**Growth and Development of Crops PCP 504**

**Prerequisites:** Students are expected to have a basic understanding of Plant Physiology PCP 101, PCP 191, biochemistry, Botany, Principles of Crop Production and Basic Principles of System dynamics

**LECTURE 1: Growth Analysis and parameters**

**Learning Objectives:**

1. **The interrelationship between Growth, Development and Yield**

2. **Defining the concept of growth, development and yield**

3. **Different dimensions of yield**

4. **Approaches to growth analysis; classical and functional, comparative analysis**

5. **Growth parameters and analysis**

6. **Merits and demerits of growth analysis**

7. **Environmental factors affecting yield, most especially limiting abiotic stressors (Irradiation, water and nutrients)**

The concept of yield in crop plant is varied, depending on the perspective upon which the author draws his definition. Functionally there are yield potential and potential yield. Yield potential refers to the yield of cultivars grown in an environment in which it is adapted, when water and nutrient are non- limiting and other biotic and abiotic growth factors are controlled. The environment here is both spatial and temporal. Potential yield refers to the maximum yield of a crop in a particular environment. The first definition is mostly employed by the breeders, assuming that there are genes controlling yield only, while the second one is agronomic presupposing that there are genes responsible for the control of stress factors. Yield potential is used for comparing cultivars, while potential yield is for comparing different crops in different locations at different times. Potential yield are varied, such as experimental station, on-farm trial, average or actual and record or wining yield. The assumption behind this conceptual approach is flawed, since genes control traits but they are modulated by the environment, nevertheless, such definitions are encountered in the literature.

Physiologically, it is the ultimate system output of a biological system, the mass of a product or the accumulation of a dry matter at final harvest. Conceptually, it could be divided into biological and economic yield.

The economic yield of the crop plant is constrained by environmental and genetic factors. The environmental factors are abiotic and biotic in nature. The importance of abiotic factor is highlighted from the pre-eminence the crop plant gives in his adaptive response to abiotic factor first before biotic. The abiotic factors that determines yields are; the amount of intercepted radiation, water, nutrient and physiological constraints to crop performance.

In case irradiance is the limiting factor to yield, crop performance could be expressed as a spatio-temporal integration of biological process, which is the product of the total amount of radiant energy (**Q, MJ m-$^{2}$**), the absorptance of incident solar radiation by the crop canopy (**$I_A$, %**), radiation use efficiency or the efficiency of the conversion of the incident radiation into dry matter (**ϵ, g of dry matter MJ$^{-1}$**), partitioning efficiency (**ρ**) and the time duration **dt**

$$Y_E = \int_{tp}^{th} Q \times I_A \times \epsilon \times \rho dt$$

**Or**

$$Y_E = \int_{tp}^{th} PAR \times I_A \times \epsilon \times \rho dt$$

Since only the visible spectrum of light is the only one of physiological value in dry matter accumulation.

**Where:**

tp: Time of planting

th: Time of harvesting

Q: Incident Solar radiation

$I_A$: Absorbed radiation, as a proportion of the incident solar radiation

ϵ: Radiation Use efficiency

ρ: Partitioning efficiency

dt: Phenology or the crop life cycle

PAR: Photosynthetic Active Radiation

The spatial aspect of the process connotes the duration of the plant life cycle. Alternatively the economic yield could be defined as:

$$Y_E = Y_B \times HI$$

Where:

$Y_B$ = Biological yield

HI = Harvest Index

Biological yield is the total amount of the dry matter accumulated during the life cycle of the plant. It is mainly the above dry matter accumulated per day, the exception to these are crops whose economically important part are below the ground like Sweet Potato, Yam, Sugar Beet, etc.

$$Y_B = \Sigma\,[Q(t) \times I_A(t) \times \epsilon(t)]$$

The first part of the equation refers to the solar radiation. The ultimate source of light to plant and all living system is from the sun. Solar radiation affects the plant in the following ways:

1. Photosynthesis
2. Photomorphogenesis
3. Rate of metabolic reaction
4. Energy exchange process like in transpiration
5. Assimilate partitioning

6. Morphological adaptation

7. Plant-to- plant competition

8. Rate of development

With respect to dry matter accumulation, we shall be limiting ourselves to those aspects of the solar radiation that affects photosynthesis. Solar radiation behaves like an energy and wave. The energy of solar radiation is referred to as photons. Solar radiation energy is related to wave length and speed of light from the following relationship:

**E = AhU / λ**

Where:

A: Avogadro's constant

H: Planks constant

Λ: wavelength

Solar radiation that is affects photosynthesis is in the visible spectrum referred to as light or Photosynthetic Active Radiation (PAR). This spectrum is mostly absorbed by chlorophyll a and b and carotene. The PAR is within the wavelength of **300 - 700µm.** PAR, UV and Infra-Red (IR) all belong to the short wave length within 300 - 3000µm, while from **3000 – 10,000µm** is long wave length of spectral distribution.

The interception of solar irradiance is a function of the Leaf Area Index, the arrangement of the leaf of the stem (phyllotaxy), leaf angle, optical property of the leaf and the spectral distribution of the solar radiation. The intercepted light is subject to absorption, transmission or reflection. Absorption of solar irradiance is by certain biological pigments; chlorophyll a and b and carotenoid. Chlorophyll absorb in the red and orange, violet and blue spectrum of PAR, while carotenoid absorbs in the violet and blue spectrum of light. Absorption of photon by pigment leads to the excitation of the pigment molecules resulting in the loss of excitation energy, thus the molecule returning to the ground state. The energy is lost as heat, heat and fluorescence or through inductive resonance, which is the transfer of energy to the adjacent molecule, which is consequently transferred to the light harvesting complex. Canopy architecture altered thought agro technique like spacing leads to changes in spectral distribution of solar irradiance. At close spacing, there is a preponderance of infra-red radiation compared to PAR. Even within the PAR there is more of far red than red, leading to differential absorptance and reflectance of solar radiation. This alters the morphology and biomass distribution, with the canopy displaying longer and narrower leaf, taller and thinner stem and a reduced leaf to stem ratio. The total absorbed solar radiation is reflected in the following equation:

$$\mathbf{I_A = I_O \times (1-\rho_c)(1 - e^{-kLAI})}$$

Where:

$I_A$ = Absorbed radiation

$I_O$ = Incident radiation

$\rho_c$ = coefficient of reflectance

e = natural logarithm

k = coefficient extinction

LAI = Leaf Area Index

Physiologically with increased valued for coefficient of extinction shows a parallel orientation of the leaf relative to the ground, which is a planophile, while a reduced value reflects an erectophile orientation. The more the value of k, the less will be the fraction of solar irradiance reflected and transmitted per unit area and time, that is the leaf is optically black, which is an unrealistic assumption. In that case, the absorbed solar radiation is 100%, with the above equation modified as

$$\mathbf{I_A = (1 - e^{-kLAI})}$$

The physiological implication of this is that for an optically black leaf, increase in incident radiation, which is totally absorbed, i.e. with increasing photosynthetic photon flux density there is a proportional increase in gross photosynthetic rate of leaf per unit of time, photosynthetic response curve to radiation is asymptotic, increasing with increasing PPFD. For an angled leaf, under constant LAI is a reduction in gross photosynthetic rate. In a canopy, reduction in leaf angle leads to increase in canopy carbon assimilation through increase in sunlit leaf area.

Canopy architecture that affects the carbon assimilation rate or dry matter accumulation are summarised as:

1. Leaf area index
2. Leaf angle
3. Leaf arrangement (phyllotaxy)
4. Leaf size (Area)
5. Canopy height (vertical separation)
6. Optical property of the leaf

An increased leaf size with reduced vertical separation could create flux pattern of dense and sunlight plant. In the case of sunlit canopy there is an increase in gross photosynthetic rate, while shading will reduce gross photosynthesis. Smaller leaf size with taller canopy or more pronounced vertical separation will engender diffuse pattern of radiation flux, thus increasing gross photosynthetic rate.

**Radiation Use Efficiency**

The efficiency of conversion of absorbed solar radiation into plant dry matter is related to the mean leaf net photosynthetic rates across the crop canopy. In growth analysis the mean leaf net photosynthetic rate is called Net Assimilatory Rate (NAR), which is estimated from the rate of dry matter accumulation and mean LAR. Rather than using mean leaf net photosynthesis, which is not very meaningful when part of the canopy is sunlit and part is shaded, we can use the increase in crop dry matter (CGR). Radiation use efficiency (RUE) is estimated empirically fro the crop growth rate during the period of 2 weeks or more and the amount of photosynthetically active radiation intercepted by the crop canopy (RARi) during the period crop growth rate is determined.

**RUE = CGR/PARi**

If the crop yield is expressed as a function of underlying physiological like carbon assimilation and irradiance, then the yield equation conceptually becomes:

$$A_G = A_N - R$$

Changing the subject of the equation, $A_N$ then becomes:

$$A_N = A_G - R$$

If R is further broken down into components part

$$R = R_D + R_P$$

Then:

$$A_N = A_G - (R_D + R_P)$$

Where:

$A_G$ = Gross assimilation of carbon

$A_N$ = Net Assimilation of carbon

R = Respiration

$R_D$ = Dark Respiration

$R_p$ = Photo Respiration

A mathematical expression of the yield equation showing $A_N$ is:

$$A_N = \frac{PPFD.\Phi.\ A_{max}}{PPFD.\Phi + A_{max}} - R_D$$

Where:

PPFD: Photosynthetic Photon Flux Density

Φ: Quantum Yield

$A_{max}$: Net Photosynthesis net of $R_D$

The Photosynthetic response curve to Irradiance is hyperbolic in nature, with different phases. With an initial increase in PPFD there is an exponential raise in carbon assimilation until it reaches a plateau and level off when carbon concentration in the cell becomes limiting, not PPFD.

The gross photosynthetic rate for the canopy is:

$$A_{G\ (canopy)} = A_{G(leaf)} \times LAI_S \qquad \text{eq.1}$$

$$A_G = \frac{PPFD.\Phi.\ A_{max}}{PPFD.\Phi + A_{max}} \qquad \text{eq.2}$$

$$PPFD_i = PPFD_o \times k \qquad \text{eq.3}$$

$$PPFD_a = 1\text{-}e^{-KLAI} \qquad \text{eq.4}$$

$$LAI_s = PPFD_a / K \qquad \text{eq.5}$$

$$K = \text{cosine}\ (\theta) \qquad \text{eq.6}$$

Where:

$PPFD_i$ = PPFD normal to sunlit leaf

$PPFD_0$ = PPFD normal to the ground

Agronomically, the yield of field crops is computed from the so called yield component per unit area.

Where water is the limiting factor, crop performance is expressed as:

$$Y_E = W \times W_{Transp} \times WUE \times HI$$

Where:

W: Amount of available water

$W_{TRANSP}$: Water Transpired

WUE: Water use efficiency

HI: Harvest Index

**WUE: (Pa – Pi)/ 1.6 (VPi – VPa)**

Where:

Pa: Partial Pressure Air

Pi: Partial Pressure Inside

VPi: Vapour Pressure Inside

VPa: Vapour Pressure Air

Total amount of water consists of the available and unavailable water in the soil. The available water in the soil is a function of the texture/structure and the volumetric water content. With soil water potential less than root water potential, the water content in the soil reaches the wilting point at which the water becomes unavailable to the plant. Conversely, with increasing wetting of the soil water, soil water potential increases, becoming more available to the plant. The volumetric water content increases up to a point at which drainage of water against gravity cannot be avoided, the field capacity. The colloidal contents of the soil predispose the water to be adhered to it, thus making water available to plants. Interrelationship between soil, plant and the atmosphere is expressed conceptually via Soil-Plant-Atmosphere Continuum.

Physiologically, water use efficiency is the ratio between assimilation of carbon and transpiration. Factors responsible for increasing water use efficiency could be deduced from the equation above; decreasing partial pressure of carbon dioxide inside the cell will increase the partial pressure gradient between the leaf plant and the atmosphere, increasing carbon assimilation, assuming carbon assimilatory capacity is non-limiting in the plant. Another option is to increase the vapour pressure in the atmosphere, by increasing ambient temperature. This will minimize transpiration flux from the plant since in most cases the vapour pressure in the plant is more than that of the ambient atmosphere.

Increasing stomatal conductance linearly increases transpiration but response of carbon assimilation is curvilinear. Initially, carbon assimilation responds linearly, when carbon concentration is no more limiting the curve reaches a plateau.

Transpiration is constrained physically and physiologically. The physical forces at play in evaporation is expressed in the Ficks equation

$$E = \frac{\Delta c \cdot D}{\Delta x}$$

Where:

$\Delta c$: Changes in concentration

$\Delta x$: Changes in distance

D: Diffusion coefficient

Concentration of gases is better expressed as partial pressure, while the between gases is quite difficult to express, the whole equation is better expressed as changed in partial pressure of gases, while the distance and diffusion coefficient is both expressed as diffusion coefficient (g). Physiologically, evaporation is regulated by stomatal aperture, which is equally dependent on certain environmental factors. Light affects photosynthesis, which leads to reduction in partial pressure of carbon dioxide inside the cell, leading to negative feedback loop for the opening of the stomata. Increase temperature affects rate of photosynthesis, displaying the aforementioned reaction. Alternatively, with an increase in temperature the rate of transpiration increases, reducing leaf water potential and turgor, eventually resulting in stomatal closure. Reduced soil water potential equally result in reduction in leaf water potential, increasing formation of ABA and the eventual closure of stomata.

In case Nutrient is the limiting factor, crop performance could be expressed as the function of nutrient through the following equation:

$$\mathbf{Y_E = N \times N_{UPTAKE} \times NUE \times HI}$$

Where:

N: Available nutrient

$N_{UPTAKE}$: Nutrient Uptake

NUE: Nutrient Use Efficiency

In case crop performance is limited by physiological constraints, this could be expressed through yield components.

**Yield components**

In an effort to more carefully evaluate the several factors contributing to the final yield of a crop and especially of crop harvested for seed, agronomist have developed the concept of yield components. The final grain yield is usually considered to be the product of the following equation:

**Yield hectare$^{-1}$(kg/ha) = yield plant$^{-1}$ x plant density**

**Yield plant$^{-1}$ or yield components = Head plant$^{-1}$ x Seed head$^{-1}$ x weight of seed (g)**

**Plant density = 10000m$^2$/spacing**

Yield component is another method for agronomy to analyse the performance of crops and it refers to factors that actually determine the yield of crop plants.

**Below are yield components of other field crops.**

| **Oats** | **Sorghum** | **Soybeans** | **Corn** |
|---|---|---|---|
| Head/plant | Heads/plant | Pods/plant | Ears/plant |
| Seed/head | Seed/head | Seeds/pod | Kernel/ear |
| Weight/seed | Weight/seed | Weight/seed | Weight/kernel |

**Principles of yield maximization in agronomic crop**

1. Principle of simultaneous and compensatory optimization among penultimate yield components

2. Principle of constant system capacity. Evolving from the above principle two high highlighting stability of system arising from the compensatory relationship among yield components

3. Principle of adaptive balance between growing season duration and days to harvest maturity. The kernel of this principle is to ensure that the crop maximally utilise available resources during the growing season. Duration of the growing season is a function of moisture, temperature and photoperiod

4. Principle of autocatalytic relationship among basic physiological process of yield, i.e growth, development and partitioning

5. Principle of genotype directed and environmentally modulated establishment of autocatalytic growth of basic physiological process

6. Principle of variability of correlation between penultimate system output and yield components for different growing season

**System approach to Yield Analysis**

The conceptual framework for yield analysis is premised on systems perspective. Underlying yield as the ultimate system output are other components that are interrelated and interconnected.

The components of the system are:

1. Penultimate components

a. Biomass accumulation

b. Days to Harvest Maturity

c. Harvest Index

2. Antepenultimate components

a. Net Rate of Biomass accumulation

b. Days to flowering

c. Duration of actual accrual of yield

d. Rate of partitioning

i. Yield $day^{-1}$ to maturity

ii. Yield $day^{-1}$ of seed fill

Please find below interrelationships and interconnections among the yield components.

A look at the pictorial representation of yield system reveals the following

1. Interrelationships and interconnectedness

2. Underlying the yield components are physiological; growth, development and partitioning

3. The effect of environmental and genetic factors on the yield components

4. Presence of trade-off among the yield components via reciprocal relationships

Basic assumptions:

1. The presence of limited environmental resources available to plants for their basic functions.

2. Presence of simultaneous and competitive sharing system's capacity

3. System capacity = Intraplant metabolite and time of gene expression

The inference from the above assumption is that in the presence of limited environmental resources modulated by genetic factors, there is

1. Constancy of system's capacity in the form of intraplant metabolite and time if gene expression.

2. Simultaneous and competitive sharing of system capacity for adaptation, yield and maturity, resulting in compensatory trade-off among systems components towards maintaining functional equilibrium.

3. Correlation among quantitatively variable traits is dependent on all other traits and the environment

4. Multiple gene modulation of physiological process

5. Interrelationship among biochemical pathway

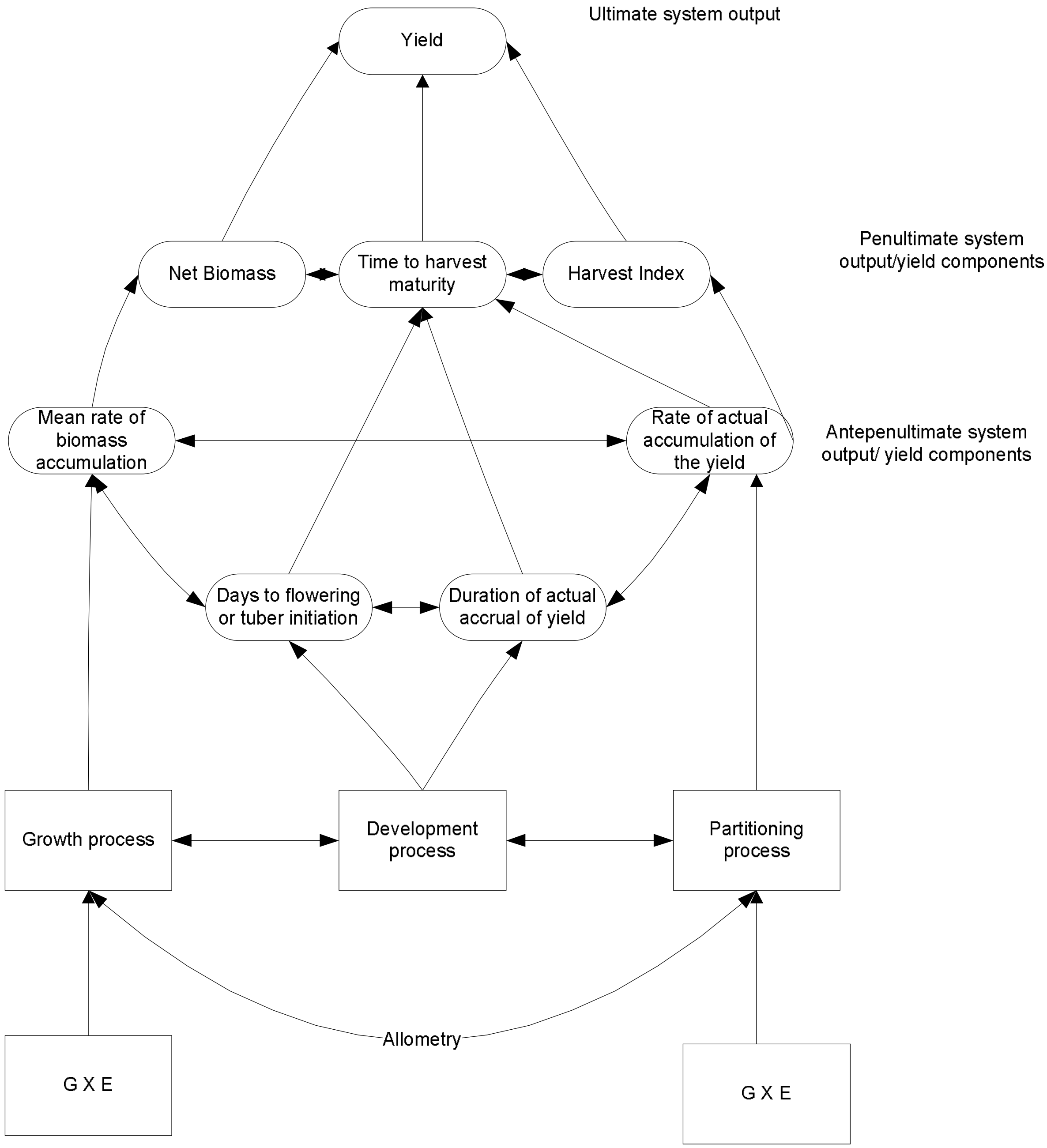
6. Relationship between the yield and other components is curvilinear

7. Other system components are

a. Maturity: Days to harvest maturity, days to flowering, duration of actual accumulation of yield

b. Adaptation: Resistance to pest and diseases, competitive capability

c. Yield: Yield components and yield quality




Limited resources   Limited intraplant metabolites   compensatory trade-off CC

Enlarge environment   Optimize components   Genetics

Where:

CC – Constant Capacity

Underlying physiological processes are growth, development and Partitioning.

Crop yield per Area = Yield per plant and Crop density

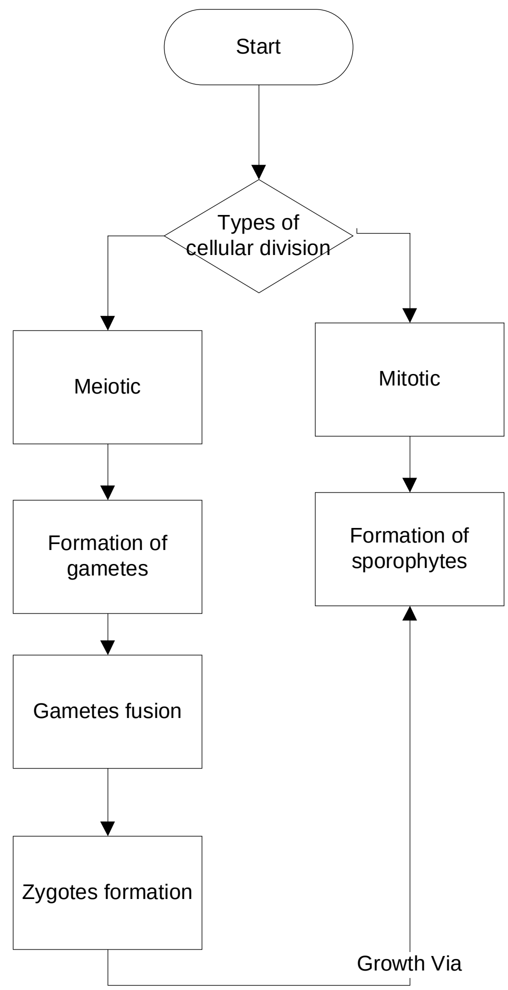
Yield per plant = Yield components

Yield components = heads per plant x seeds per head

Crop density per hectare = 10,000$m^2$/ spacing

**Growth:** Is a quantitative change in living systems. Growth has a cellular basis, involving cell division, elongation and differentiation.

**Flow chart of cell division process**




**Comparative analysis of cellular division**

| Cellular division types | Parameters for comparison | | | |
|---|---|---|---|---|
| | Chromosome | Division type | Effect on heredity | Parental type |

| | | | | |
|---|---|---|---|---|
| | **numbers** | | | |
| Meiotic | Haploid | Reductive | Genetic variation | Bi-parental |
| Mitotic | Diploid | Multiplicative | Conservation of heredity | Mono-parental |

**Cellular elongation Kinematics**

Expansin + protein extrusion acidification of cell membrane loosing of cell well (Stress relaxation) water uptake formation of turgor pressure irreversible stretching of cell wall (yielding) increase in cell volume via increase in volume of vacuolecell elongation

Rate of water uptake (RWU) = A + Lp ($\Delta\phi_w$)

Where

A = Surface Area of the cell

Lp = Permeability of plasma membrane

$\Delta\phi_w$ = Water potential differential

Growth Rate = m (Y)

Where:

m = coefficient of extensibility

Y = yield threshold

Cell elongation is when

RWU = GR

**Merits and Demerits of growth measurements Techniques**

Growth is the increment in dry mass, volume, length, form or area that results from the division, expansion and differentiation of cells. Growth measures the response of the crop to the environmental inputs and these measurements indicates if the growth is optimal or sub-optimal; and also what remedies or interventions are needed for optimum growth development and yield.

Mathematically it could be expressed as:

Growth: dx/dt

Where:

X = Weight, volume or height

T = time

**Size**

The size of the plant is measured by taking the height of the plant, the diameter of the canopy, circumference/girth of stem, number of branches or numbers of leaves per plant.

**Merits**

1. Reliability and ease of measurement

2. Simplicity, speed and non-destructiveness of measurement. Organised used can be reused on continuous basis

**Demerits**

1. Not all increase in size connotes growth, as examined when a crop is etiolated in case growth under low light intensity.

2. Impracticability of this method for tall and matured tree crops

3. This method does not take into account growth in girth, degree of branching and lateral spread

**Weight**

It measures the total amount of dry matter in the plant and therefore the actual amount of photosynthesis or net photosynthesis. Net photosynthesis is gross photosynthesis less respiration. Weight could either be in fresh or dry. Both are easy to measure except that it must involve destructive sampling. The implication is that the plot size must be increased proportionately so as to be able to accommodate the number of destructive sampling, which involves cutting of the plant at the ground level. Fresh weight is a very good measure of plant growth and as a rule all plant samples must be neatly harvested at ground level.

**Merit of measuring the fresh weight:**

1. The ease of measurement on the field

2. It could be carried out without harming the plant

It must be noted that the larger the time interval between harvest, the more the average values of the growth parameters will differ from the instantaneous values if the plant are not growing exponentially.

**Demerits of measuring the fresh weight:**

1. Delayed measurement of sample could lead to non uniform moisture loss, thereby leading to some variability in fresh weight

2. The plant must be harvested or subjected to destructive sampling, thus subsequent samples has to be carefully selected to avoid compensatory growth due to absence of previously harvested stand

3. Poor sampling can introduce variability in weight measurement, hence, it is subject to errors arriving from variability in the amount of water in a tissue

4. It is not a constant and reliable index of growth

5. It could be bulky for large sample

Dry weight is a better measure for weight than fresh weight in that variability of fresh weight due to delays in weighing does not apply in measuring dry weight. This is measure of dry matter, mostly representing materials which have been accumulated during growth. This involves drying the sample to a constant weight at the temperature of 70 – 150 $^{0}$ C for 72 hours in the oven.

**Merits:**

1. It provides the actual amount of dry matter in the plants

2. It is a constant and reliable index of plant growth. Since plants have a high composition of water and the level of water in a plant will depend on the amount of water in its environment (which is very difficult to control), using dry weight as a measure of plant growth tends to be more reliable

3. It indicated the actual amount of photosynthesis or net photosynthesis

**Demerits:**

1. This can only capture data once as a final measure mostly at the conclusion an experiment

2. Interpretation may not be straight forward due to decreasing dry weight of germinating seed or etiolated plant

3. It is a destructive sampling technique since it involves drying in an oven to a constant weight

4. There could be variability in measurement due to variability in moisture content if sample is not properly dried or ash could be measured

5. The act of removing plant from its growing medium could cause trauma and affect the on going growth rate and thus the experiment under consideration

Note that increment in dry mass may not however coincide with changes in each of the components of growth.

**Plant Volume**

It is a measure performed by water displacement.

**Merits:**

1. It is appropriate for fruits and similar organs

2. It can easily be done for small plots

3. It can be used to measure the area of the canopy of a plant

4. It is useful in simulating the degree of inter-specific shading in an intercropping system

5. It provides good information on the relative competitive abilities of different crops in an intercropping system

**Demerits:**

1. The volume measured may include a lot of intercellular spaces which are not truly part of the organism

2. It is not easy to measure for bulky materials since the most accurate measure of volume is through displacement of water.

**Growth analysis techniques, merits and demerits**

Growth analysis is a specific mathematical technique for analysing plant growth over period of weeks across areas of 0.1 to $10m^2$. This technique was pioneered by F.H. Blackman and extended by Briggs, Kidd and West and also by D.J. Watson. The following ecophysiological variables are employed in the calculation of growth analysis; Relative Growth Rate (RGR), Absolute Growth Rate (AGR), Leaf Area Ratio, (LAR), Leaf Area Index (LAI), Net Assimilatory Rate (NAR), Crop Growth Rate (CGR), Leaf Mass Fraction (LMF), Stem Mass Fraction (SMF), Root Mass Fraction (RMF), Allometric relationship between different plant organs; shoot to root ration, Leaf Area Duration (LAD), Specific Leaf Area (SLA) etc.

Different growth analysis can be carried out, depending on what is considered a key factor for growth. In growth analysis two basic measurements are made, dry weight and leaf area and a large numbers of parameters are derived from these measurements. Some of the important parameters have been listed below:

| **Parameter** | **Symbol** | **Unit** |
|---|---|---|
| Crop growth Rate | **CGR** | g (crop)$m^{-2}$ $d^{-2}$ |
| Leaf Area Index | **LAI** | $m^2$ (leaf) $m^{-2}$ |
| Specific Leaf Area | **SLA** | $m^2$(leaf) $g^{-1}$(leaf) |
| Relative Growth Rate | **RGR** | g (crop) $g^{-1}$(crop) $d^{-1}$ |
| Net Assimilatory Rate | **NAR** | g (crop) $m^{-2}$ (leaf) $d^{-1}$ |

Plant growth analysis is an explanatory, holistic and integrative approach to interpreting plant form and function.

There are different approaches to growth analysis; classical and functional. In classical approach, the samples are harvested infrequently, but in large samples, with higher numbers of replicates, without curve fitting. While in functional approach, the course of event in harvest is frequent, with small harvest size and lesser amount of replicates, with curve fitting.

**Parameters of Growth Analysis**

**Plant/crop performance = Productive Efficiency X Leafiness**

The crop performance is this case could be expressed as dry matter accumulation indicated as Relative Growth Rate or Crop Growth Rate. Two types of measurements are needed for growth analysis:

1) The plant weight; this is usually the oven dry weight (kg)

2) Leaf Area

**Relative Growth Rate:**

It measures the plant capacity to add to its dry matter. An assumption necessary for appropriate application of the relative growth rate procedure is that plant growth follows the compound interest law. The analogy with financial investment was first developed by Blackman (1919). One definition of the compound interest law is: the amount of growth made in a unit of time is a constant percentage of the size of the plant at the beginning of the period and the constant percentage does not change with size (e.g. it is size independent).

**$RGR = Ln\ W_2 - LnW_1/t_2 - t_1$**

Where: $W_1$: Dry Weight of sample at time $t_1$

$W_2$: Dry Weight of sample at time $t_2$

$t_1$: Harvest time $t_1$

$t_2$: Harvest at time $t_2$

Ln: natural log

Note that the weights of the samples are In-transformed before averaging. This gives a better estimation of the relative growth rate (William A. And Hendrik Poorter 2002)

**Merits**

1. The calculation is only really useful for short harvest interval where growth is assumed to be linear and for comparisons under similar environmental conditions, i.e. between treatments in a trial

2. The main reason for the usage of the RGR is to eliminate growth differences that arise from initial size differences

RGR could be factorised into three components:

**RGR = LAR X NAR**

**LAR = SLA X LMF X ULR**

Then:

**RGR = SLA X LMF X ULR**

Where:

**RGR**: Relative Growth Rate

**LAR:** Leaf Area Ratio, this expresses the ratio of photosynthesis to respiring material within the plant

**SLA:** Specific Leaf Area ($m^{-2}$ $kg^{-1}$), measure of leaf density

**SLA = Leaf area per plant ($cm^2$ g-1)**

**Leaf weight per plant (g)**

**LMF:** Leaf Mass Fraction ($g\ g^{-1}$). Fraction of total biomass allocated to the leaves

**ULR:** Unit Leaf Rate ($g\ m^{-2}\ d^{-1}$) is the same as NAR

**Demerits:**

1. Plant species characteristic of favourable environments often have inherently higher maximum relative growth rates ($RGR_{max}$) than do species fro less favourable environments.

2. It tends to decline as plant age and care is needed in interpreting comparisons of RGR as plant reaches maturity

3. RGR are compared at just one time interval. In this regard, hunt (1990) concluded that the efficiency index is perhaps best reserved for use in the case of population of unicellular organism that are reproducing in an unconstrained environment (i.e. where the interest rate is constant)

4. There is the disadvantage of ontogenetic drift, occurring in most tree seedlings. Most tree seedlings grow according to the variable interest law.

**Crop Growth Rate**

Physiologically, this growth parameter means the rate of dry matter accumulation per unit land area per unit of time in crop stand.

**CGR = LAI X NAR** eq.1

**CGR = W2 – W1/ (t2 – t1) X land area**

eq.2

**Merits**

1. Growth rates can be compared at different times in the season and for different treatments

2. It can help to quantify the effect of changes in environmental factors

**Demerits**

1. It is dependent on the area of leaf surface and its efficiency as a producer of dry matter (NAR)

2. Yield may be proportional to the efficiency of the leaf surface, NAR and its duration

Leafiness could be expressed in different forms:

| Parameter | Physiological meaning |
|---|---|
| **LAI** | Leafiness/crop stand |
| **LAR** | Leafiness/plant |
| | Ratio of photosynthesis/Respiration |
| **SLA** | Leaf density or relative thickness of leaf, leafiness expressed on area basis |
| **LWF** | Leafiness in weight basis |
| **LAD** | Leafiness of crop growing duration |

**Leaf Area Index (LAI)**

This expresses the ratio of leaf area (one side only) to the ground area occupied by the crop, or the leaf area per unit area of land. By convention only one side of the leaf lamina (blade) is measured. The rate of increase of the leaf area determines the rate of increase in photosynthetic capacity of the plant. A LAI of 4 – 7 is considered ideal for maximum dry matter production of most cultivated crops, as a higher level is desirable where total biomass, not complete economic yield is the objective, e.g. forage grasses.

Leaf Area Index is calculated as:

$$\mathbf{LAI} = \frac{\textbf{Total Leaf Area}}{\textbf{Land Area}}$$

Leaf area could be determined manually or automatically using leaf area meter. Manually leaf area could be determined from this relationship

**Leaf Area: L X W X A**

Where:

L: leaf length

W: leaf maximum width

A: Constant (0.75), in case of maize

For some crops that do not have regular geometrical shape, such as sweet potato, cork-borer method could be adopted.

Protocol:

1. Measure leaf area of 30 leaf with cork borer with a diameter of 1.5cm

2. Oven dry 30 leaf discs and the rest of the leaves at 900C for 72 hours

3. Calculate the leaf area using the following formula

**Leaf Area = (Area of 30 leaf discs) X (dry mass of 30 discs) + (dry mass of the rest of the leaves)**

**Dry mass of 30 leaf discs (g)**

**Merits:**

1. It indicates crops efficiency use of light energy throughout the season

2. It is used as a means of elucidating the causes of variation in the yield

**Demerits:**

1. The measurement of green leaf area to produce a value of LAI is subject to varied deficiency such as nutritional stressors

2. It is often difficult to get accurate estimate of leaf area in practice

3. The assumption that all leaves are capable of making equal contribution to growth is not accurate, it has been established that leaves decline in their efficiency of light conversion as they age. Also the arrangement (phyllotaxy) and position of the leaves in the canopy also affects their efficiency

4. Crop growth rate is not directly related to it for the whole life of the crop and this limits its usefulness as a tool for explaining variation in crop yield

5. The efficiency of the leaf area as a producer of dry matter is inversely related to LAI for much of the life of the crop

**Leaf Area Ratio (LAR)**

It expresses the ratio between the total leaf area or photosynthesizing tissue to the total respiring plant tissues or total plant biomass.

**LAR = Total Leaf Area/Total Plant Weight**

**Merits:**

1. It reflects the leafiness of a plant

2. It measures the efficiency of the leaf surface in producing dry matter

**Demerits:**

1. Its value declines as the crop increases in dry weight when leaf area remains relatively constant

2. It decreases with age of the plant because of the reduction in leaf area

**Net Assimilatory Rate (NAR)**

Net rate of dry matter accumulation per unit leaf area of crop community per unit of time, is usually expressed in g $m^{-2}$ $day^{-1}$

NAR physiologically means the carbon assimilatory capacity or productive efficiency of the crop or plant within a time frame. It expresses the difference between carbon gain and loss from the plant or crop stand. If one is to examine the plant performance from this relationship;

**Where the productive efficiency = Carbon gain – Carbon Loss**

NAR is computed from the following relationships:

**NAR = $W_2 – W_1 / t_2 – t_1$ X 1/leaf area** eq. 1

**NAR = means of $W_2$ – means of $W_1$ (Ln means of $A_2$ –Ln means$A_1$)/($A_2 – A_1$) ($t_2 – t_1$)**

eq. 2

**NAR = $A_a – LR_a$ – SR X SMF/LAR – RR – RMF/LAR / [C]** eq.3

Where:

$A_a$ - Rate of $Co_2$ assimilation per unit leaf area per unit of time

LRa – Rate of leaf respiration per unit leaf area (or mass)

SR – Rate of stem respiration per unit mass per unit of time

SMF – Stem mass fraction

LAR – Leaf Area Ratio

RR – Rate of root respiration per unit mass per unit of time

RMF Root Mass Fraction

[C] – Carbon concentration per unit mass

**Merits**

1. It is used to analyse the response of plant growth to environmental conditions, e.g. fertiliser response in sole and intercropping

2. It measures plant efficiency in producing dry matter

3. It measures the capacity of the plant to add dry weight in relation to the area of the assimilatory surface, in other words it is a measure of photosynthetic efficiency

**Demerits:**

1. It varies with time for a number of agricultural crops and if the season trends is smoothed, has a low values in the dry season and increases in the rainy season to reach maximum values in June and July

2. It is important to have adequate leaf surface to benefit from the higher potential rates of evapotranspiration

3. It is affected by temperature, light intensity, water and nutrient supply

4. It values differ between and within crop species and decline with increasing plant maturity

5. Calculating NAR after vegetative growth in meaningless since most of the dry matter produced will be exported as food reserve

6. Although NAR is relatively easy to estimate from harvest data, it is not really an appropriate parameter to gain insight into the relation between physiology and growth. It shifts concentration from the underlying processes: photosynthesis, respiration and assimilate allocation

**Leaf Area Duration (LAD)**

It expresses the magnitude and persistence of leafiness during the period of crop growth.

**LAD = (A2 –A1)(t2 – t1)/(ln A2 – Ln A1)**

**Where:**

LAD – Leaf Area Duration

A – Leaf Area

There are other growth parameters measured such as:

1. Shoot/root

2. Fresh weight

3. Dry weight

4. Dry matter content = Dry weight/Fresh weight

5. Allometric relationship

With respect to the trajectory of the dry matter accumulation, growth parameters most appropriate during the following ontological drift:

**Appropriate growth parameters during plant ontological drift**

| Stage of dry matter accumulation | Appropriate Growth parameter |
|---|---|
| **Exponential** | RGR, NAR, LAR, SLA and LMF |
| **Constant** | CGR, LAI and RUE |
| **Levelling off** | LAD, LMF, SMF, RMF |
| **Decline** | HI, Shelling percentage, Stover weight |

**Sampling method:**

**Sampling time**: This depends on the growth parameter in question. Please see above table for decision with respect to the sampling time.

**Harvest frequency:** It dependent on the approach adopted in measuring growth parameters and the parameter in question. Classical approach or the non-curve fitting method envisages infrequent course of event with large harvest size and more numbers of replicates. While functional or curve fitting approach envisage frequent course of event with small harvest size and lesser numbers of replicates.

**Harvest interval:** Is dependent on the growth parameter in question. See above table.

**Harvest size:** It is dependent on the approach adopted, in the classical method 5 plants per plot is usually adopted.

The plant parts to be investigated like leaves stem and flowers must be separated and kept in an oven at $80^0$C for 24 hours to determine their dry matter.