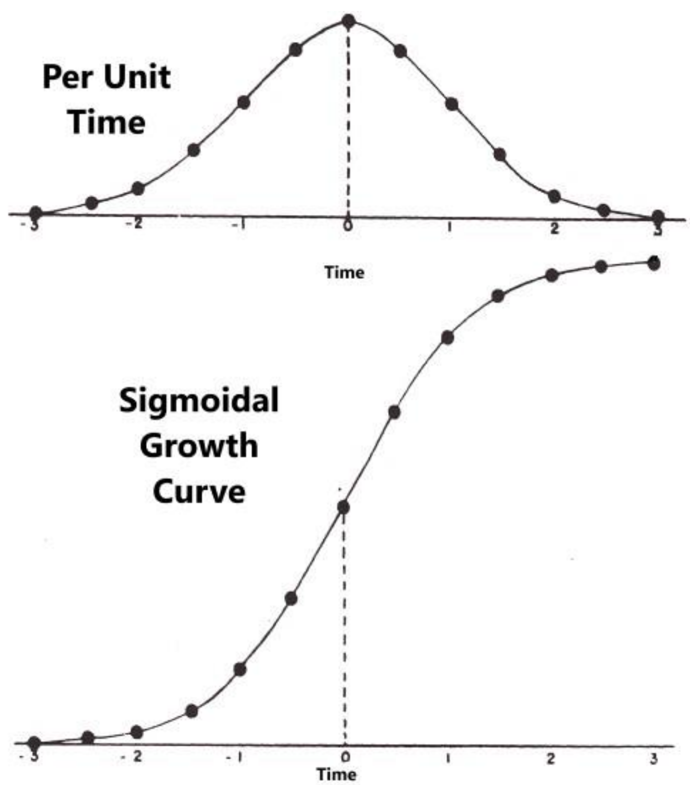
GROWTH KINETICS

AND

QUANTITATIVE MEASUREMENTS OF GROWTH



REFERENCES

Growth Kinetics
and
Quantitative Measurements of Growth

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GROWTH KINETICS

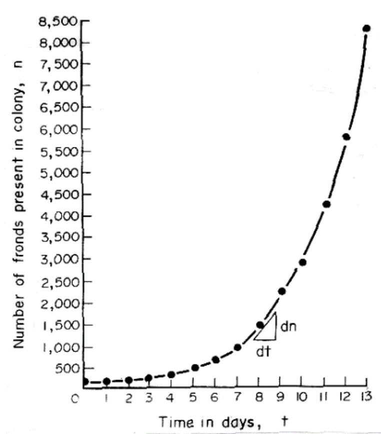
What is Growth - an irreversible increase in size, amount, mass or number.

GROWTH

Some growth exhibit a logarithmic or exponential increase. The size, mass or number increases by a constant, similar to simple compound interest. The principal (current size, mass or number) times the interest rate (growth rate) yields the interest (growth increase for that day). The interest is added to the principal, to yield a new principal. The new principal times the interest rate yields and even higher interest for the next day, which again is added back to the principal. So growth occurs at a compounded rate (logarithmic or exponential growth).

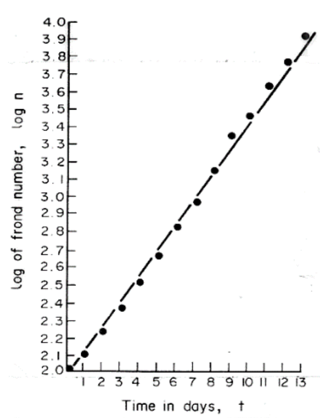
Absolute Growth Rate (AGR)

If you plot growth (size, mass or number) versus time, a constantly increasing growth curve is obtained. If you calculate the slope between any two times, you get the **absolute growth rate,** which is the change in actual growth over time. You get a different slope, hence different AGR for each pair of times chosen to calculate the slope. (Fig. 2.23A, Wareing and Philips 1981)



Relative Growth Rate (RGR)

If you plot the logarithm of growth (size, mass or number) versus time, a linear line is obtained. If you calculate the slope of the line, you get the **relative growth rate**, which is the change in relative growth over time. Since the line is linear, you get the same RGR, regardless of which time interval chosen to calculate the slope. (Fig. 2.23A, Wareing and Philips 1981).



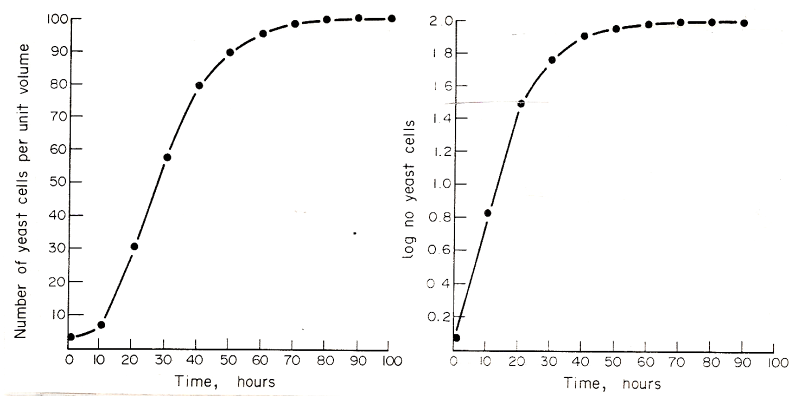
Growth with no Limitations

If there is no limitation growth, such as a guaranteed fixed rate of growth of a investment account, then growth will continue at this rate forever. That is why you should start saving money very early so you will have enough to retire much later!

SIGMOIDAL GROWTH

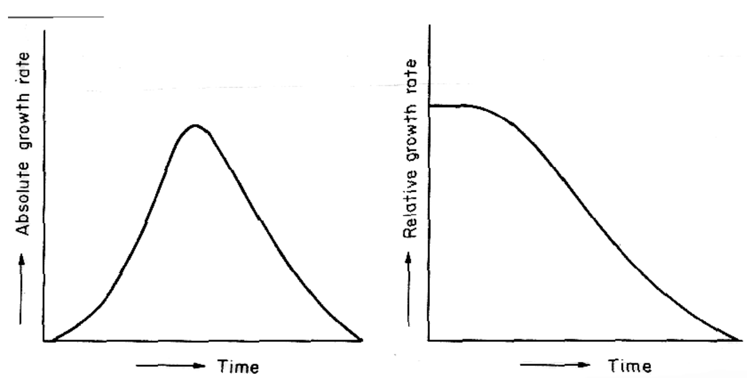
Growth of Biological Systems

Exponential growth can never be sustained indefinitely. Eventually, substrates are depleted, the population exceeds the area available, tissues or individuals begin to age or die, etc., which decreases the growth rate. Growth may still increase, but at a reduced rate (ex. if crowding causes shading), it may reach a steady state (everything is in equilibrium, for example in a population), or growth may begin to decrease (ex. due to death or senescence of individuals or plant parts). If you plot long term growth of plants, animals, population, etc. versus time you get the classical **sigmoidal growth curve**. If you plot the logarithm of the sigmoidal growth curve, you get a linear line during the exponential phase, after which the curve decreases over time. (Fig. 2.24, Wareing and Philips 1981)

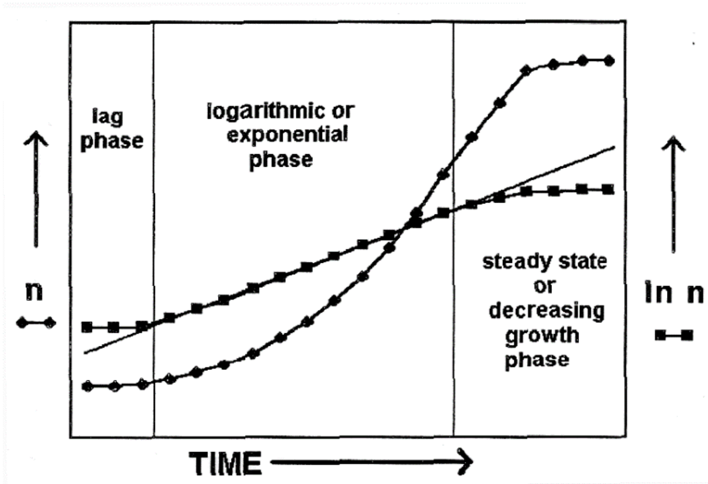


Changes In Growth Rates Over Time

If you calculate the absolute growth rate (AGR) over increments of time, then plot AGR versus the time interval, you get a bell-shaped curve, i.e. the AGR changes constantly with time. If you calculate the relative growth rate (RGR) over increments of time, then plot RGR versus the time interval, you get a straight-line region during the logarithmic phase followed by a decreasing RGR. The RGR is constant during the logarithmic phase. (Fig. 2.27, Wareing and Philips 1981).



MATHEMATICAL MODELS OF GROWTH



Exponential Model

$n = n_o e^{kt}$

Linear Model – Used During Logarithmic or Exponential Phase

$\ln n = \ln n_o + (\text{slope})\ (\text{time})$

where n = number, size (height, leaf area), or mass (dry weight, fresh weight) at any time > 0.
n_o = number, size (height, leaf area,), or mass (dry weight, fresh weight) at time = 0.
slope = rate of growth

Or more commonly expressed as a regression or slope equation

$y = a + bx$

$y = \text{intercept} + (\text{slope})\ (x)$

Absolute Growth Rate (AGR)

$$AGR = \frac{dn}{dt}$$

$$= \frac{n_2 - n_1}{t_2 - t_1}$$ yields average slope over that time interval

Relative Growth Rate (RGR)

$$RGR = \frac{dn}{dt} \bullet \frac{1}{n}$$

$$= \frac{\ln n_2 - \ln n_1}{t_2 - t_1}$$ yields constant slope during logarithmic phase

QUANTITATIVE MEASUREMENTS OF GROWTH

Leaf Area Ratio (LAR)

- LAR is an indication of the efficiency of a given leaf area to produce a given plant size; e,g, the amount of leaf area per unit weight.
- A plant with a low LAR is more efficient, e.g. it takes less leaf area to produce the weight or yield of the crop.

a) over life of crop

$$LAR = \frac{\text{final leaf area}}{\text{final plant dry weight}} = \frac{LA}{W}$$

b) over any time interval

$$LAR = \frac{\text{leaf area}_2 - \text{leaf area}_1}{\text{plant dry weight}_2 - \text{plant dry weight}_1} = \frac{LA_2 - LA_1}{W_2 - W_1}$$

; units = $cm^2\ g^{-1}$ or cm^2/g

Net Assimilation Rate (NAR)

- NAR measures the accumulation of plant dry weight per unit leaf area per unit time.
- It is a measure of overall efficiency of production for a given time.

$$NAR = \frac{RGR}{LAR} = \frac{1}{LAR} \bullet RGR$$

$$= \frac{1}{\frac{LA_2 - LA_1}{W_2 - W_1}} \bullet \frac{\ln W_2 - \ln W_1}{t_2 - t_1}$$

$$= \frac{W_2 - W_1}{LA_2 - LA_1} \bullet \frac{\ln W_2 - \ln W_1}{t_2 - t_1}$$

; units = $g\ cm^{-2}\ day^{-1}$ or $g/cm^2/day$

Leaf Area Index (LAI)

- Measures the fraction of crop cover, e,g, the amount of leaf area per unit soil area.
- LAI is near 0 at planting, and is usually 2-3 at full canopy coverage. In other words at full canopy there is 2 to 3 times more leaf area that soil area.

$$LAI = \frac{\text{leaf area}}{\text{soil area}} = \frac{LA}{A}$$

; units = $cm^2_{leaf}\ cm^{-2}_{soil}$ or cm^2_{leaf}/cm^2_{soil}

Crop Growth Rate (CGR)

- CGR measures the efficiency of production of a total field of plants over a given soil area.

$CGR = NAR \bullet LAI$; units = $g\ cm^{-2}_{soil}\ day^{-1}$ or $g/cm^2_{soil}/day$

APPLICATION OF QUANTITATIVE MEASUREMENTS OF GROWTH

Efficiency of Different Species of Plants

The following table gives the net assimilation rates (NAR) of various species. The higher the NAR the more efficient the species, which usually translates into higher growth rates. (from Table 3.10, Larcher 1980)

	Net Assimilation Rate (mg dry matter per dm^2 leaf area per day)	
Plant Type	**Average Over Growing Season**	**During Main Growth Phase**
C4 Grasses	>200	400-800
Herbaceous C3 Plants		
Grasses	50-150	70-200
Dicots	50-100	100-600
Woody Dicots		
Topical and Sub-Tropical	10-20	30-50
Deciduous Temperate Trees	10-15	30-100
Conifers	3-10	10-50
Ericaceous Shrubs	5-10	15
CAM Plants	2-4	10

Efficiency of Sun versus Shade Plants

The following table gives the net assimilation rates (NAR), leaf area ratio (LAR), and relative growth rate (RGR) of shade versus sun plants at both high and low light intensities. (from Table 3.1, Leopold and Kreidmann1975).

Note: At low light intensities, the sun plant has 6-fold decrease in NAR and tries to compensate by increasing its LAR (i.e. produces about 2-fold more and/or larger leaves), but the RGR still decreases dramatically. At low light intensities, NAR of the shade plant only decreases 3-fold, and increases its LAR 2.4 fold, both of which help maintain a higher RGR; in other words the shade plants have adapted themselves to the lower light intensity.

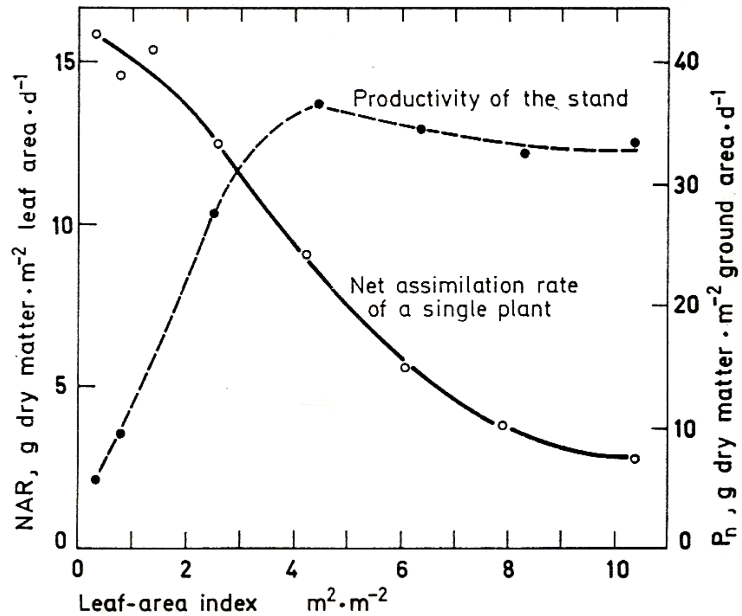
	NAR		**LAR**	**RGR**	
% Daylight	**mg/cm^2/ wk**	**%**	**cm^2/g**	**g/g wk**	**%**
Sun Plant - Sunflower					
100%	8.0	100	82	0.66	100
24%	2.9	36	140	0.42	64
12%	1.3	17	170	0.23	35
Shade Plant - Impatiens					
100%	6.1	100	132	0.80	100
24%	3.3	54	239	0.78	98
12%	2.0	33	315	0.63	79

APPLICATION OF QUANTITATIVE MEASUREMENTS OF GROWTH - con't

Effect of Leaf Area Index (LAI) on Net Assimilation Rate (NAR) and Crop Growth Rate (CGR)

Note that as the LAI increases (due to greater canopy coverage of soil), the NAR (productivity of each plant) decreases (probably due to increased plant-plant shading), but the CGR (productivity of the entire crop over a given area of soil) increases. Thus, the best LAI is somewhere around 4. (from Fig. 3.64, Larcher 1980)

Fig. 3.64. Relationship between the net assimilation rate of maize plants and the production rate of stands of maize (crop growth rate) as a function of leaf-area index. After W. A. Williams et al. (1965)



Use of Quantitative Growth Measurements to Explain Other Growth Phenomena

Increasing ambient carbon dioxide increases photosynthesis, which in turn increases growth. In tomato and bean, increasing carbon dioxide increases both total plant growth, as measured by increased RGR, and the efficiency of growth, as measured by increased NAR. This increased growth efficiency allows the plant to have a smaller shoot system (decreased LAR), which is the source, while still enhancing the size of the root system (see increased root/shoot ratio), which is a sink (from Table 3-2, Leopold and Kriedemann 1975).

	Tomato		**Bean**	
	300 ppm CO_2	**1,000 ppm CO_2**	**300 ppm CO_2**	**1,000 ppm CO_2**
RGR (mg g^{-1} d^{-1})	222	254	122	172
NAR (mg dm^{-2} d^{-1})	71	89	46	80
LAR (dm^2 g^{-1})	3.0	2.8	3.2	2.7
root/shoot ratio	0.19	0.21	0.18	0.25