

PHOTOSYNTHESIS

12.1 PHOTOSYNTHETIC EFFICIENCY

Photosynthetic efficiency is the amount of dry matter fixed by the crop in a unit area per unit time. Photosynthetic efficiency (E_{μ}) of a crop can be estimated with the following formula

$$E_{\mu} = \frac{\text{Chemical energy captured by a crop}}{\text{Solar energy received}}$$

Thus, photosynthetic efficiency can be understood as net gain of chemical energy per total incident solar radiation in a unit area.

Considering supplies of total PAR (Photosynthetically active radiation) to land area on a growing crop, overall biomass production efficiencies are always much below 18 percent. However this 18% is only a theoretical estimation which is calculated as follows. Assume that 12 moles of photons represent the maximum number of photons needed to fix one mole of CO_2 and that an average photon in the PAR region (400-700nm) has a wavelength of 550nm. From Planck's equation ($E = h\nu$) relating photon energy and wavelength we can calculate that one mole of such photons has an energy of 217,000 J (51,900 cal). Twelve moles of photons would therefore have an energy of 2.6×10^6 J. This is the input energy. The output energy, one mole of fixed carbon in carbohydrate, has energy of about 0.48×10^6 J. Efficiency equals output energy / input energy or 18 percent.

Furthermore, **only 40-45 percent of the sun's energy is in the PAR region**, so the **theoretical maximum efficiency** from all the sun's energy is only about **8 percent** (45 percent of 18 percent). However, experimentally, the efficiency of energy conversion in plants—the ratio of energy stored as organic substance to the amount of energy available from the sun varies between 0.1 to 1.0% under conventional agricultural practices to between 6 and 10% under conditions of intensive agriculture. Many crops including forest trees and herbaceous species, convert only 1 to 2 percent of the PAR striking the field during the growing season into stored carbohydrates. Much PAR is wasted by striking the bare ground between young plants before leaves have grown enough to absorb it.

Optimizing the interception of solar radiation by the canopy is an important component of biomass production. This is influenced by the rate of development of leaf area, leaf area duration and canopy architecture.

12.1.1 Photosynthetic efficiency of C₃ & C₄ crops:

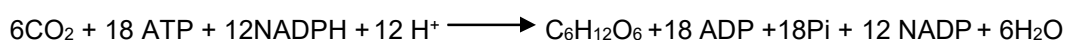
In normal air, increasing temperatures gradually decrease efficiencies of C₃ plants, with efficiencies of C₄ plants remaining constant. As temperatures rise above 30°C efficiencies of the most C₃ plants become lower than those of C₄. This efficiency crossover with increased temperature results from lower net photosynthesis in C₃ plants because of faster CO₂ loss by photorespiration. The absence of detectable photorespiration in C₄ plants even above 30°C gives them a substantial efficiency advantage at high but not at low temperatures and especially in non-shaded conditions

The relative photosynthetic efficiencies of C₃ & C₄ crops can be calculated by considering the energetics of these processes occurring in plants. Among C₃, C₄ and CAM pathways, it is clear that in C₃ plants occurrence of photorespiration leads to loss of Carbon through glycine decarboxylation. Further, such oxygenase function of RuBISCO increase under abiotic stress such as higher temperature, water stress etc. due to reduced levels of CO₂ in sub-stomatal cavity.

In course of evolution a relatively more efficient alternate C fixation mechanism under water limited and high temperature environments was evolved in plants i.e., “C₄ pathways” as seen in C₄ plants.

In terms of energy requirements:

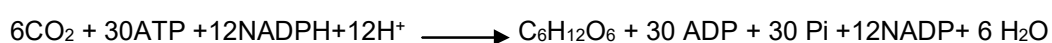
- C₃ photosynthesis under normal conditions requires **3 ATP + 2NADPH** for fixation of one molecule of CO₂. This is calculated from the following equation.



- Under ambient CO₂ concentration / and O₂ conc. in the air, with occurrence of photorespiration simultaneously in C₃ plants this requirement increases to approximately. **5ATP + 3.2 NADPH**

On the Other hand

- In C₄ plants the energy requirement for fixation of one CO₂ molecule is **5 ATP + 2 NADPH**



- In C₄ plants Photorespiration is negligible due to the CO₂ concentration mechanism. However, for concentrating CO₂ in bundle sheath cells it needs two additional ATPs. Thus, it needs 5 ATP.

- Any photo respiratory CO₂ evolution from bundle sheath cells is refixed by PEP carboxylase due to its high affinity for CO₂

Thus, on the basis of

1. Energetics in lines with C loss due to photorespiration and
2. Affinity for CO₂

It can be concluded that under ambient conditions compared to C₃ plants, C₄ are “Photosynthetically Efficient”.

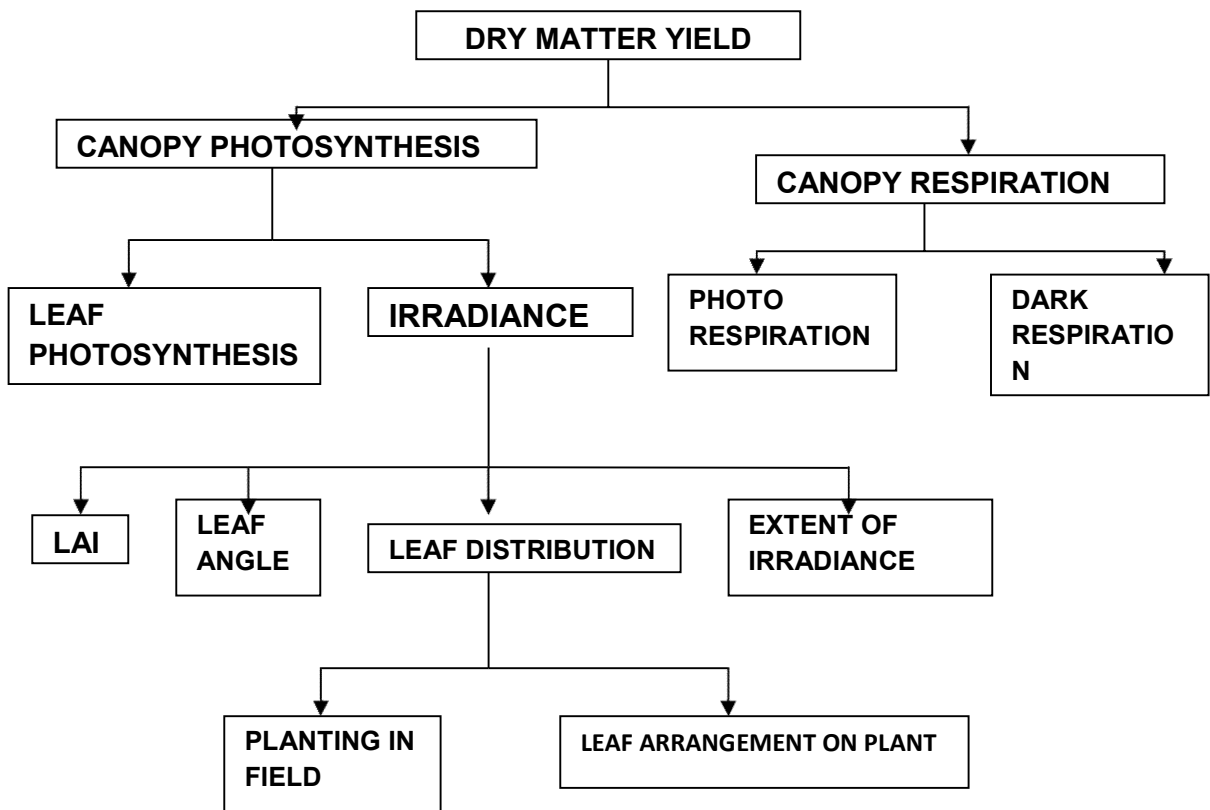
12.2 SIGNIFICANCE OF C₃, C₄ & CAM PATHWAYS- A COMPARISON

C ₃	C ₄	CAM
Typically temperate species e.g. rice, wheat, barley, sugar beet, soybean, sunflower, spinach, potato, tobacco, , oats and rye.	Typically tropical or semitropical species e.g. Maize, sugarcane, sorghum, Amaranthus Plants adapted to high light, high temperature and also semiarid	Typically arid zone species e.g. cacti, orchids. Agave, succulent plants. Pine apple is the only cultivated crop among this group.
Moderately productive, yields of 30 tones dry weight per hectare possible (sunflower is highly productive)	Highly productive, 80t per hectare for sugarcane is possible	Usually very poorly productive (However, Pineapple is highly productive).
Mesophyll Cells containing chloroplasts do not show Kranz-type anatomy. Only one type of chloroplast.	Kranz-type anatomy is essential feature. Often have two distinct types of chloroplast (both in Budle sheath and mesophyll cells)	Lack Kranz anatomy. Only one type of Chloplast.
Initial CO ₂ acceptor is ribulose biphosphate (RuBP) a 5 carbon sugar.	Initial CO ₂ acceptor is phosphor enol pyruvate (PEP) (a 3-carbon acid)	CO ₂ acceptor is PEP in the dark and RuBP in the light
Initial CO ₂ fixation product is the 3 – carbon acid phosphoglycerate	Initial CO ₂ fixation product is the 4-carbon acid oxalo acetate .	CO ₂ fixation products are oxalo acetate in the dark and phospho glycerate in light.
Only one CO ₂ fixation pathway	Two CO ₂ fixation pathways separated in space.	Two CO ₂ fixation pathways separated in time.
High rates of glycolate synthesis and photorespiration	Low rates of glycolate synthesis, no photorespiration.	Low rates of glycolate synthesis; no photorespiration

Low water use efficiency and low salinity (ion) tolerance	High water use efficiency and salinity tolerance.	High water use efficiency and salinity tolerance.
Photosynthesis saturates at 1/5 full sunlight	Do not readily photo saturate at highlight,	Do not readily photo saturate at high light.
High CO ₂ Compensation point (50-150ppm)	Low CO ₂ compensation point (0 – 10-ppm)	High affinity for CO ₂ by night
Open stomata by day (photo active)	Open stomata by day (Photoactive)	Open stomata by night ((Skoto active)

12.3 PHOTOSYNTHESIS AND CROP PRODUCTIVITY

Crop plants grow almost entirely by photosynthesis. Thus, plant productivity interms of primary production of biomass is simply a measure of the total photosynthesis of the plants less respiration, which has occurred during its growth.



Total Dry matter yield or total biomass is a consequence of crop canopy efficiency in intercepting and utilizing the solar radiation variable during the growing season. Leaves are the main plant organs which intercept solar energy. For maximum crop growth rates, sufficient leaf area must be available in the canopy to intercept most of the solar radiation incident on the crop canopy. This is called as LAI. Mere interception of solar energy is not sufficient, it has to be converted in to the biomass and it depends on the Net Assimilation Rate (NAR) Thus, total dry matter production or productivity of a crop is a factor of how long the crop can maintain an active, green leaf canopy that can produce photosynthates.

$$\text{CROP GROWTH RATE} = \text{LAI} \times \text{NAR}$$
