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Course: PCP 202

Department: PP & CP

Topic: Photosynthesis

Basic concepts: Metabolism, Anabolic process, quantum yield, photosystems, Emerson effect, pigments, Hill's reaction, assimilatory powers, CAM, C_4 plants, photorespiration, phophosphorylation.

Learning objectives:

1. Understanding relationship between photosynthesis and yield
2. Understanding mechanism of photosynthesis
3. Understanding factors affecting photosynthesis
4. Comparative analysis of C_3, C_4 and CAM
5. Photosynthesis, carbon sequestration and environmental health

Theoretical Background: Living systems are thermodynamically open system; such systems exchange energy and matter with the environment. Conceptually, there are two types of such energy transformation in living systems; anabolic and catabolic process. Anabolic process involves the transformation of energy into biological polymer, while catabolic process is breakdown or degradation of biological polymer and the consequent liberation of energy. Photosynthesis is an anabolic process found predominantly in higher plants, whose mode of nutrition is autotrophic. Autotrophic organism are further divided into phototrophic and chemotrophic organism depending on the energy source. All major crops of agronomic values belong to photoautotrophic organism, since they are capable of transforming radiant energy, in the presence of pigments into biological polymers. Chemotropic organism uses other source of energy and they are predominantly found among the lower plants.

Chemically the process could be represented as follows:

CO_2 + Hydrogen donor → (CH_2O) + H_2O + (S or O_2) General framework

Where:

Hydrogen acceptor = CO_2

Hydrogen donor = H_2O, H_2S (chemolithotroph), organic acid (chemoorganotroph)

In the case of phototrophic organism:

CO_2 + H_2O → (CH_2O) + O_2 + H_2O (In the presence of light and pigment) (eq.1)

ADP + Pi + NADP + H_2O → ATP + $NADPH_2$ + O_2 + H_2O (eq. 2)

18ATP + 12 $NADPH_2$ + $6CO_2$ → $C_6H_{12}O_6$ + 18ADP + 18Pi + NADP (eq.3)

Equations 1 and 2 Energy acquisition process

Equation 3 Carbon assimilation process

Photosynthetic efficiency metrics:

1. Percentage of energy conversion of radiant energy into assimilatory powers ($NADPH_2$ AND ATP), which is approximately 32 %
2. Quantum yield = O_2/light energy. With increasing wavelength of light there is a reduction in the evolution of O_2, a phenomenon referred to as red drop. ($E = hc/\lambda$). It was later observed that in other to enhance photosynthesis there is a need for two light harvesting systems, Emerson effect.
3. Percentage of carbon assimilation; NAR = RGR/ LAR

Tab. 1 Conceptual Framework of Photosynthesis

<table>
<tr><th rowspan="2">Parameters for comparison</th><th colspan="2">Photosynthetic stages</th></tr>
<tr><th>Light</th><th>Dark</th></tr>
<tr><td>Process type</td><td>Energetic
(Acquisition and conversion of energy)</td><td>Metabolic
(Assimilation of CO_2
o Calvin cycle
o Hatch+Slack cycle
o CAM cycle</td></tr>
<tr><td>Organ</td><td>Quantasome
o Pigment system (PSI +PSII)
o Grana</td><td>Stroma
(Thylakoid matrix)</td></tr>
<tr><td>Process product</td><td>o ATP
o NAPH.H_2
o Products of photolysis</td><td>o O_2
o $(CH_2O)_n$</td></tr>
</table>

Tab. 2 COMPARATIVE ANALYSIS OF TYPES OF PHOTOPHOSPHORYLATION

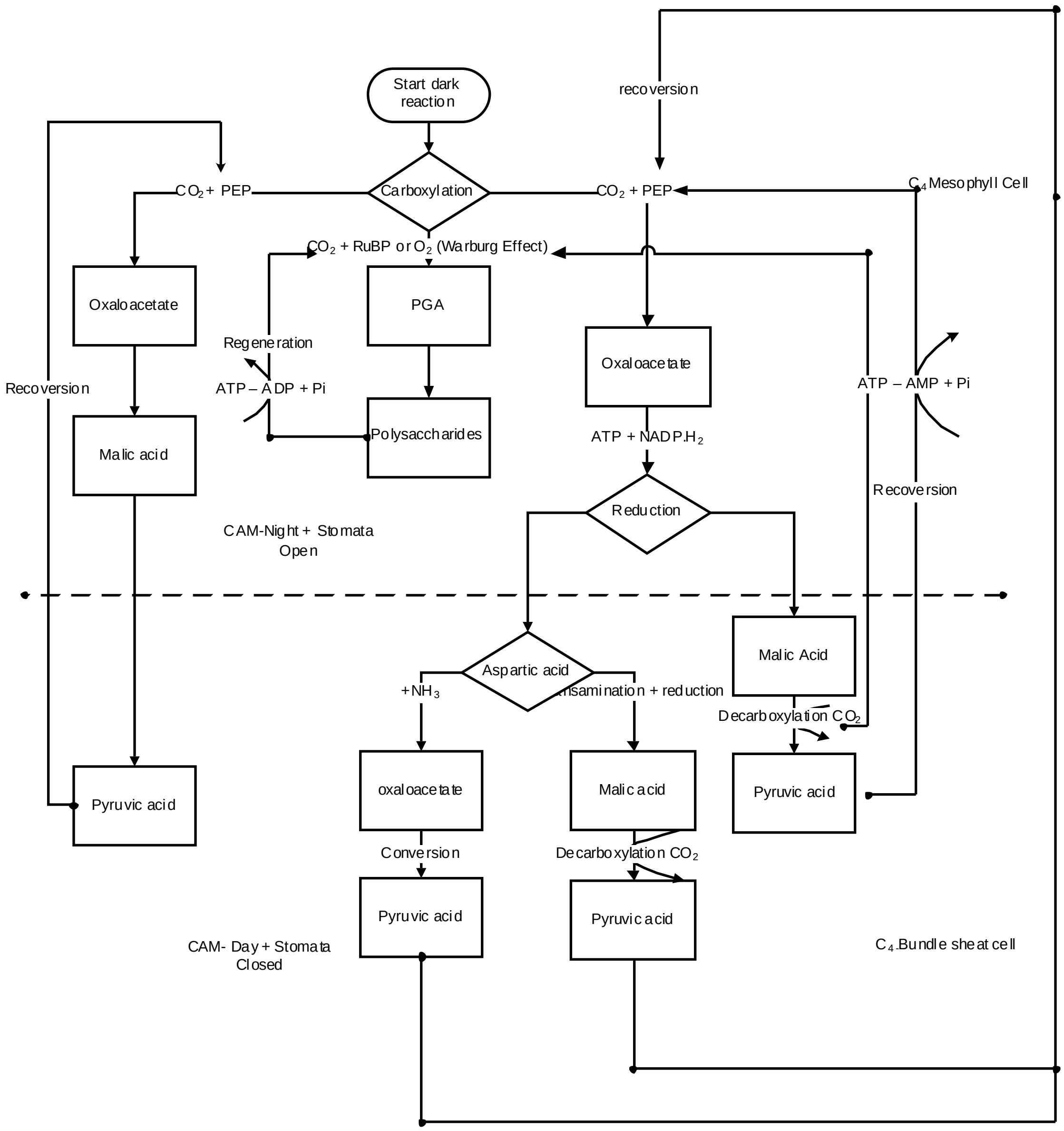
	Types of photophosphorylation	
	Non-cyclic	**Anoxysenic photosynthesis (cyclic)**
Organism	Green plant	Bacteria
Type of photosynthetic unit	PS I and II	PI
Electronic flow	PII→PI→CO_2 unidirectional	Circular
Wave length	680nm – 700nm	700nm
Types of assimilatory power	$NADPH_2$, ATP	ATP
Capacity for photophosphorylation	Low	High
Photosynthetic efficiency	High	Low

Tab.3 Dimensions of Dark reaction during photosynthesis

Parameters for Comparison	**Dark reaction cycle**		
Plant type	**C_3**	**C_4**	**CAM**
Nomenclature	Calvin cycle or Pentose phosphate reduction cycle	Hatch + slack cycle	CAM cycle
CO_2 acceptor	Ribulose 1,5 Biphosphate (RuBP)	RuBP Dicarboxylic acid Phosphoenolpyruvic acid (PEP)	PEP RuBP
First stage product	Phosphoglyceric acid (PGA)	Oxaloacetic acid/malic acid (Carboxylic acid)	Malic acid and Malate
Compartmentalization of carboxylation	None	Spatial (Mesophyll + Bundle sheath	Temporal (Diurnal pattern in mesophyll)
Plant habitat	Hydrophytes Mesophytes	Xerophytes	Halophytes
Morphology of the chloroplast	Monomorphic	Dimorphic	Fleshy leaf, stem and petioles
Bundle sheath	Few or no chlorophyll	Chlorophyllous	-
Morphology of chlorophyllous mesophyll	Not distinguishable 5> mesophyll	Kranz anatomy 4-5 mesophyll	-
Photorespiration	More	lesser	-

Flow chart of Dark reactions of C3, C4 and CAM Plants

Figure 1



Model prepared by Sakariyawo 2009

Factors affecting photosynthesis are:

1. Light
2. Water
3. Temperature
4. Carbon dioxide concentration
5. Mineral nutrients, most especially, NPK and some micro nutrients

Topic: Translocation and assimilate partitioning in relation to yield determination

Basic concepts: Translocation, transport, assimilate or photosynthates, partitioning, allocation, phloem, xylem, source, sink, sink strength.

Theoretical Background: Product of photosynthesis are transported, allocated and partitioned among various sinks. From the agronomic point of view, it is not only enough to generate adequate photosynthates, but they should be partitioned to organs of great economic returns, this is reflected in the harvest index, indicating the proportion of the economic biomass relative to the general biomass.

Transportation in long distant is referred to as translocation of solute or sap, while short distant movement of molecules and ions is generally accepted as transportation.

A solute **translocation pathway** is the phloem, a living cell compared to the xylem which is dead. The phloem is consisting of:

1. Sieve elements
    a. Sieve tube element
    b. Sieve plate pores
2. Sieve cell
3. Companion cell
4. P-protein

Translocation pattern: Source - Sink

The pattern of solute translocation is from the source to sink. The source are organs with assimilate concentrations more than their need; conversely the sink organs are with assimilate concentrations lesser than their needs.

Transported Materials:

1. Inorganic
2. Organic
    a. Carbohydrates (non-reducing sugars)
    b. Proteins (Amino acids, amides, P-protein, protein kinase, ubiquitine, chaperones, protease inhibitors)
3. Hormones

Mechanism: The photosynthates produced from the reduction of CO_2 is eventually allocated to various metabolic processes, or partitioned into various organs. The photosynthates could be allocated into the process of RuBP regeneration, storage of transitory starch or synthesis of sucrose for eventual transportation. The decision of whether to store photosynthates as starch or synthesize sucrose depends on the concentration of inorganic phosphorus in cytosol. When it is high sucrose is synthesised and eventually transported, while low concentration of it, leads to storage in the form of starch.

Sucrose is transported to the phloem-companion cell complex through apoplast or symplast path. Loading of sucrose via H^+/sucrose symport transportation leads to the reduction of water potential, while unloading at sink leads to the increase in water potential. This process in the phloem pathway leads to osmotically **generated pressure gradient**, with the sap moving by **mass pressure** from source to sink. Allocation of photosynthates for storage or differential distribution to various organ is a function of the activities of certain enzymes like *acid invertase*, *starch phosphorylase* and *sucrose synthetase*. Differential distribution (partitioning) of photosynthates among sink organs is dependent on various factors. There are different models proposed to explain assimilate partitioning in crop plant. Please see the matrix below for comparative analysis. We shall be focusing our attention on functional equilibrium model. The basic assumptions of this model are:

1. Assimilate is constant at a given period in time.

2. Partitioning is a proportional process and involves a trade-off at any given period in time
3. Changes in partitioning during ontogeny (developmental stages) reflect changes in plant's priority – phenotypic plasticity
4. Differential distribution is to process that is limiting at that point in time

Functional equilibrium model:

Dry matter allocation = $W_r/W_s \propto A_s/A_r$

Where:

Wr – Weight of root

Ws – Weight of shoot

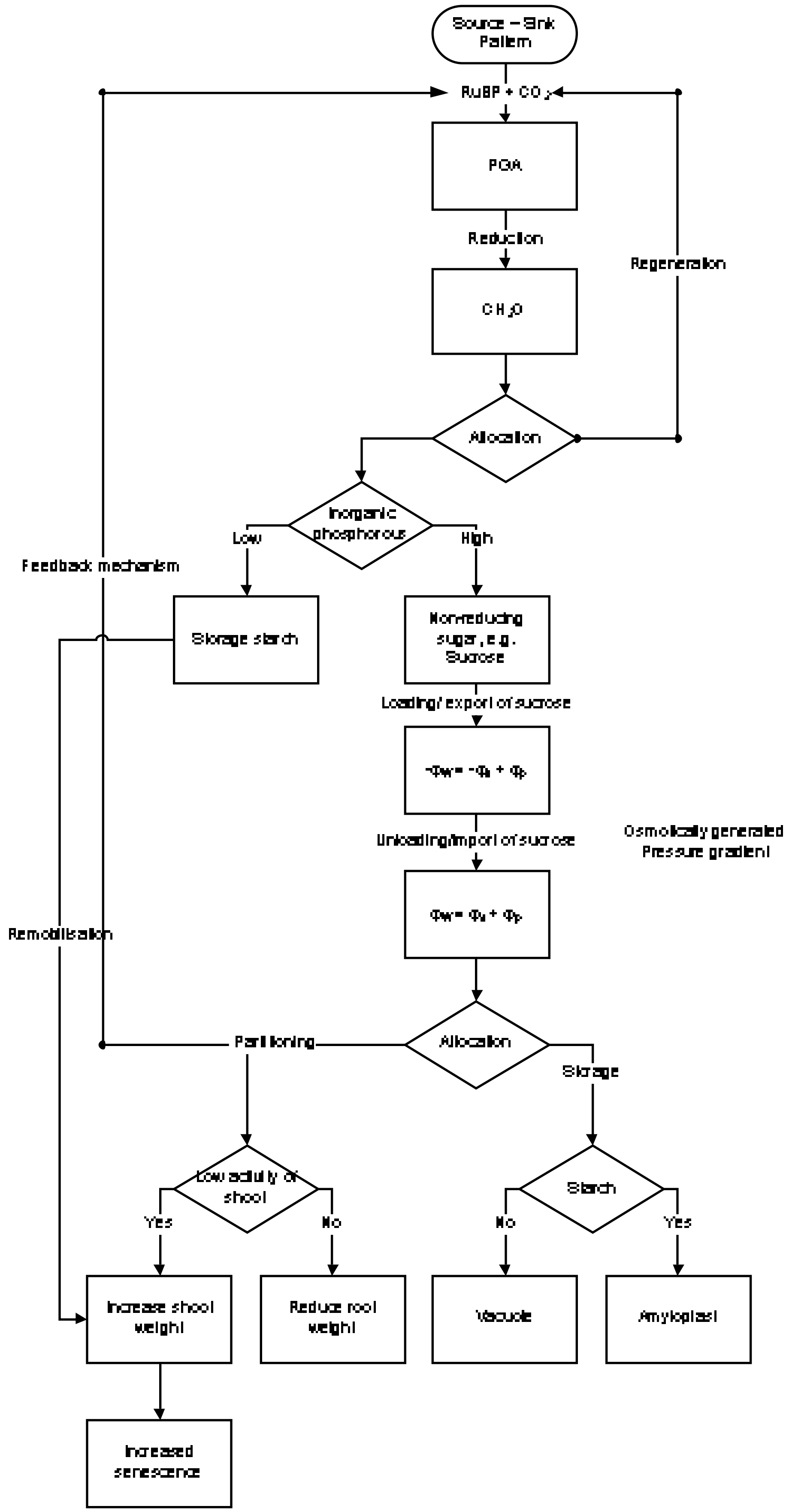
As – Activity of shoot (carbon assimilation)

Ar – Activity of root (nutrient and water uptake)

With respect to yield, high yield is recorded when there is a there is functional balance of physiological activities, contrary to which assimilates could be partitioned to other sinks indicating priority process, which may not be of economic value to the farmer.

COMPARATIVE ANALYSIS OF MODEL S OF ASSIMILATE PARTITIONING

Models name	Assumptions	Model	Deficiency of the model
Descriptive Allometry	Predetermined RGR among organs	Allometric pattern = f{genotype x environment x dev}	Fluctuation in dry matter allocation could not be explained by the model
Functional Equilibrium (Teleonomic model)	Existence of functional balance among the plant organs (Shoot and Root)	1. Dry Matter Allocation = $W_r/W_s \; \alpha \; A_s/A_r$ 2. Or Carbon/Nitrogen	Not applicable to other organ aside from shoot and root
Canonical Model	Interrelationship of parts	1. Non linear, dynamical process 2. Numerical analysis	Too quantitative
Sink Strength	Commonality of assimilate pool	1. DMA = f{sink strength-(source strength + transport resistance) 2. fi = si/ΣS	Sink strength is conceptual, not measurable
Transport Resistance		DMA = f{pressure gradient x differences in labile carbon}	Complexity in computing resistance transport parameters



Source – Sink Pattern
RuBP + CO2
PGA
Reduction
CH2O
Regeneration
Allocation
Inorganic phosphorous
Low
High
Feedback mechanism
Storage starch
Nonreducing sugar, e.g. Sucrose
Loading/ export of sucrose
-Ψw= -Ψs + Ψp
Unloading/import of sucrose
Osmotically generated Pressure gradient
Ψw= Ψs + Ψp
Remobilisation
Partitioning
Allocation
Storage
Low activity of shoot
Yes
No
Starch
No
Yes
Increase shoot weight
Reduce root weight
Vacuole
Amyloplast
Increased senescence

The above Conceptual Model according to Sakariyawo 2009