# **Glossary -** Eco-Physiology of Plants

**Biocenosis**: A self-sufficient community of organisms (plant and animals) naturally occupying and interacting within specific biotope, and share similar environmental conditions; accidentally or intentionally join each other and create an unilateral or mutual nutritional dependence in a particular biotope.
B. **Connection**: Structure of relations between organisms of a habitat (unlimited in size) interrelated by their webs of life (food webs, trophic levels, etc.)

**Biotope**:

**Biotopic-Factor** (Standort F.) All physical and chemical influences that act upon organisms (i.e. plant) forming the biotope.

- Action-related: Environmental influences acting upon the organism;
- Reaction-related: Environmentally stimulated reaction of the organism;

**Antropogenic** BF: Manmade influences altering normal growth (atmospheric and aquatic pollution, indirectly induced fertilizers, mowing by machines and grazing by live stock, logging, trampling, sealing of soil by roads, buildings etc.)
**Natural** BF: Naturally occurring influences neither direct nor indirectly manmade;

- Abiotic: Non-living; usually applied to the physical and chemical aspects of an organism's environment;
  **Physical**: Climate, radiation, temperature, humidity, precipitation, wind, snow, ice, etc.
  **Chemical**: Partial pressure of $CO_2$ and $O_2$, $H_2O$, $NO_3$, and $NH_3$, macro-nutrients (C, H, O, N, S, P, K, Ca, Mg, Fe), micro-nutrients (Mn, B, Zn, Cu, Mo, Cl, Na, Se, Co, Si);
  **Mechanical**: Wind-, snow- related effects, fire, currents, wave-pattern, surge;
  **Orografic** (Gk. oros, mountain): Altitude, surface structure, inclination, exposition;
- Biotic: Competitors, resources (type, amount, etc), predators (parasites, etc.) symbionts, comensals, destruents;
- Edaphic (Gk. edaphos, soil): Interaction of a-/biotic effects upon the organism;

**Climate**: The accumulation of seasonal weather patterns in an area over a long period of time; i.e.: the prevailing weather conditions of a particular region, altitude, in relation to its locality.

**Compensation Point**: see photosynthesis - rate of.

**Ecology**: The scientific study of how organisms interact with their environment and with each other and of the mechanisms that explain the distribution and abundance of organisms.
**Tasks** of E.: Working in an open system to execute environmental research, research design, establish a database, develop process models, integrate it into site models, creating biome models which should harmonize with the real-world application. This involves the following:

- Description: Proposing a thesis verified by sole observation.
- Connections: Explaining and understanding the causes.
- Prognosis: Anticipating trends and consequences if certain conditions, events, previously not present interfere with organisms, populations etc.

**Ecosystem**: see system.

**Environment**: The combination of all the external conditions and the potential effect of the inner environment (hetero-mosaic of abiotic conditions);

**Isotope**: Atoms whose nuclei have the same number of protons but different numbers of neutrons. One of several possible forms of a chemical element that have same number of protons, differ from others in the number of neutrons in the atomic nucleus, but not in chemical properties e.g.: $^{13}C$ isotope of $^{12}C$ (normal).
According to their C-fixing pathway ($C_3$, $C_4$, CAM), plants absorb $^{12}C$ far better than $^{13}C$; this preference is caused by the increased affinity of $^{12}C$ by PEP-carboxylase and even more by Rubisco. An indicator for the overall C assimilation of a plant is provided by the ratio of the stable isotopes $^{13}C$ to $^{12}C$ in dry matter (the ratio of ($^{13}C$ / $^{12}C$) of a plant matter is referred to a standard and expressed in parts per 1000:

$$\delta^{13}C = \frac{(^{13}C / ^{12}C)_{sample} - (^{13}C / ^{12}C)_{standard} \cdot 1000}{(^{13}C / ^{12}C)_{standard}} = <0;$$

$C_3$ plants: -23 - -36‰; $C_4$ plants: -10 - -20‰
CAM plants: -15 - -25‰

**Osmosis**: see water potential;

**Photo-Adaptation**: See solar radiation.

**Photo-Homeostatic Effect**: Structures that results in an arrangement of leaves during shoot growth and leaf development, by virtue of its finely tuned adjustment to the steep light gradient within the crown as a consequence of the distribution of radiation in plant cover (closed plant stands build up a system in which successive layers of leaves partially overlap and shade one another. Incident light id absorbed progressively in its passage through deeper layers).

**Photo-Respiration** (PR): In $C_3$ plants only; photosynthesis in $C_3$ plants is always accompanied by PR, a process that consumes $O_2$ and releases $CO_2$ in the presence of light. Since no ATP is yielded by PR, it diverts some of the light-depending reactions from biosynthesis of glucose into reduction of $O_2$. Up to 50% of $CO_2$ fixed in $C_3$ plants may be again reoxidized to $CO_2$.

**Assimilation**: Liberation of $O_2$ by photo-autotrophic active organisms. The assimilatory quotient (AQ) helps to determine the overall yield between $O_2$ release and $CO_2$ uptake:

$$AQ = \frac{[mol_{O2}\uparrow]}{\Delta t} \cdot \frac{\Delta t}{[mol_{CO2}\downarrow]}$$

AQ as an dimensionless quantity, is always >1 (1.3), since a $C_3$ plant releases more $O_2$ than it consumes under sunny conditions;

**Dissimilation**: Conversion of $O_2$ to $CO_2$ of heterotrophic organisms.

**Respiration**: An intracellular process in which molecules, particularly pyruvate in the Krebs cycle, are oxidized with the release of energy. The complete breakdown of sugar or other organic compounds to $CO_2$ and $H_2O$ is termed aerobic respiration, although the $1^{st}$ step of this process is anaerobic.

**Photosynthesis**: (Gk photos, light; syn, together; thienai, to place) Temperature dependant conversion of light- to chemical energy; the production of carbohydrates from $CO_2$ and $H_2O$ in presence of chlorophyll by using light to form saccharose, conveyed down to the roots where it will be converted into starch (storage site).

- Light dependent Reaction: Occurs within the thylakoid-membrane (energy trapping reaction):
  $2\ H_2O \rightarrow \text{photons} \rightarrow 4(H) + O_2$, $(H) = H^+ + e^-$
- Light independent Reaction: Synthesis of glucose from $CO_2$, ATP and NADPH in stroma of thylakoids:
  $CO_2 + 4(H) \rightarrow \text{Calvin cycle} \rightarrow CH_2O + H_2O$

The temperature dependence of this process is empirically characterized by the temperature coefficient:

$$Q_{10} = \frac{k_{T+10}}{k_T}$$

$k_T$, Boltzman constant = 1,380 658 $12 \cdot E^{-23}$ [J/K]
$Q_{10}$, measured change in rate of reaction for an alteration in temperature of 10[°C]

In temperate regions, a T-increase o10°C causes $Q_{10}$ to double (>2); i.e.: increase of net photosynthesis under bright light; above a T-optimum (e.g.: 35°C) the rate of net photosynthesis decreases rapidly as photo-respiration increases (determined by the temperature compensation point).

**Gross** (true) P.: The total $CO_2$ fixed; can only be determined mathematically.

**Net** (apparent) P.: The net uptake $CO_2$ (= apparent $CO_2$ uptake); more $CO_2$ is consumed in photosynthesis than is liberated simultaneously in photo-respiration; is determined by light, temperature, $CO_2$ and $O_2$ concentration, $H_2O$, wind, nutrients, developmental level, morphology of leaves (epi-, hypo-, amphi-stomatic), activity of photosynthetic and respiratory pigments, diffusion barrier (epidermis, intracellular spaces):

$$\left(\frac{[mol_{CO2}\downarrow]}{\Delta t}\right)_{apparent} = \left(\frac{[mol_{CO2}\downarrow]}{\Delta t}\right)_{gross} - \left(\frac{[mol_{CO2}\uparrow]}{\Delta t}\right)_{gross}$$

gross $CO_2$ uptake determined by dark respiration

**Rate** of P.: Determined by the amount of $CO_2$ used and $O_2$ released; in [mol, ppm] or weight [$g_{GAS}/t_{Drymass}$]. The amount of $CO_2$ in the atmosphere determines the photosynthetic rate; a low amount of $CO_2$ in the atmosphere leads to the consumption of $O_2$ (photo-respiration) to raise the atmospheric $CO_2$ level.

- **$CO_2$ Compensation Point** (Γ, gamma): A temperature dependant value, for the assessment of photosynthetic efficiency of a leaf with respect to the use of the $CO_2$ reservoir in the atmosphere in [µL/L]; (<Γ = high rate of $CO_2$ fixation in comparison with $CO_2$ release; a >Γ = low rate of $CO_2$ fixing system compared with the rate of respiration). Water-plants and lichens use different mechanisms (carbo-anhydrase binds dissolved $CO_2$ as $HCO_3^-$);
  Photosynthesis and $CO_2$ CP: At a certain photosynthetic rate (operational point,) the internal $CO_2$ concentration is somewhat lower than the atmospheric concentration, resulting in a slightly lowered photosynthetic activity $Ph_{act}$, than would be possible at an atmospheric $CO_2$ concentration, $Ph_{335}$. Maximal achievable photosynthetic rate $Ph_{pot}$ (max. growth) can be reached by increasing the $CO_2$ concentration to a saturation level (to be found individually for each species; greenhouse veggies from the Netherlands).
- **Light Compensation Point** (LC): The amount of light (PhAR) at which $CO_2$ uptake equals $CO_2$ ($O_2$ uptake = $O_2$ release); a >LC indicates a high light flux for photosynthesis to balance respiration; a <LC, indicates that photosynthetically compensated C-balance is kept even at low light flux; release in [$\mu mol/(m^2 \cdot s)$]; e.g.:
  *sciophytes* 15-45$\mu mol/(m^2 \cdot s)$ ≈ 100-250lx, *heliophytes* 80-200$\mu mol/(m^2 \cdot s)$ ≈ 500-800lx.

- **Temperature Compensation Point** (CP): Genetically and regulatory determined characteristic of T-dependent $CO_2$-fixation. Fixation is limited by enzymes of the photosynthetic apparatus (RUBISCO).
  Lower CP: The temperature at which photorespiration equals $CO_2$-fixation under dim light.
  Upper CP: The temperature at which $CO_2$-fixation reaches maximum level under bright light (optimum in desert plants at 47°C, in arctic plants at 15°C).

**Photosynthetic Pigments**: A substance that absorbs light, often selectively (see plant physiology)

**Carotenoids**: Class of fat-soluble pigments (yellow and orange pigments); found in chloro- and chromoplasts of plants. Carotenoids act as accessory pigments in photosynthesis.

- **β-C**.: A yellow to red carotenoid with the empirical formula $C_{40}H_{56}$, found in fruits e.g.: pericarp of tomatoes.
- **Fucoxanthin**: (Gk. phykos, seaweed + xanthos, ye/br) Brownish pigment of brown algae and chrysophytes.
- **Xanthophyll**: (Gk. xanthos, yellowish-brown + phyllon, leaf) A ye fat-soluble light shielding pigment.

**Chlorophyll**: (Gk. chloros, green + phyllon, leaf) The green pigment of plant cells, which is the receptor of light energy in photosynthesis; a tetrapyrrole ring structure on top with 4 internally placed N-atom, itself facing towards the centrally located Mg-atom; the entire complex is attached to a hydrophobic $C_{20}H_{39}$ phytol tail, which anchors the molecule into the photosynthetic thylakoid membrane.

- C. **a**: blue-green; with an extra $CH_3$ molecule attached at the opposite end of the tetrapyrrole.
- C. **b**: yellow-green; aldehyde (CHO) instead of $CH_3$ attached at the opposite end of the tetrapyrrole.
- C. **c**: $CH_2CH_3$ or CH= $CH_2$ instead of $CH_3$ attached at the opposite end of the tetrapyrrole.

**Phycobilins**: A group of water-soluble accessory pigments, which occur in red algae and cyanobacteria.

**Phytochrome**: A phycobilin-like pigment (photoreceptor for red and far-red light) found in the cytoplasm of plants and a few green algae; phytochromes do not participate in photosynthetic reactions.

- $\mathbf{P_r}$ absorbs red light (660 nm), the biological inactive form of the.
- $\mathbf{P_{fr}}$ absorbs far-red light (730 nm), the biological active form triggering reactions.

**Plants, Types of** : According to the light-independent reaction, $CO_2$ fixation is achieved by the following:

**$C_3$ P**.: (Calvin cycle) Enzymatically mediated photosynthetic reactions of shade-plants (temperate regions) during which $CO_2$ is attached to ribulose, a $C_5$-sugar (RuBP, a $CO_2$ acceptor), yielding a $C_6$-sugar which spontaneously breaks into 2 $C_3$-sugars (3-PGA). Rubisco is resynthesized out of $5C_3$-sugars giving $3C_5$-sugars. Sugar-compounds can temporarily be converted to starch, stored in amyloplasts, and reconverted into sugars via ATP and NADPH to ADP and $NADP^+$ (glucose is more stable and compact than ATP, NADPH):

$$6CO_2 + 12NADPH + 12H^+ + 18ATP \rightarrow 1glucose + 12NADP^+ + 18ADP + 18P_i + 6H_2O$$

- Photorespiration (PR): In $C_3$ plants only; see there.

**$C_4$ P**.: Sun-loving, fast growing plants of the tropics; $CO_2$ is first fixed to PEP (via PEP carboxylase in mesophyll cells) to oxaloacetate (a $C_4$ compound), which is rapidly converted to malic acid. This malate is then transported to bundle sheath cells (spatial separation), where the $CO_2$ is released (turbo charger) converting back to pyruvate. The $CO_2$ thus enters the calvin cycle, ultimately yielding sugars and starch. Pyruvate returns to the mesophyll cells for regeneration of phosphoenolpyruvate (PEP); requires more energy than in $C_3$ plants.

- Spatial separation: Photosynthesis in chloroplasts of mesophyll cells, synthesis of sugars and starch in the bundle sheath; due to spatial separation no competition between $O_2$ and $CO_2$, hence no photorespiration.

**CAM P**.: (Crassulacean Acid Metabolism) A variant of the $C_4$ pathway; phosphoenol-pyruvate fixes $CO_2$ in $C_4$ compounds (PEP carboxylase) at night. The malic acid so formed is stored in the vacuole. During the day, fixed $CO_2$ (malic acid) will be decarboxylated and transferred to the ribulose biphosphate (RuBP) of the calvin cycle within the same cell. Characteristic of most succulent, slow-growing, desert-plants; e.g.: cacti.

- Temporal separation: $CO_2$ fixation at night (dark reaction), photosynthesis during the day (light reaction). There is a gradual shift from $C_3$ (DoS = 1) to CAMetabolism (DoS = 8); according to the **D**egree **o**f **S**ucculence ( DoS = weight/surface area in [$g_{H2O}/m^2$]) and availability of water;
  Facultative CAM: In abundance of water the $CO_2$ fixation switches to a $C_3$ pattern.
  Obligate CAM: $CO_2$ fixation permanently mediated by PEP (CAM-pattern).

**Spheres of the Earth** (L. sphaera) A 3-dimensional surface, all points of which are equidistant from a fixed point.

**Bio**-s.: That part of the planet that supports life; includes the atmosphere, water and the outer few kilometers of the earth's crust.

- **Atmo-**s. (Gk. atmos, vapor): The gaseous mass or envelope surrounding a celestial body in space (esp. the earth); its constituents on planet earth are: 78% $N_2$, 21% $O_2$, 0.95% inert gases, 0.035% $CO_2$, 0.01% $H_2O$; other trace-molecules: $SO_2$ (sulfur dioxide), $CH_4$ (methane), $NO_2$ (nitric oxide), $O_3$ (ozone).

**Layers** of the A. above ground level: Troposphere (0-12km), Stratosphere (12-80km), Ionosphere (>80km).

- **Hydro**-s. (Gk, hydor, water): All the waters of the earth found in soil (ground water bodies), swamps, polar caps, glaciers, river, lake, and ocean. 71% of the earth's surface is covered by oceans = 75% off overall water).
  **Atmospheric water**: water in its gaseous phase, trapped in the periodic cycle of circulation (evaporation = endergonic process, precipitation = exergonic). The main protagonist in climatic systems.
- **Litho**-s. (Gk. lithos, stone): Solid part of the earth; sometimes used synonymously with the earth's crust. The main storage site for O, Al, Fe, Ca, Mg, K, P, etc. The lithosphere is in constant interaction with the hydrosphere (erosion, weathering) which causes the transfer of raw materials. Atmosphere and lithosphere are connected by volcanic activity.
  **Soil**: The top layer of the earth's surface, suitable for the growth of plant life (separated from its stony supporting layer).

**Eco**-s.: A functional term resulting from the interaction between biosphere and its inorganic environment. This includes the interlocked flow of energy, material cycles (C-, N-, P-, water-cycle etc.), and interaction between ecosystems.

**Phyto**-s.: The space in which plant life under the influence of local conditions is supported. Under natural conditions the site at which morphogenetic and evolutive processes take place. Phytomass constitutes for 99% of living organisms, only 1% is occupied by animals.

**Soil**: The top layer of the earth's surface, suitable for the growth of plant life (supported by the stony layer).

**Solar Radiation**: Emission and propagation of energy through space or through matter in the form of electromagnetic waves; the solar spectrum (260 - 3000nm) reaches the earth's surface with approx. 1.39kW/m$^2$ (at an altitude of 80km); summarized by the heat budget;

**Global Radiation Balance** (S):

$S = I + H + G - \sigma \cdot T^4$ -reflection $\neq 0$ [J/(m$^2$·s)]

**Total Energy Turnover**: The sum of all radiative components and wavelengths penetrating the surface ≈ 900W/m$^2$.

$S + B + L + V + Q + N + P + D =$ [J/(m$^2$·s)]

- I, direct solar radiation, (+)
- H, diffuse background radiation of sky, clouds, (+)
- G, opposing radiation, IR-reflection, (+)
- $\sigma \cdot T^4$, black body radiation, (-)
- B, flow of heat into (day) the soil (reverse at night)
- L, flow of heat from air to soil and v.v.
- V, evaporation and convection
- Q, flow of heat by transported masses of air
- N, flow of heat by snow and rain
- P, heating of phytomass, (-)
- D, energy required for photosynthesis ($\eta$ = 1%!)

**Attenuation of Radiation**: Absorption, scattering and reflection of radiation by a plant's leaves; in a stand of plants depends mainly on the density of the foliage, on the arrangement of the leaves within the stand, and on the inclination of the leaves to incoming radiation.

The degree of absorption can be quantitatively expressed by the **L**eaf **A**rea **I**ndex (LAI):

$$LAI = \frac{\text{total leaf area}}{\text{ground area}} = \frac{\sum A_{leaf}}{\sum A_{ground}}$$

both nominator and denominator expressed in [m$^2$], so that LAI is dimensionless; $LAI_{decid.forest}$ 7-8; $LAI_{bush}$ 6-8; $LAI_{corn}$ 4;

- **Lambert-Beer's Law**: Describes capability of absorption in transparent media:
  $I_x = I_0 \cdot e^{-C \cdot LAI}$
  - C, attenuation coeff. of particular groups [-]
  - $I_0$, intensity of radiation in open space [J/(m$^2$·s)]
  - $I_x$, intensity of radiation below canopy [J/(m$^2$·s)]
- **Relative Light Harvest**: Relative average light -intensity present at a certain spot;
  $$L_{Rel} = \frac{I_{location}}{I_{open\ space}} \cdot 100 \quad [\%]$$
  an alternative method, sufficient to provide a quick determination of radiation intensity present;
  Heliophytes (sun-loving plants): $L_{min} \approx L_{max} \approx 100\%$,
  Sciophytes (shade-loving plants): $L_{min} < 1\%$, $L_{max} < 50\%$,

**Heat Budget**: Accounting for the total amount of the sun's heat received on the earth during any one year as being exactly equal to the total amount lost from the earth by reflection and radiation into space.

**Irradiance** (L. irradiare, to shine): Exposition to radiation; a plants irradiance particularly depends upon atmospheric influences (cloudiness), altitude (the higher the more intense), orografy (inclination, exposition) and latitude (Kepplers 2$^{nd}$ law - for the N-ern hemisphere: in winter further away, and in summer closer to the sun; results in colder winters and warmer summers - 7 days longer than in the S-ern hemisphere).

**Photo-Adaptation**: Short-term-reactions, acclimation, and evolution of genotype at a particular site; Evolution as a filter that emphasized certain characteristics well adapted to conditions prevailing over time. All sorts of adaptation are superimposed to permit fine adjustments guaranteeing the greatest possible utilization of the available radiation.

- **Evolutive** A.: Genotypically determined habit preferences and photo-*ecotypes* (helio-, scio-phyta) resulting from selection and adaptability (evolution).
- **Modificatice** A.: Adjustment of the average condition of radiation during morphogenesis (young to adult); e.g.: sun-loving plants do not flourish under shady conditions; changing light condition will result in new adapted shoots, while the ill-adapted senesce and are shed; plants under bright light produce a robust axial system, their leaves have several layers of mesophyll, and cell rich in chloroplasts, as well as a dense vascular system (higher in dry matter then shade loving plants). Plants adapted to dim light have long internodes and thin leaves with a large surface, just to thrive in locations where only a modes amount of energy is available.
- **Modulative** A.: Short time influences that are quickly reversible; e.g.: closure of guard cells, solar tracking, photonasty (opening / closure of flowers), photodinesis (repositioning of chloroplasts), cytoplasmic streaming.

**Photo-Energetic Effects**:

- Radiation as a source of energy: Main source to drive metabolic processes,
  Photo-Conversion: Change of molecular structures under the influence of light;
  Photo-Oxidation: Acceleration of metabolic reactions by xanthophylls and other macro-molecules;
  Photo-Lesion: Destruction of macro-molecular units under the influence of light;
- Photo-Destruction: If modifications (adjustment of leaf exposition, arrangements of chloroplasts, hairy cuticula, formation of cork-layer) fail to regulate radiation influx, the leaf suffers stress; (see there).
- Photo-Cybernetics: Stimuli triggering certain developmental processes such as:
  Photo-Stimulation: Formation of chlorophyll under light;
  Photo-Tropism: Stimulation of growth;
  Photo-Induction: Stimulation of germination, and flowering;
  Photo-Periodism: diurnal (according to earth's rotation), and seasonal adaptation via phytochromes;

**Photosynthetic Active Radiation** (PhAR): The range utilized for photosynthesis by plants; an average of 47% of the incoming solar energy falls within the spectral range of 380-710nm (corresponds to the visible spectrum).

According to the Total Energy Turnover, only 1% of the energy utilized for photosynthesis is fixed as wood. The energy stored in a leaf can be summarized as:

$I_{\text{absorbed solar rad.}} + I_{IR} = E_{\text{in leaf}} - (I_{\text{IR emitt.}} + \text{convection} + \text{conduction} + \text{evaporation}) = E_{\text{stored in leaf}}$

**Soil-Plant-Atmosphere Continuum**: See water potential;

**Stress** (L. stringere, to constrain): A significant deviation from conditions optimal for life, which elicitate changes and responses at all functional levels of the organism; these changes may be reversible, but if stress persists longer can be permanently, thus reducing the allover yield. Permanent changes depend upon stress-intensity and stress-duration.

Stress factor (stressor) indicates the stress stimulus, and stress response or state of stress which denotes the response to the stimulus as well as the ensuing state of adaptation.

- **Stimulus** oriented S.: Explaining the specific mechanism of stress response. Often, the external factor does not reach the ultimate site of the stress reaction (the protoplasm) immediately or in its original intensity, because plants possess a variety of protective mechanism to delay or even prevent disruption of the equilibrium between environment and cell interior. Buffering of stress factors can be by:
  Avoidance: All protective mechanisms that delay or prevent disruption of the thermodynamical or chemical equilibrium (cuticula, periderm, etc.)
  Tolerance: The ability to resist and survive the stressor (the change of equilibrium).
- **Functional** oriented S.: The dynamic response of the whole organism which can lead to a characteristic:
  Stress syndrome: Which includes the process leading to resistance; therefore, of *homeostatic* nature, aimed at normalizing the plant's vital function. The stress response is a race between the effort to adapt and the potentially lethal processes in the protoplasm.
  Distress: Dynamics of stress comprises a destabilizing effect upon the organism.
  Eustress: Dynamics of stress promotes a stabilizing and resisting effect upon the organism.

**Phases of** S.: The impact of stressors destabilizes vital structures and functions, inducing an:

- Alarm phase: Functional declines (stress reaction);
- Restitution: Mechanisms counter-reacting the stressor; if unable to cope lead to acute damage;
- Phase of resistance: Initial counter-effecting may lead to over-compensation (hardening); under prolonged exposure to a constant stress, a higher degree of resistance develops which may result in restabilization (adjustment).
- Phase of exhaustion: Over-taxing the organism with acute or chronic stress may lead to irreversible changes (exhaustion).

**Winter-stress**: Shorter days and low temperatures decreases speed of chemical reactions, causing the internal cell-equilibria to shift towards the energy release, lowering metabolic energy reserves, uptake of water and nutrients, assimilation, and growth (frost inhibits water uptake completely). Chilling sensitive plants suffer lethal damages, while freezing-sensitive tissue is killed as soon as ice forms within.

- **Frost** stress can be avoided by protective and evasive mechanisms:
  Freezing Point Depression: Lowering osmotic value of cell sap; provides moderate protection. Compartimentation of the central vacuole.
  Hardening: A stepwise process in which increasing temperatures in spring (> sugar, sugar - starch conversion) causes flush-growth (< levels of sugar + starch) that is followed by slow growth in late summer (> levels of sugar +starch) and completed by increased frost resistance and no growth in winter (starch sugar conversion); this can be easily observed by analyzing the growth rings of woody plants; (woody plants withdraw chlorophyll-precursors, $Mg^{2+}$ , $Ca^{+}$, sugar into mark rays - di- / oligosaccharides)
  Thermal Insulation: Dense growth surrounding regenerative buds (cushion), withdrawal of perennating organs beneath a covering of leaves or litter or in the ground (geophytes) and by abscission of sensitive organs (deciduous plants). Strengthening of phosho-lipid-bilayers of bio-membranes.
  Translocated Ice Formation: Water is transported from the tissue into intercellular spaces, where it freezes to form extensive masses of ice. This process causes the cell sap to thicken (freezing point depression)

**Stomata**: (Gk. stoma, mouth) Minute openings, bordered by guard cells in the epidermis of leaves and stems through which gases pass ($CO_2$, $O_2$, $H_2O$-vapor); the entire stomatal apparatus (guard cells plus pores).

- **Guard Cell**: Pairs of specialized epidermal cells surrounding a pore, or stoma; changes in turgor pressure of a pair of guard cells cause opening and closing of the pore.
- **Subsidiary Cell**: Special epidermal cells surrounding the guard cells, are also crucial for stomatal opening in that ions ($K^+$, etc.) are transported to/fro the guard cells; if the turgor of the guard cells becomes greater than that of the epidermal cells the stomata open; when not turgid, they closed.
  OPENING: Increase in turgor is an osmoregulatory process brought abut by the active transport of ions ($K^+$) are transported from the subsidiary cells into the guard cells the pores open. Charge in balance is prevented by the movement of inorganic anions ($Cl^-$), by the formation of organic anions (malate) or by the release of protons ($H^+$, pH rises as the pores open).
  CLOSURE: Is played by the controlled entry of cytoplasmic $Ca^{2+}$ via calcium channels and its release via calmodulin, acting together with abscisic acid (ABA).

**Gas Exchange**: Two reaction patterns are distinguished according to temperature and light conditions (partial pressure of $CO_2$ constant); net photosynthesis results out of the dominance of those two reactions:
**Photosynthetic** G.E.: During the day - $CO_2$, + $H_2O$ in / $O_2$ out.
**Respiratory** G.E.: Photo-respiration at night - $O_2$ in / $CO_2$ out.

- **Fick's 1st Law**: Diffusion through a medium, in which the resulting motion of diffusion follows the least significant concentration (due to Brownian motion) of the dissolved substance within the medium; rate of diffusion in water 1/10 of that in air:
  D, coeff. of diffusion [$m^2/s$]
  A = surface ⊥ diff.-gradient [$m^2$]
  $$\frac{-dn}{dt} = D \cdot A \cdot \frac{dc}{dl}$$
  -dn/dt, number of particles which diffuse during the time interval dt through the surface
  dc/dl, gradient of concentration in the direction of diffusion
- **Resistance** to GE (diffusion): The complex morphological structure of a leave imposes diffusion resistances; < in bright light plants, > in dim light plants, conifers, etc.
  $r_\Sigma = r_a + r_l + r_w + r_k$
  $r_a$ external res. (surface of leave, etc.)
  $r_l$ stomatal res. (number + aperture)
  $r_w$ transition barrier of gas to parenchyma
  $r_k$ chemical resistance

**Stomatal Regulation**: Stomatal movements results from changes in turgor pressure with in the guard cells. The major solute responsible for this gradient is potassium ($K^+$); higher $K^+$ and $Cl^-$ concentration causes stomata to open (water rushes in due to osmosis), whereas closure when it drops. Opening occurs when solutes are actively accumulated in these cells. Stomatal closure is brought about by the reverse process (a declining guard cell solute); water moves out of the guard cells lowering turgor pressure. Guard cells chloroplasts fix $CO_2$ photosynthetically to form sugar, which contribute to the solute buildup required for stomatal opening.

- Rule of thumb: Guard cells close stomata, if $CO_2$ concentration within the leaf is greater than atmospheric concentration; closure also occurs during the night. CAM-plants show reversed open / closure pattern.

Factors that effect stomatal movement (for regulation of stomata see scan below):

1. Increase in <u>$CO_2$ concentration</u> (sensors in guard cells, PEP & Rubisco) cause stomata to close.
2. <u>Water shortage</u> increases concentration of **ab**cidic **a**cid (ABA, originating from mesophyll) which causes $K^+$ to leave the guard cells resulting closed stomata.
3. <u>Temperatures</u> > 30 to 35°C causes stomatal closure.
4. <u>Circadian rhythm</u> (L. circa, approx. + dies, day) contribute to stomatal opening and closure. Stomata open with light (blue light stimulate stomatal opening, independent of $CO_2$ due to $K^+$ uptake by the guard cells) and close in darkness (red light stimulate stomatal closing).
5. <u>Dryer air</u> and <u>wind</u> accelerates dehydration of plant; water loss can be retarded by epidermal hairs or stomatal openings lowered into the mesophyll.
6. Glycolytic breakdown of starch (in guard cells of $C_4$-plants only) to PEP is used to form <u>malate</u> (along with $CO_2$), an increase level of <u>malate</u>, cause stomata to open.

**Distribution** of S.: According to the stomatal distribution on a leaf, following patterns can be distinguished:

- **Amphistomatic** Leaf: Stomata are found on both sides of the leaf.
- **Epistomatic** Leaf: Stomata are located on the upper side of the leaf, as in water plants.
- **Hypostomatic** Leaf: Stomata located at the lower side of the leaf.

**System**: A group of interacting elements functioning as a complex whole.

**Ecosystem**: A community of organisms interacting with a particular environment, i.e.: a holistic concept of the plants, the animals habitually associated with them and all the physical and chemical components of the immediate environment or habitat which together form a recognizable self-contained entity.

**Function** of E.: The proper, normal or characteristic activity of an ecosystem.

- Organical: structure, starting from a single cell entity (protozoa) all the way up to multi-cell individuals (metazoa) who live and grow in association.
- Ecological: connection of different species that live in their biotop and are biocenotically connected.

**Structure** of E.: Something made of parts that are put together in a particular way to form a whole.

- Geographical: physical structure of space;
- Chemical: amount and distribution of organic and inorganic resources;
- Biological: trophic levels, spectrum of life-forms (species diversity);

**Water**: Liquid substance of H-O-H molecules, in which intermolecular forces (H-bonds) are responsible for the high boiling point; the water molecule is bent due to the lone pair of the O and possess a dipole moment, since the O-atom (more electronegative) deprives the H-atoms off their electron clouds.

| thermal energy [kJ/kg] | ice | ice & water | water | water & steam | Steam |
|---|---|---|---|---|---|
| phase of water | 0-21 (Δ21) | 21-356 (Δ331) | 356-775 (Δ419) | 775-3035 (Δ2260) | - |

**Ground-**W.: Water beneath the earth's surface that supplies wells and springs.

- Haft-W.: Water that is kept by cohesion and capillary forces in the soil and does not drift down to the groundwater.
- Senk-W.: Excess water that cannot be stored by the soil drains off to feed groundwater reserves.

**Condensation**: The phenomenon of going from gaseous state to the liquid state (see physics - matter).

**Evaporation**: The escape of molecules from the surface of a liquid; also called vaporization.

**Freezing Point**: The temperature at which a liquid freezes (crystallization); the normal freezing point is the freezing temperature under a pressure of 1atm, i.e.: liquid and solid phase are in equilibrium.

**Humidity**: (L. humere, to be moist) To make humid, containing a large amount of water or water vapor. In a given volume, the partial pressure ($p_p$) of any particular gas ($O_2$, $N_2$, $H_2O$-vapor, etc.) is the same as if the gas occupied that volume alone (see chemistry gas - Dalton's Law); if more water vapor is added to a given volume of air at a given temperature, the $p_p$ of $H_2O$ is increased; when $p_p$ equals vapor pressure ($v_p$) for that temperature, the air is saturated. Water vapor begins to condense into liquid $H_2O$ if the temperature is >0°C, or into ice crystals (snow or frost) if the temperature is <0°C.

- **Absolute** H.: The amount of water vapor that a given volume of air can store without condensation, usually given in [g/m$^3$]; the warmer the air, the more vapor can be held (exponential relation).
- **Dew Point**: The temperature at which air becomes saturated with water vapor and starts to precipitate; that is, the temperature at which the relative humidity = 100%; this can be achieved by either increasing the amount of water vapor in the air at a given temperature or by lowering the temperature and thereby lowering $v_p$; i.e. when the surface cools below the dew point at night due to radiation;
  Dew forms if the dew point is >0°C;
  Frost forms if the dew point is <0°C.
- **Relative** H.: $$H_{rel} = \frac{\text{partial pressure } (p_p)}{\text{vapor pressure } (v_p)} \cdot 100 \quad [\%] = \frac{\text{absolute humidity}}{\text{max. humidity}} \cdot 100 \quad [\%]$$

**Vapor**: The gaseous phase of a substance (specifically, of a substance that is a liquid or a solid at the temperature in question);

- V. **Pressure** ($p_v$): The pressure exerted by the vapor of a liquid (or solid) when the vapor and the liquid (or solid) are in dynamic equilibrium; the higher the intermolecular forces the lower the vapor pressure;
  e.g.: $H_2O(g) \leftrightarrow H_2O(l)$

**Water Potential** ($\Psi$): The algebraic sum of the solute potential and the pressure potential, or wall pressure; the potential energy of water. Water moves from places of *higher* (+) water potential to places with *lower* (-) water potential i.e. along a decreasing $\Psi$-gradient (exergonic); any reverse transport requires energy (endergonic);

$\Psi = \Psi_{turgor\ -p} + \Psi_{\Pi\ (osmot.\ H2O\ pot.)} + \Psi_{gravity} + \Psi_{capillar} < 0$ — the more neg., the higher water uptake

**Chemical Potential** ($\mu_j$): The energetic condition of open chemical systems; in [J/mol]:

$\mu$ = free energy/molar amount = $\Delta G/n$

$\mu_{H2O} = \mu_{H2O}^0 + R \cdot T \cdot \ln(a_{H2O}) + \bar{v}_{H2O} \cdot p + F \cdot E \cdot z_{H2O} + g \cdot h \cdot m_{H2O}$

ground-level + term of concentration +term of pressure + electrical term + term of gravity

According to the equations above, an exchange can only occur if there are concentration-, pressure-, elevation-gradients present within a given system

| | | |
|---|---|---|
| R, gas constant | 8.314 | [J/(mol·K)] |
| T, temperature | | [K] |
| $a_{H2O}$, relative activity of water | | [-] |
| $\bar{v}_{H2O}$, partial molal volume | | [$m^3$/mol] |
| p, pressure | | [$N/m^2$] |
| F, Faraday const. | $96.94E^3$ | [J/(V·mol)] |
| E, voltage | | [V] |

**Osmosis**: (Gk. osmos, impulse, thrust) The diffusion of water, or any solvent, across a differentially permeable membrane in the absence of other forces, the movement of water during osmosis will always be from a region of greater water potential to one of lesser water potential.

- O. **Potential** ($\Pi$): The change in free energy or chemical potential of water produced by solutes; carries a negative (minus) sign; also called solute potential.
  $\Pi = - R \cdot T \cdot \ln(a) / \bar{v}_{H2O}$
- O. **Pressure**: The potential pressure that can be developed by a solution separated from pure water by a differentially permeable or semipermeable membrane; it is an index of the solute concentration of the solution; the more negative $\Pi$, the higher affinity of water.

**Permanent Wilting Point** (PWP): The amount of water remaining in soil when a plant fails to recover from wilting even if places in a humid chamber. $\Psi_{pwp\text{-}soil} \approx$ -15bar ($\approx 1.5E^6$ Pa)

**Soil-Plant-Atmosphere Continuum**: The plant bridges the steep $\Psi$ (water-potential) gradient between soil and air. The shoot is exposed to a low $\Psi$, i.e. vapor pressure deficit, whereas the roots are embedded into a more or less humid environment. The steepest $\Psi$-gradient is that between the shoot surface and the dry air. This is due to the high energy requirement for the evaporation of water (2.45kJ/g water at 20°C) and to the epidermal resistance to diffusion at the inter-cellular spaces of a leaf's mesophyll (see water potential and scans below)

$\Psi_{Soil} > \Psi_{Root} > \Psi_{Leaf} > \Psi_{Air}$ — $\mu_{H2O}$, chem. pot. of bound water

$\Psi = p - \Pi + \rho_{H2O} \cdot g \cdot h = (\mu_{H2O} - \mu_0) / \bar{v}_{H2O}$ — $\mu_0$, chem. pot. of pure water

**Thermodynamics**: (Gk. therme, heat; dynamics, power) The study of heat (Kinetic Energy) and its transformation to other forms of energy (see physics - heat);

- **1st Law of** T.: States that in all processes, the total energy of the universe remains constant (energy conservation - energy cannot be lost or gained, just transformed).
- **2nd Law of** T.: States that the entropy, or degree of randomness, tends to increase. Heat will never spontaneously flow from a cold object to a hot object.
  $\Delta G = \Delta H - T \cdot \Delta S$

  | | |
  |---|---|
  | $\Delta G$, free energy of change | [J/mol] |
  | $\Delta H$, entalphy | [J/mol] |
  | T, temperature | [K] |
  | $\Delta S$, entropy | [J/mol] |

  $\Delta G$ defines the available energy content of a chemical substance; if negative, the system can supply energy (exergonic), whereas of positive, the system requires energy (endergonic) to achieve a change.

**Temperature**: The quantity that tells how warm an object is, with respect to some reference. A measure of the average kinetic energy per molecule in a substance, measured in [°C] or in [K]. Plants behave like *black bodies*, i.e. a body that absorbs all the radiation incident upon it.

**Trophic Level**: (Gk. trophos, feeder) A step in the movement of energy through an ecosystem, represented by a particular set of organisms.

**Autotrophic**: An organism that is independent of outside sources for organic food materials and manufactures its own organic material from inorganic sources.

**Heterotrophic**: An organism with a requirement for energy-rich organic molecules from outside (animals, fungi and most bacteria).

T. **Interactions**: The exchange of matter between producers and consumers which results in

Competition: A interaction between 2 or more organisms (species), in which, for each, the birth and / or growth rates are depressed and / or death rate increased by the other organism (or species). In plants mainly focused at space-, light-, resources-, water-competition.

Communication: Plant hormones (phyto-hormones) and other secondary plant-chemicals extracted by an organism interfere with their environment; e.g.: protection, pollinators, growth suppressors, etc.

Cooperation: An interaction that enables growth of one organism (species) by protecting and favoring the growth and development of an other organism (species); e.g.: shade-plants, etc.

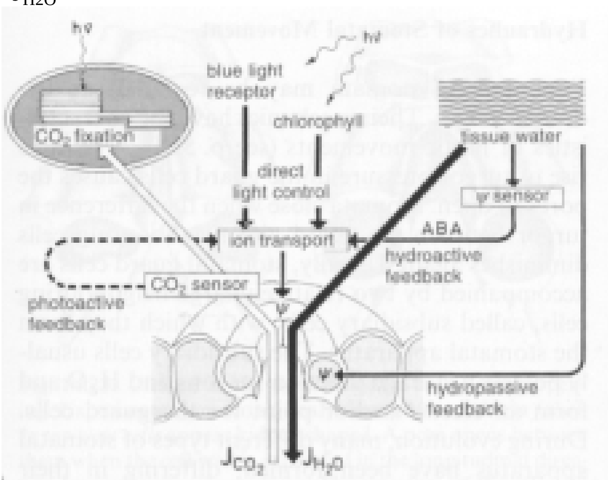
- **Carnivory**: The consumption by an organism of living animals or parts of living animals.
- **Saprophily**: An organism that carries out external digestion of non-living organic matter and absorbs the products across the plasma membrane of its cells; e.g.: fungi. By doing so re-mineralize the soil.
- **Symbiosis**:(Gk. sumbiosis, companionship) The living together of two organisms of different species.

  **Comensalism**: Members of the two species in which one member benefits and the other is neither benefited nor harmed.

  **Mutualism**: Relationship between 2 species beneficial to both (e.g. host = plant; symbiont = bee).

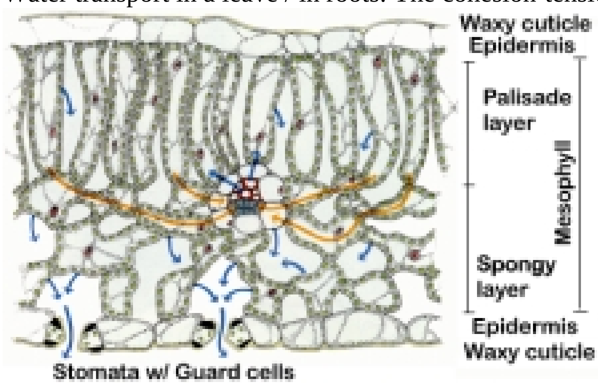
  **Parasitism**: One member (parasite) lives in or on the living body (epi-/endoparasite) of a plant or animal (host) and obtains its nourishment at the expense of the host.

Model of the regulation of gas transport through stomata by light, $CO_2$ and water potential in the leaf: fluxes $J_{CO2}$, $J_{H2O}$

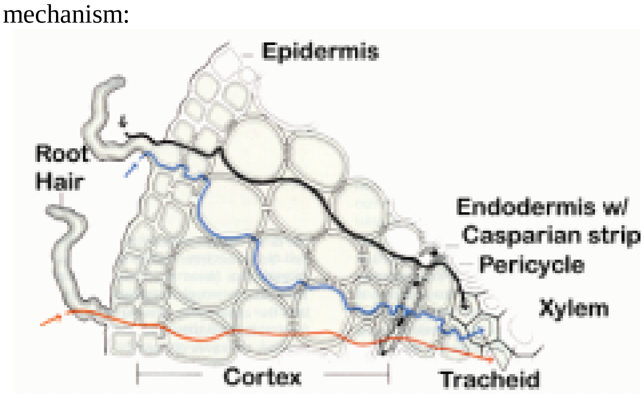



The $CO_2$ sensor of guard cells measures the $CO_2$ concentration in the sub-stomatal cavity, which is influenced by a variable e.g. light. The $CO_2$ sensor regulates, via ion import or export ($K^+$, $Cl^-$, etc.), the water potential ($\psi$) of the stomatal guard Cells, and thus stomatal aperture and $CO_2$ flux, to a predetermined, constant set point of $CO_2$ concentration (photo-active feedback system). In normal daylight the regulation by light signals is more important. These signals are received in the guard cells by chlorophyll and a blue light photoreceptor (direct control by light). The *hydro-active* feedback system controls the stomatal aperture according to the water potential in the mesophyll, whereby the hormone abscidic acid participates as the signal carrier. A *hydro-passive* feedback exists between the water state of the stomatal guard cell and the whole leaf.

Water transport in a leave / in roots: The cohesion-tension mechanism:




Pathways followed by water molecules of the transpiration stream as they move from the xylem of a minor vein to the mesophyll cells, evaporate from the surface of the mesophyll cell walls, and then diffuse out of the leaf through an open stoma (blue);
Sugar molecules manufactured during photosynthesis move from the mesophyll cells to the phloem of the same vein and enter the assimilate stream (gold);




Pathways for the movement of water from the soil, across the epidermis and cortex, and into the tracheary element of the root apoplastic (black) symplastic (blue), and transcellular (red). Water following an apoplastic pathway is forced by the Casparian strip of the endodermal cells to cross the plasma membranes and protoplasts of the endodermal cells on its way to the xylem, to enter again the apoplastic pathway again once passed this point and make its way to the lumina of the tracheary elements.

| Out of a 100% solar radiation reaching the earth, incident: | | | | |
|---|---|---|---|---|
| | Reflected | Absorbed | Re-emitted as diffuse background radiation | Σ |
| Clouds | -25% | -10% | 17% | 52% |
| Direct | - | -9% (aerosols) | 24% (direct) | 33% |
| Atmosphere | -9% | - | 6% | 15% |
| Ground radiation | | | 47% | |