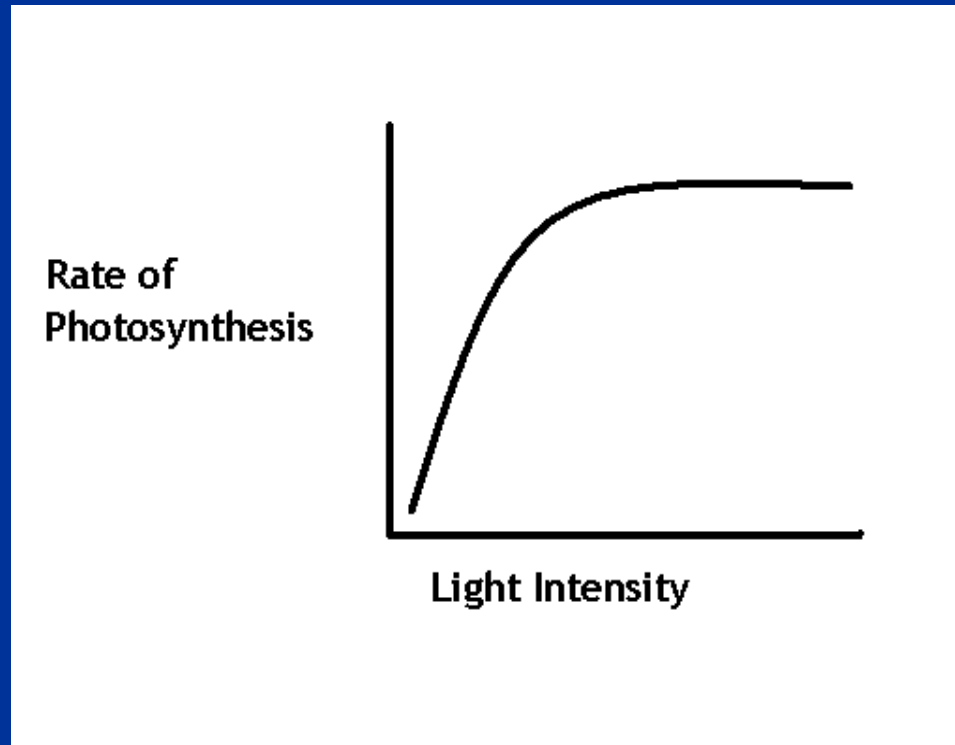


# Ekologiefyziologie fotosyntézy

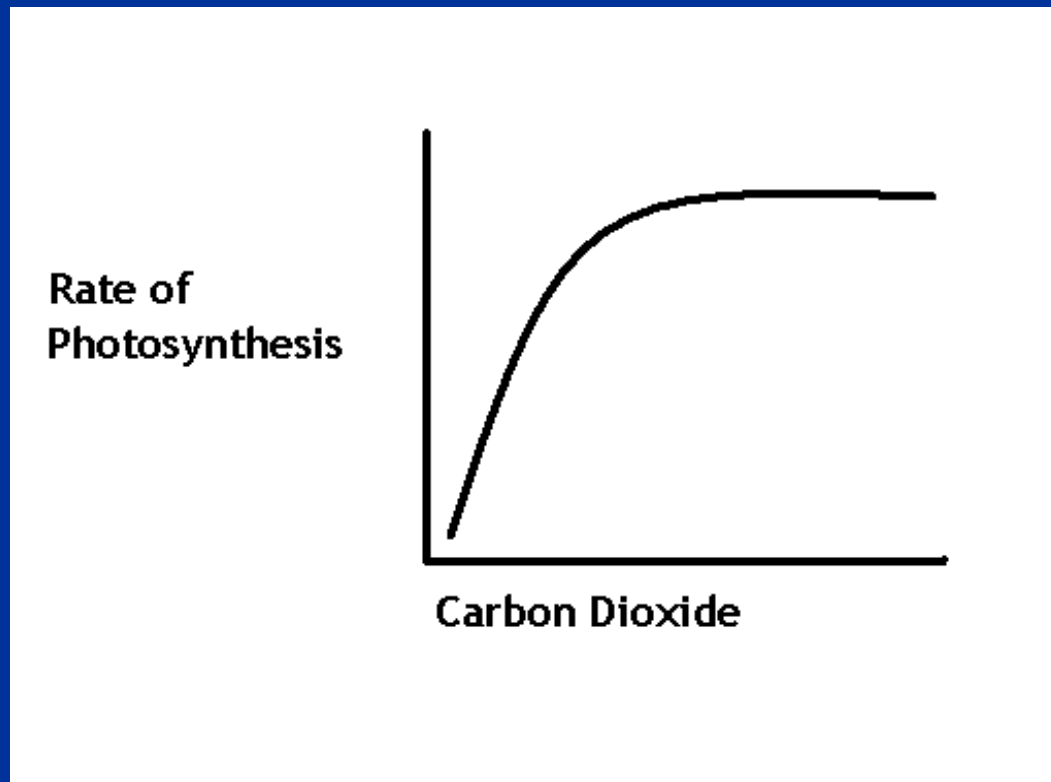
# PHOTOSYNTHESIS

- What affects photosynthesis?
  - Light intensity: as light increases, rate of photosynthesis increases



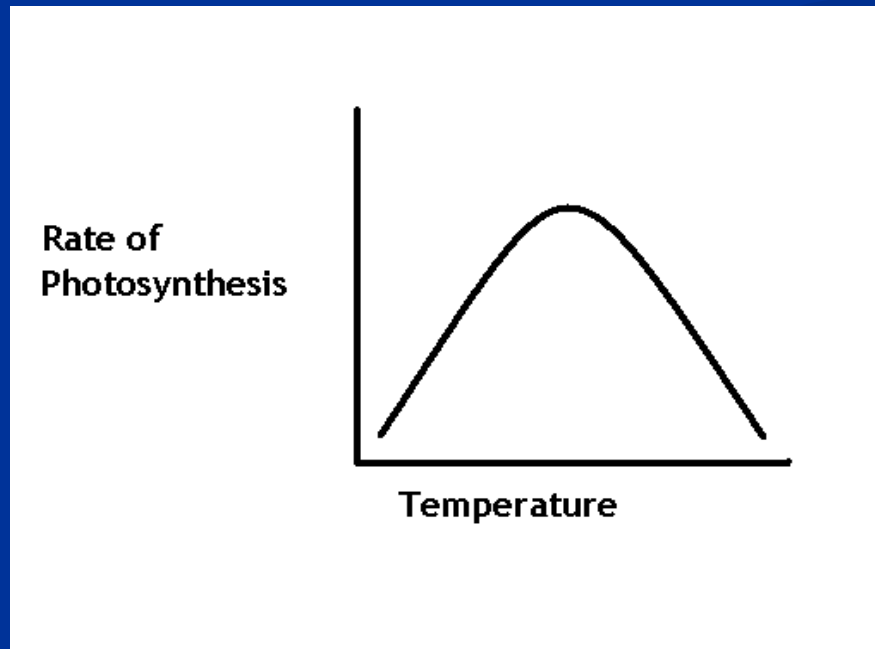
# PHOTOSYNTHESIS

- What affects photosynthesis?
  - Carbon Dioxide: As  $\text{CO}_2$  increases, rate of photosynthesis increases



# PHOTOSYNTHESIS

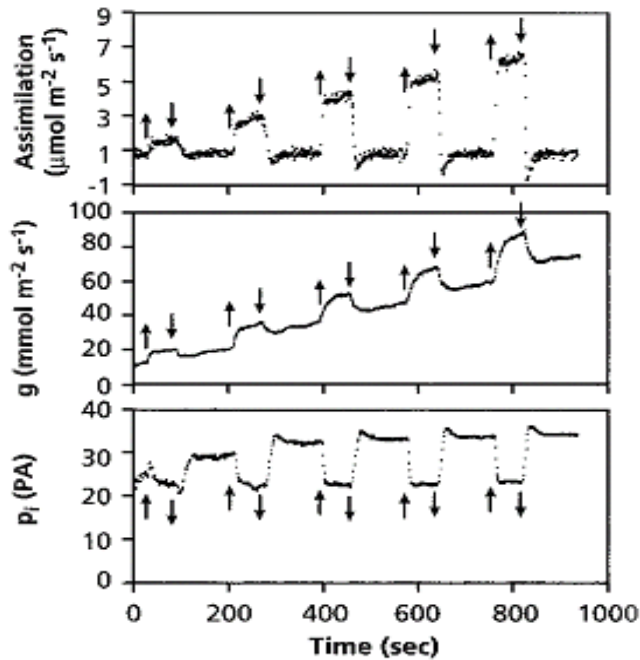
- What affects photosynthesis?
  - Temperature:
    - Temperature Low = Rate of photosynthesis low
    - Temperature Increases = Rate of photosynthesis increases
    - If temperature too hot, rate drops



# Ekologie fotosyntézy - sluneční záření

## ■ Heliofyty vs. sciofyty

- Využití slunečních skvrn
  - variabilní intenzita a délka (ca 40-60% celkového příkonu záření podrostu)
  - fotosyntetická indukce - aktivace fotosyntetického aparátu
  - sciofyty - vysoká efektivita



• Distinctive characters of s

respiration  
light compensation point  
half saturation point  
light saturation point  
maximum rate of photosynthesis  
quantum yield

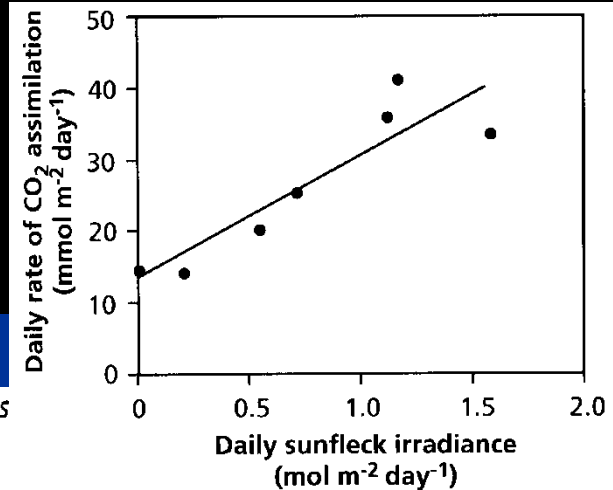


FIGURE 24. Total carbon gain of *Adenocaulon bicolor* as a function of daily photon flux contributed by sunflecks in the understory of a temperate redwood forest (Chazdon & Pearcy 1991). Copyright American Institute of Biological Sciences.

# Ekologie fotosyntézy - sluneční záření

## Slunné vs. stinné listy

- listová plocha
- tloušťka mezofylu, poměr sklerenchym. pletiv   motnost sušiny na plochu
- počet chloroplastů a obsah chlorofylu, počet a rozměr průduchů
- světelný kompenzační bod a saturační hodnota PhAR

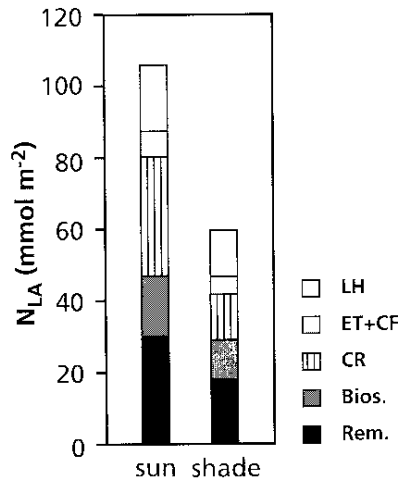


FIGURE 13. Nitrogen partitioning among various components in shade- and sun-acclimated leaves. Most of the leaf's nitrogen (here expressed per unit leaf area; N<sub>LA</sub>) in herbaceous plants is involved in the photosynthetic apparatus. Some of the fraction labeled Biosynthesis and Remainder is indirectly involved in synthesis and maintenance processes associated with the photosynthetic apparatus. LH = light harvesting (LHC, PSI, PSII), ET + CF = electron transport components and coupling factor (ATPase), CR = enzymes associated with carbon reduction (Calvin cycle, mainly Rubisco), Bios = Biosynthesis (nucleic acids and ribosomes), Rem = remainder, other proteins and nitrogen-containing compounds (mitochondrial enzymes, amino acids, cell-wall proteins, alkaloids, etc.) (after Evans & Seemann 1989).

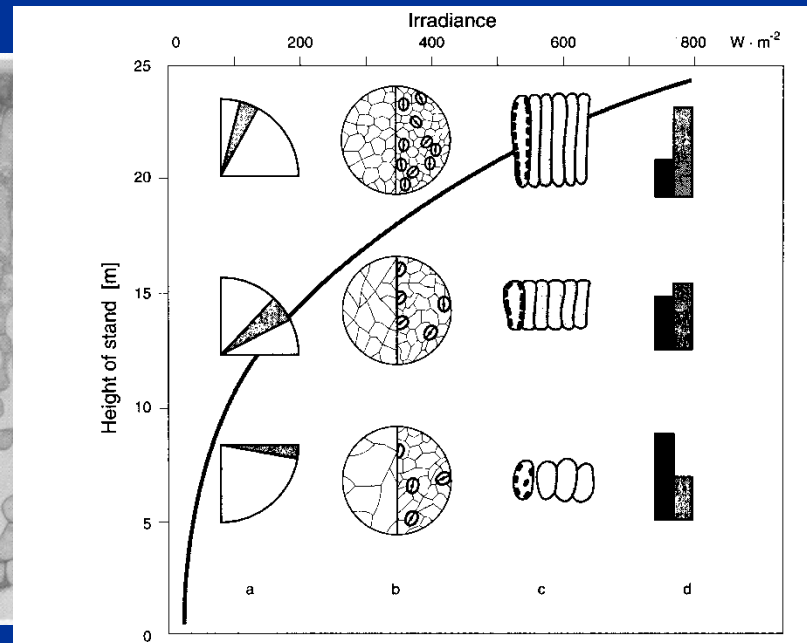
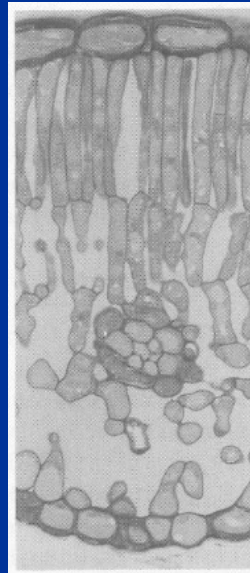


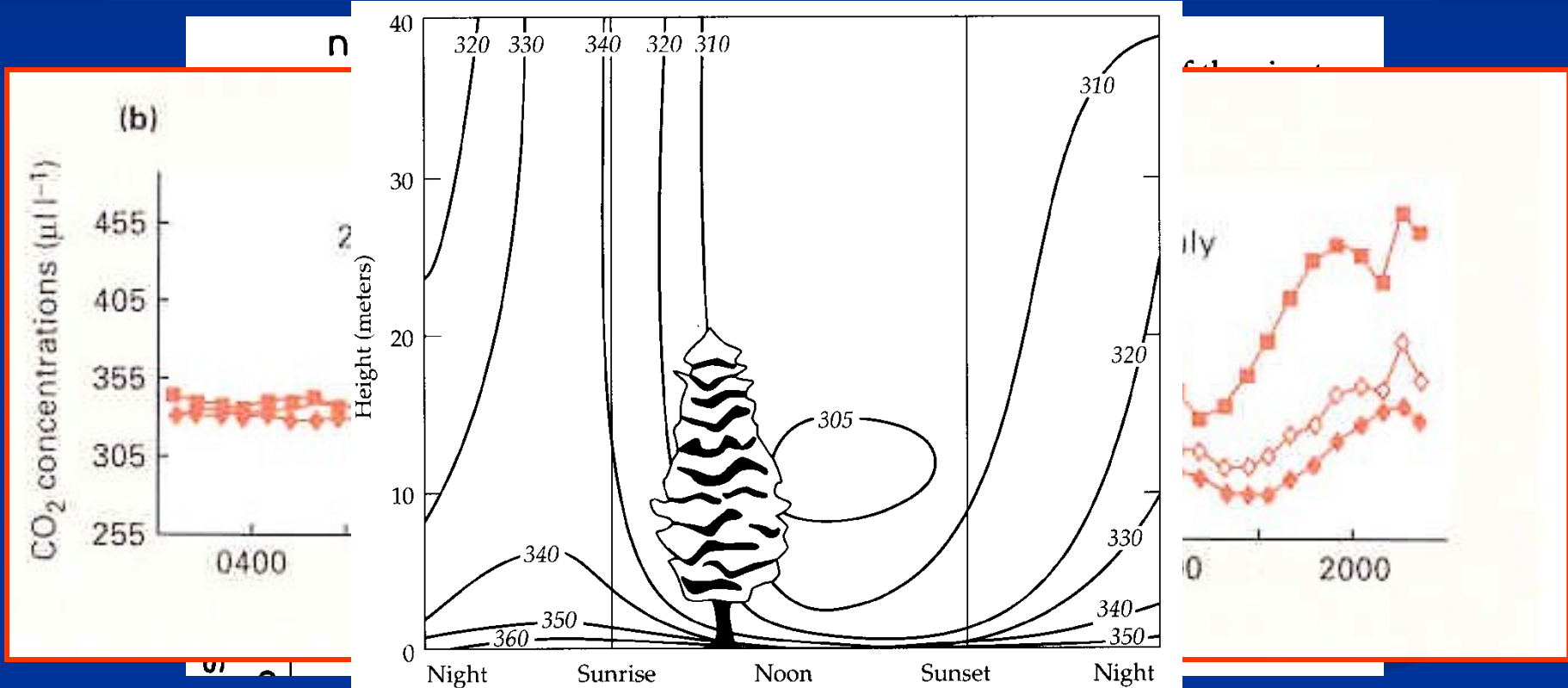
Fig. 1.34a–d. Structural adaptations to the light climate in an *Quercus-Tilia* forest. The curve indicates the average irradiance at noon on clear days in July. a Predominant leaf inclination. b Density of venation on the leaf surface (left half) and stomatal density on the lower surface (right half). c Typical shape of the cells of the palisade parenchyma. d Chlorophyll content per cell, referred to fresh weight (left) and surface area (right). (After Tselniker 1978; Goryshina 1980, 1989). For modificative responses to the microclimate in conifer forests see Aussenac (1973), for structural and functional adaptations of sclerophyllous leaves of mediterranean shrubs see Gratani (1993)

Photon flux density  
[ $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ ]

CO<sub>2</sub> gas exchange

# Dostupnost CO<sub>2</sub> - vliv rostlin na koncentraci plynů

- Obsah CO<sub>2</sub> ve vzduchu není pro rostliny limitujícím faktorem
- limitní koncentrace CO<sub>2</sub> mohou být ve vodě
- v porostech při povrchu půdy je vlivem respirace půdních (mikro)organismů a kořenů koncentrace CO<sub>2</sub> zvýšená



Změny kon

**Figure 12-10** Typical profiles of concentrations of CO<sub>2</sub> for a forest canopy at different times of day. Isopleth lines for CO<sub>2</sub> are in parts per million (ppm). From Holmén, K. 1992. "The global carbon cycle." In *Global Biogeochemical Cycles*, pp. 239–262. London: Academic Press. Used with permission.

zimě a v létě

# Ekologie fotosyntézy - dostupnost CO<sub>2</sub>

- Koncentrace CO<sub>2</sub> v atmosféře relativně stabilní (0.035%, 350 ppm, 35 Pa)
- Fickův zákon - difúze přímo úměrná konc. gradientu a nepřímo úměrná sumě odporů  $J_{CO_2} = \frac{A(p_i - p_a)}{r_{chl} + r_{mes} + r_{st} + r_{ias} + r_{bl}}$  kritická především difúze přes průduchy
- CO<sub>2</sub> saturační křivka (*A-p<sub>i</sub> křivka* - A - asimilace, p<sub>i</sub> - parciální tlak CO<sub>2</sub> v listu) - C3 rostliny p<sub>i</sub> obvykle ~ 25 Pa, C4 ~ 10 Pa (vyšší afinita PEP vázat CO<sub>2</sub>)
- kompenzační bod - čistá asimilace rovna nule (fotosyntéza = respirace)

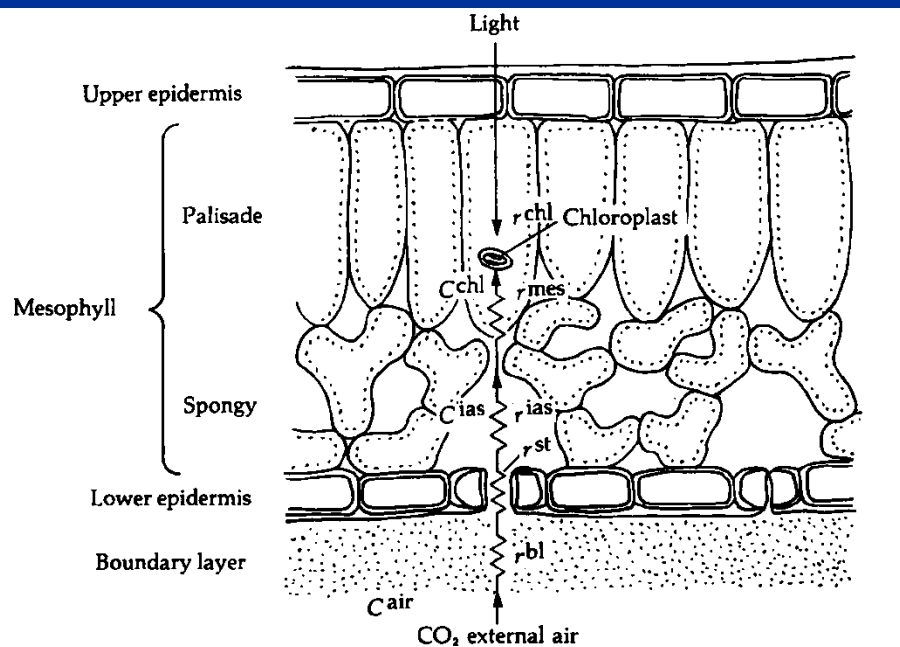
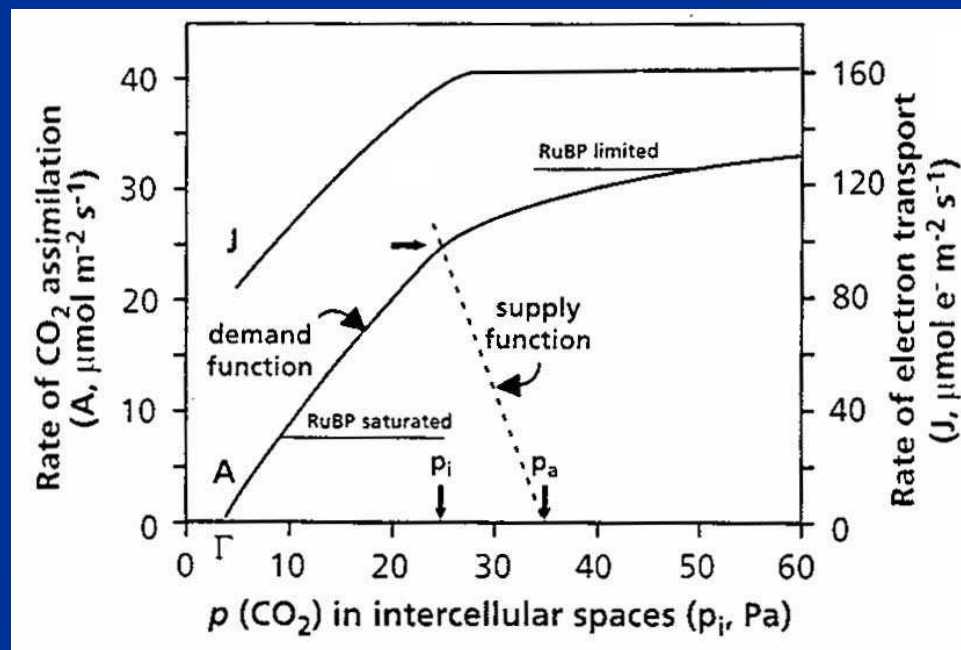


Figure 15-6 Transport pathway, transport resistances, and concentration gradients in a photosynthesizing leaf. See text for definition of terms.





# Evolve C4 rostlin

- C4 možná odpověď na klesající koncentrace CO<sub>2</sub>
  - Lambers *et al.* pozdní Miocén před 5-8 mil. lety (trávy snad až 30 Mya)

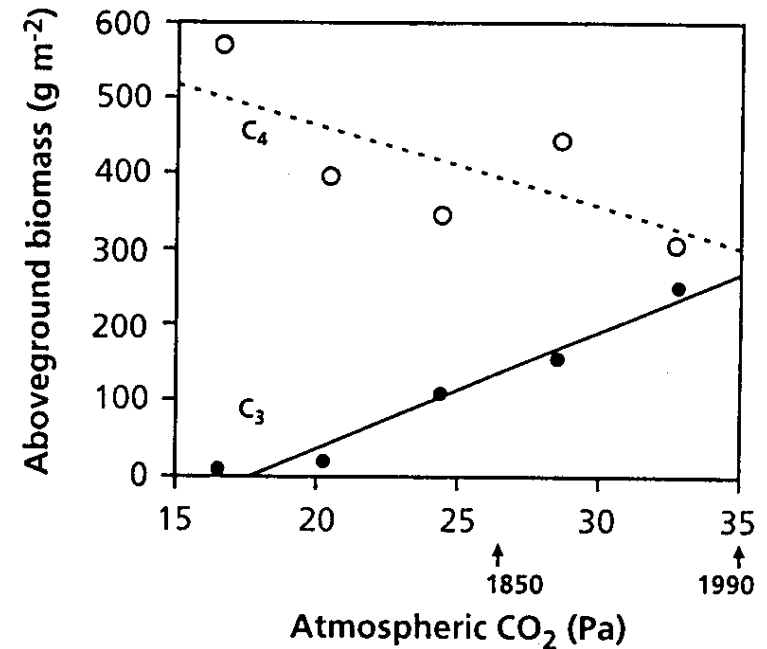
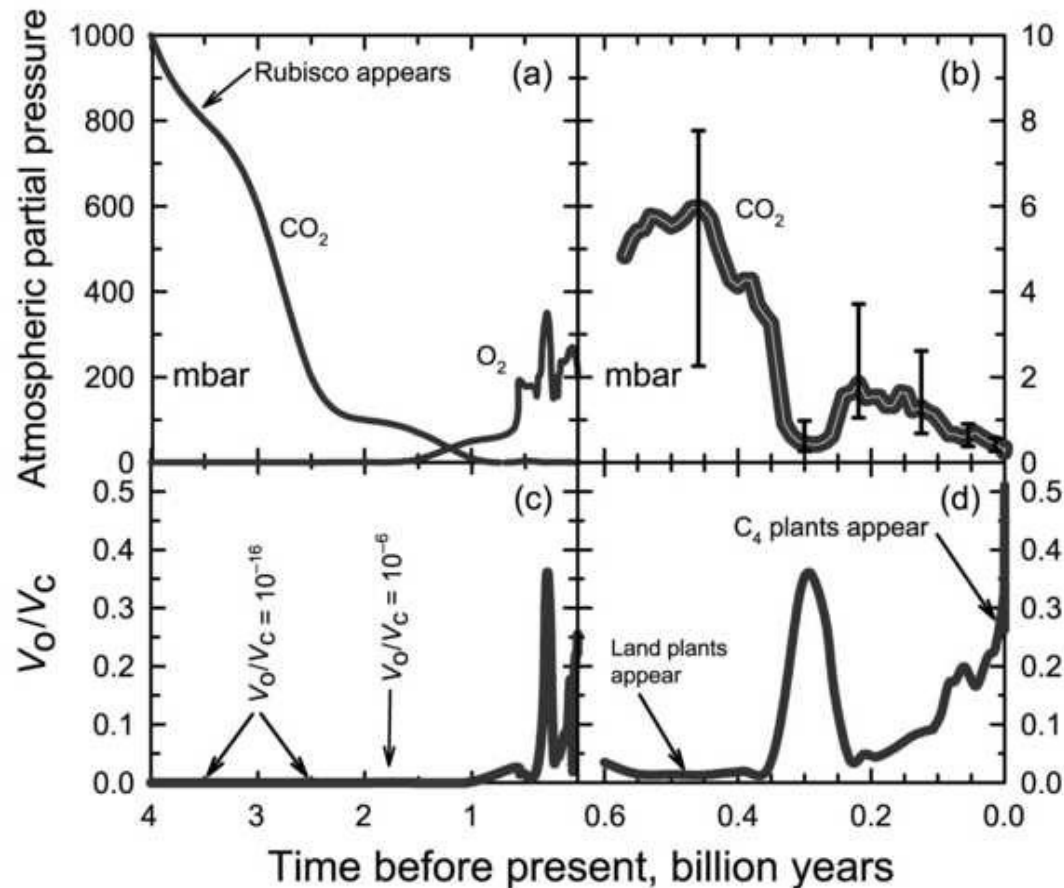
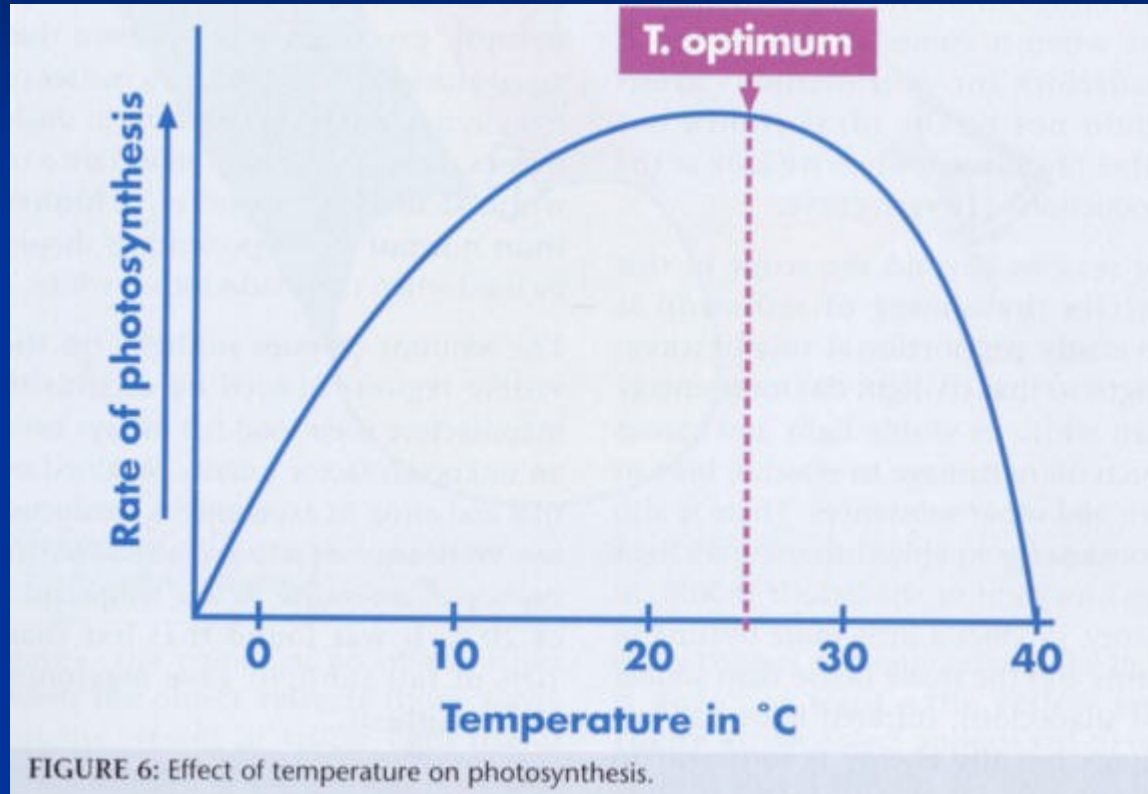


FIGURE 9. Above-ground biomass of C<sub>3</sub> and C<sub>4</sub> species that developed from the seed bank of a Texas savanna soil over a range of CO<sub>2</sub> concentrations from 15 to 35 Pa over a period of 13 weeks (Johnson et al. 1993). Copyright Kluwer Academic Publishing.

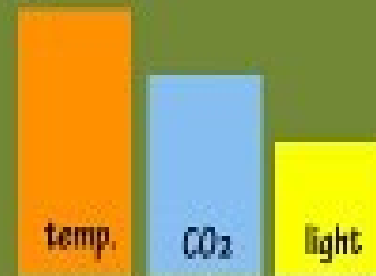
# Teplotní křivka fotosyntézy



## Limiting factors on photosynthesis



Assuming that the supply of nutrient and other environmental conditions are correct, three factors affect the rate of photosynthesis: temperature, carbon dioxide (CO<sub>2</sub>) and light.



If one factor is in short supply, photosynthesis will be restricted. Increasing the temperature and CO<sub>2</sub> content will not increase photosynthesis if the plants do not receive enough light.

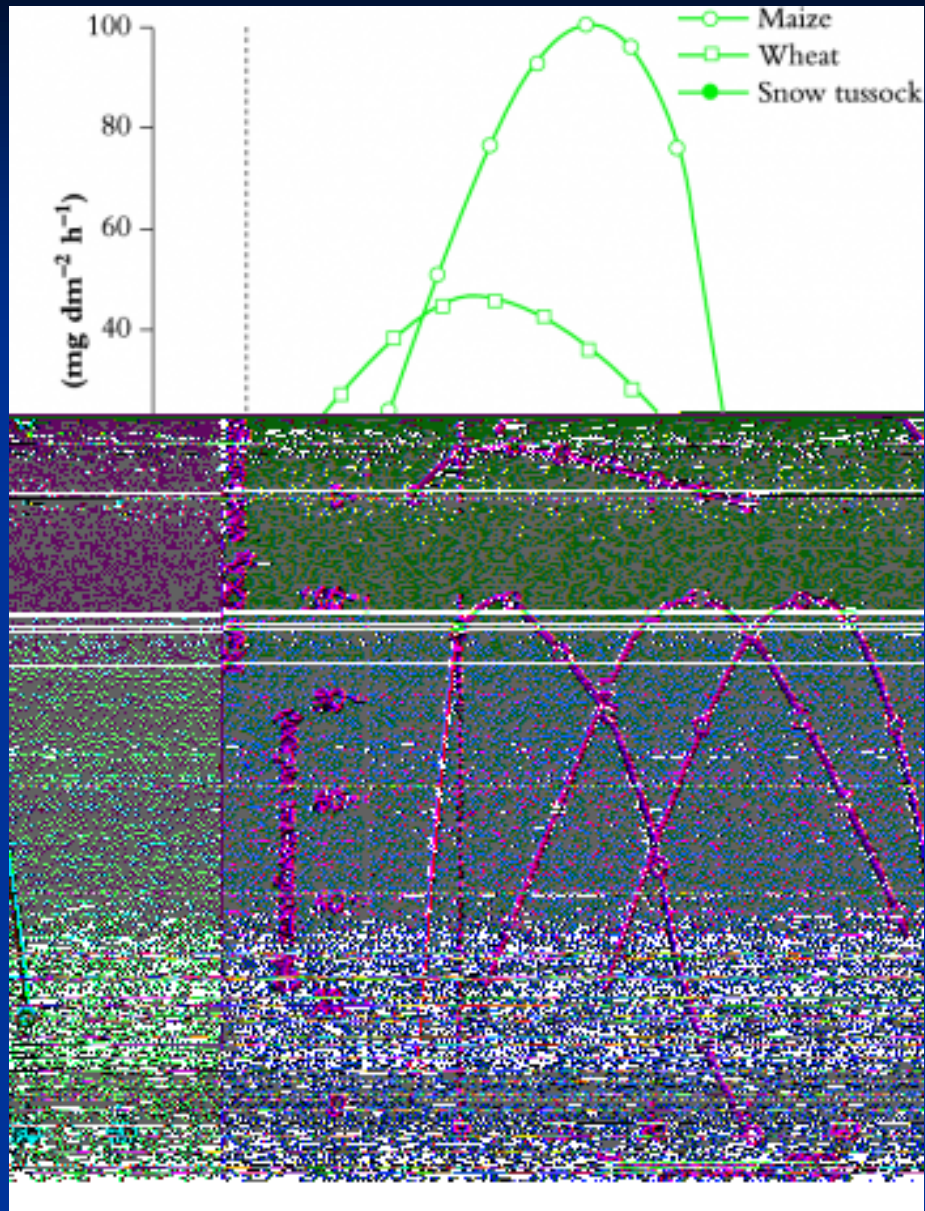


In most aquariums, the CO<sub>2</sub> content of water is limiting factor. even with the correct temperature and good lighting, plants will not grow well if they receive little CO<sub>2</sub>.

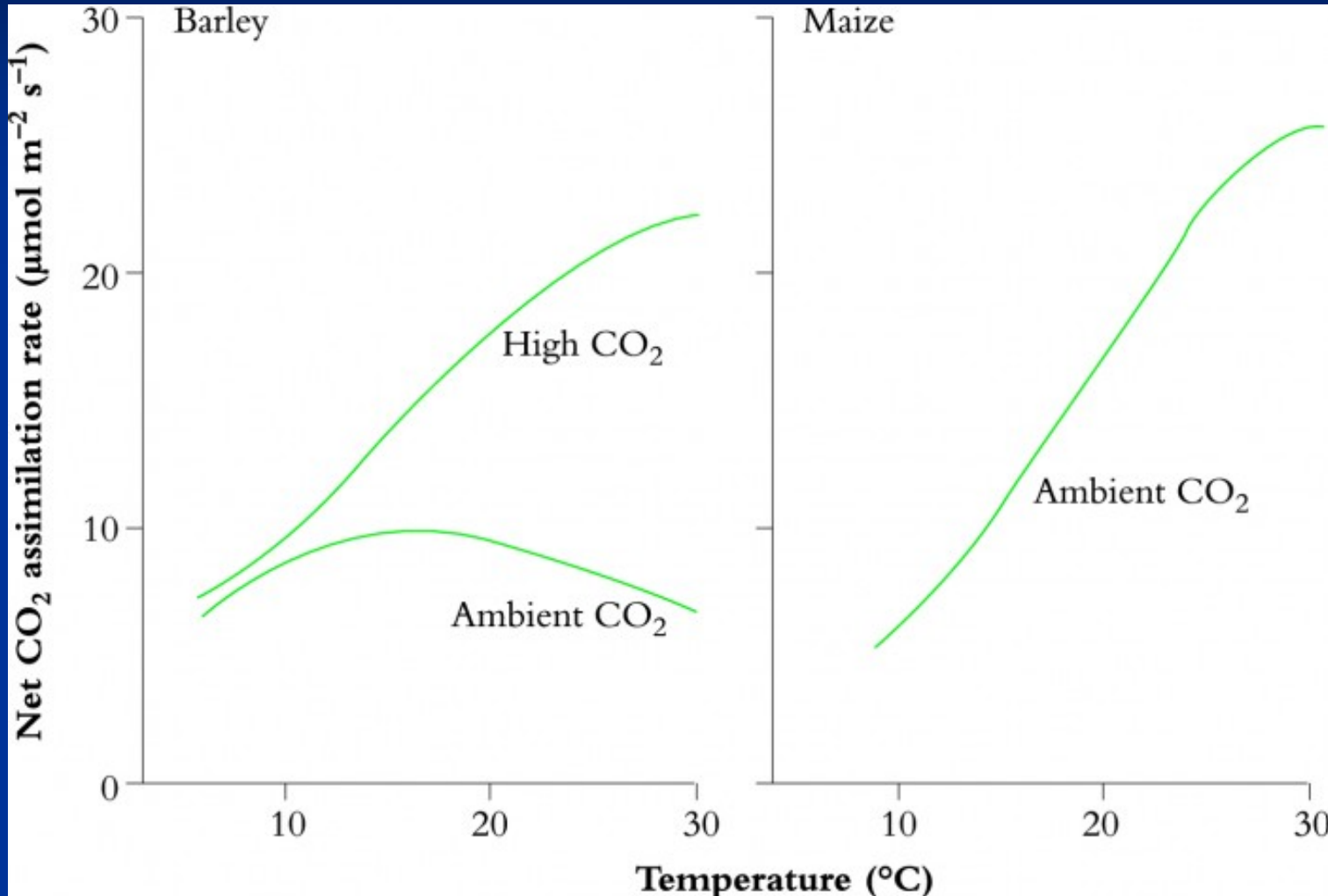


Once CO<sub>2</sub> and lighting levels are sufficiently high, and the temperature is at an optimum level, the rate of photosynthesis will increase rapidly. Mostly this will produce a healthier aquarium plant.

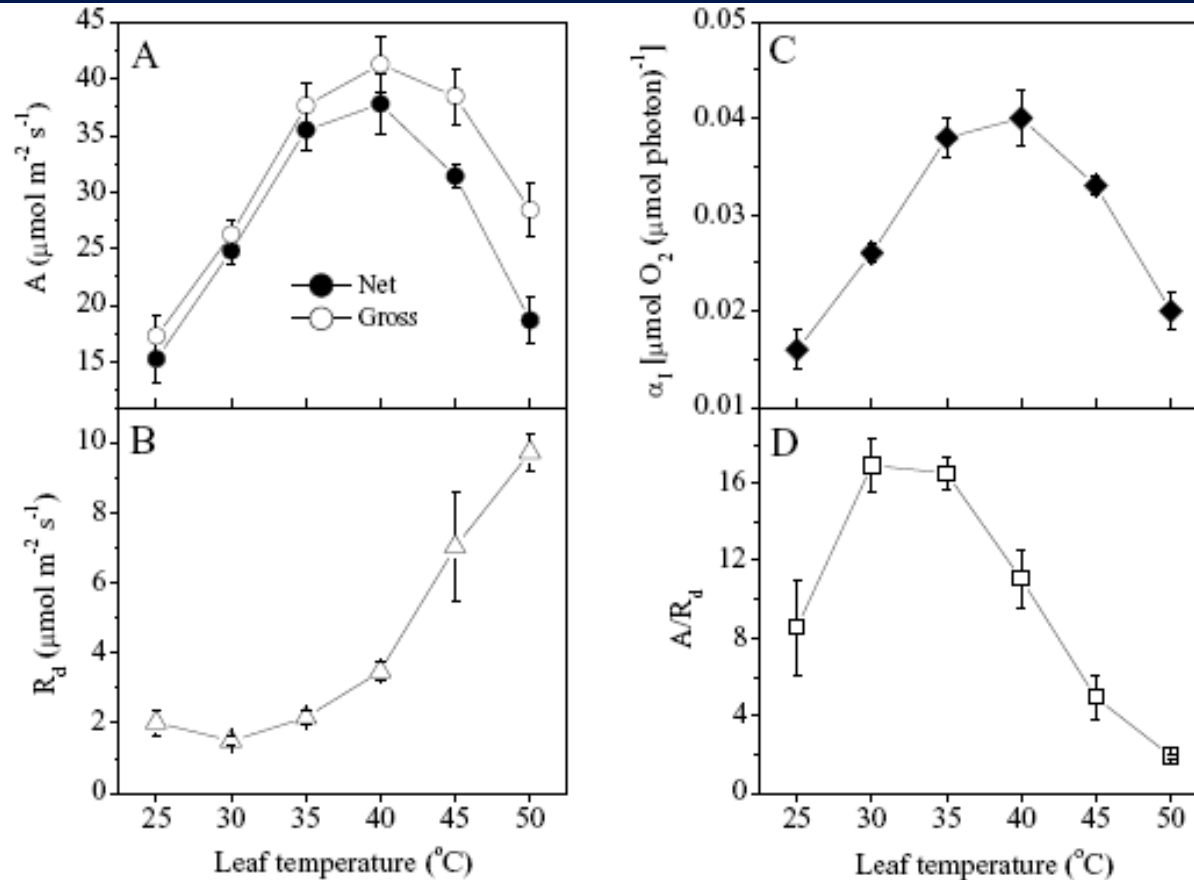
# Teplotní křivka – mezidruhové rozdíly



# Vysoká teplota v kombinaci s CO<sub>2</sub>



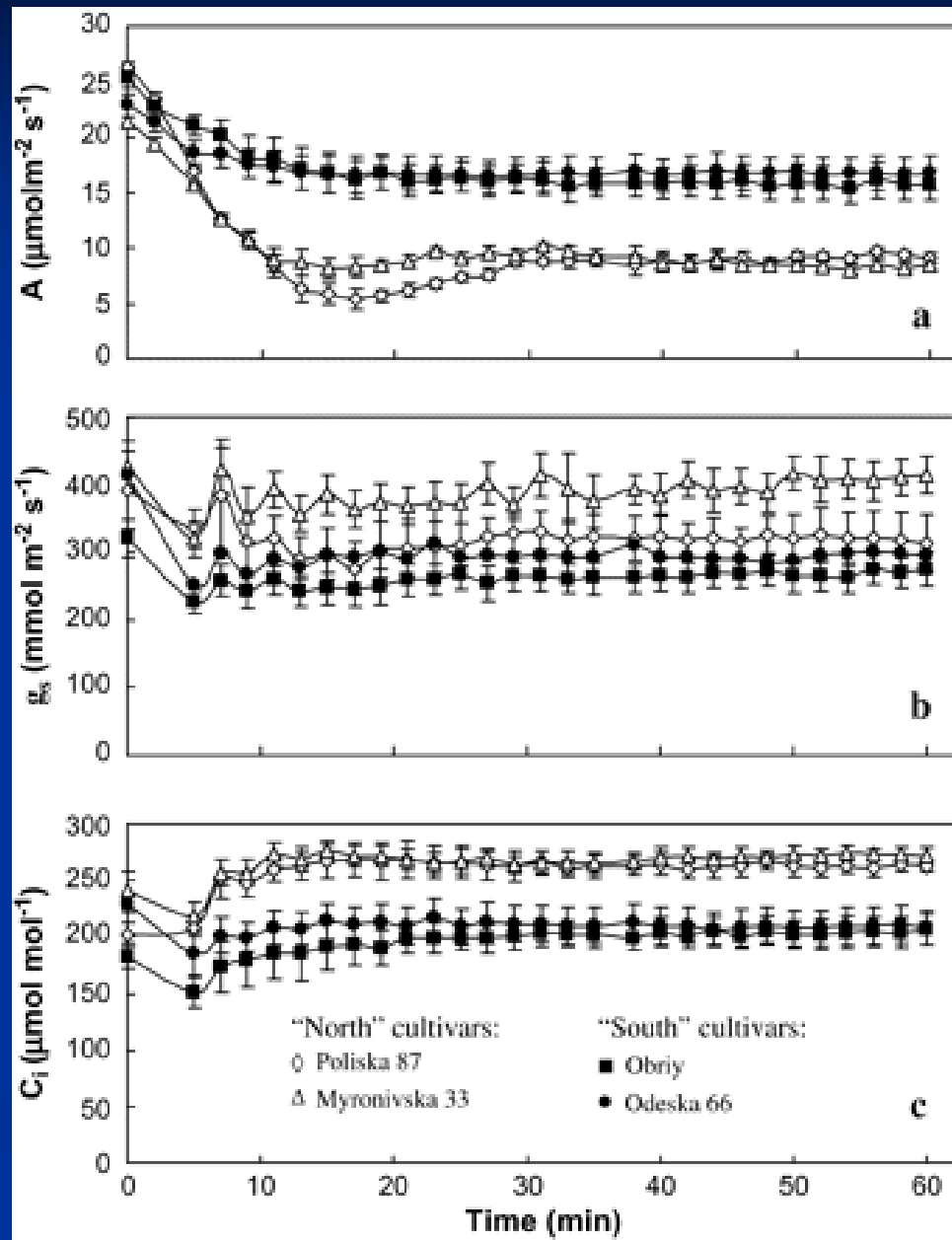
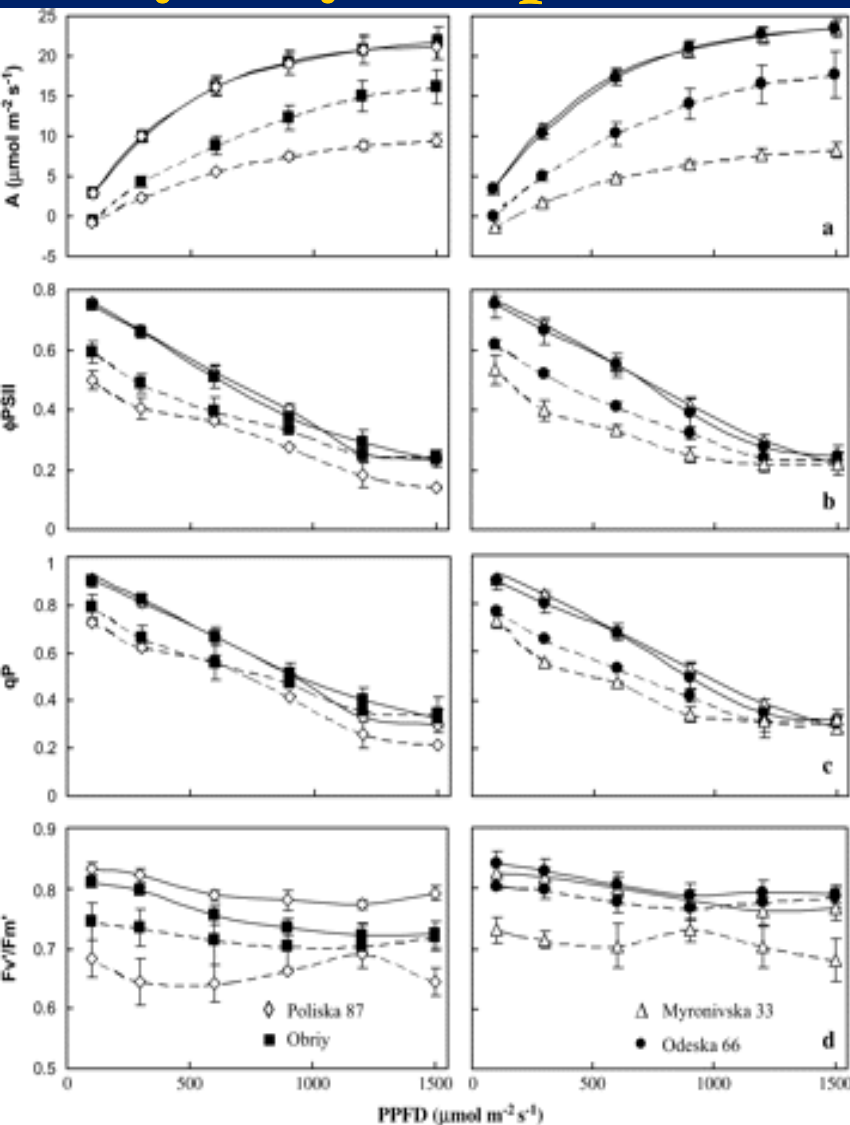
# Fotosyntéza a transpirace

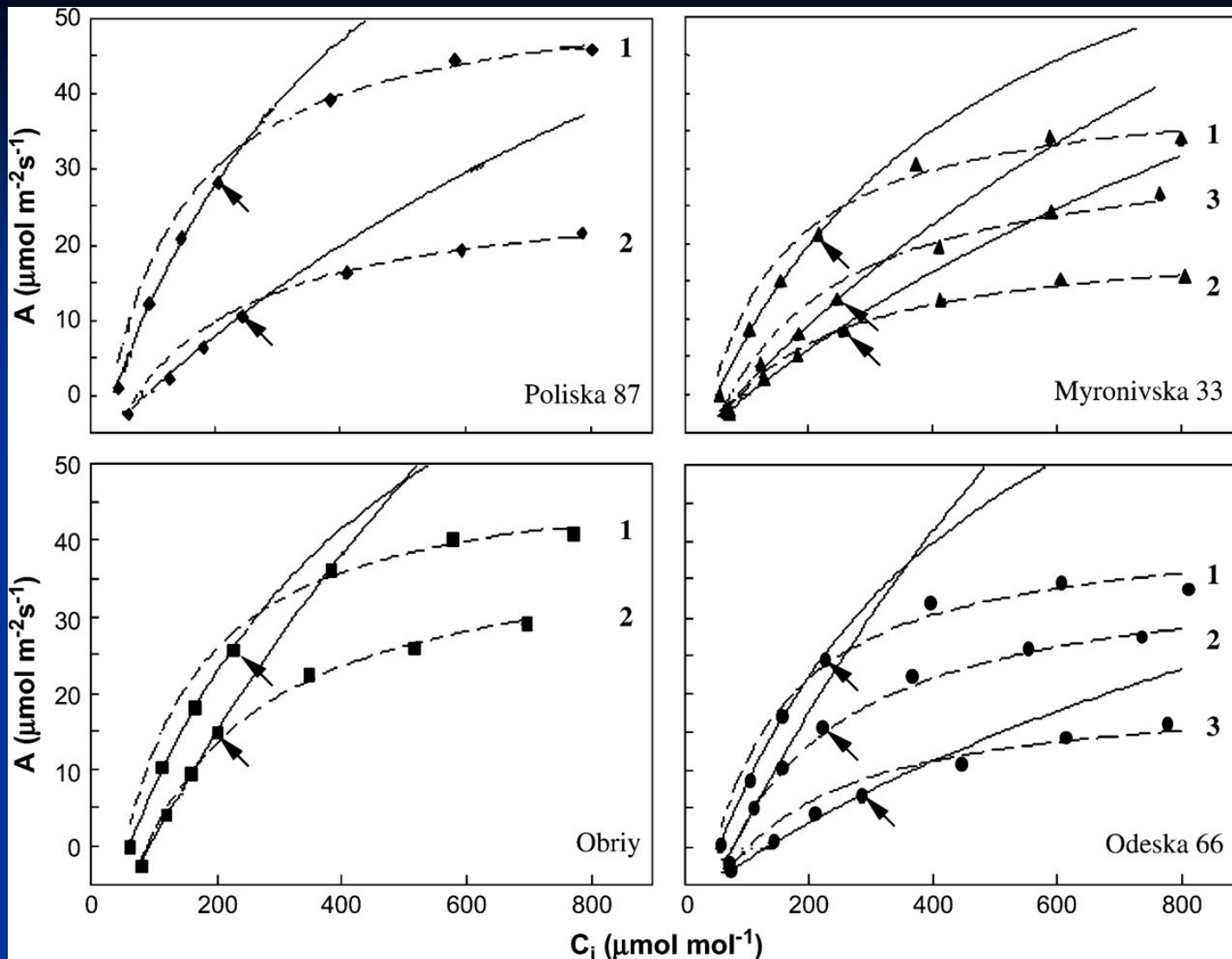


**FIGURE 1** – Net and gross photosynthesis ( $A$ , A), dark respiration ( $R_d$ , B), instantaneous quantum efficiency of photosynthesis ( $\alpha_1$ , C) and relationship between photosynthesis and respiration ( $A/R_d$ , D) as a function of leaf temperature in sweet orange leaf discs under non-photorespiratory condition. Gross photosynthesis refers to the sum of net photosynthesis and respiration. Each point represents the mean value ( $n=5$ )  $\pm$  SE. Leaf discs were excised from plants grown under greenhouse conditions.



# Metody měření senzitivity fotosyntézy vůči vysokým teplotám







# Ekologie fotosyntézy - zásobení vodou

**Přímo** – inhibice metabolismu (elektronový transport, fosforylace).

**Nepřímo** – zavírání průduchů.

**Vlhkostní kompenzační bod** – u poikilohydrických rostlin, limitní hodnoty relativní vzdušné vlhkosti, při kterých fotosyntéza ustává.

**Koeficient využití vody ve fotosyntéze:**  $WUE_{ph} = \text{fotosyntéza/transpirace} [\mu\text{mol CO}_2/\text{mmol H}_2\text{O}]$ .

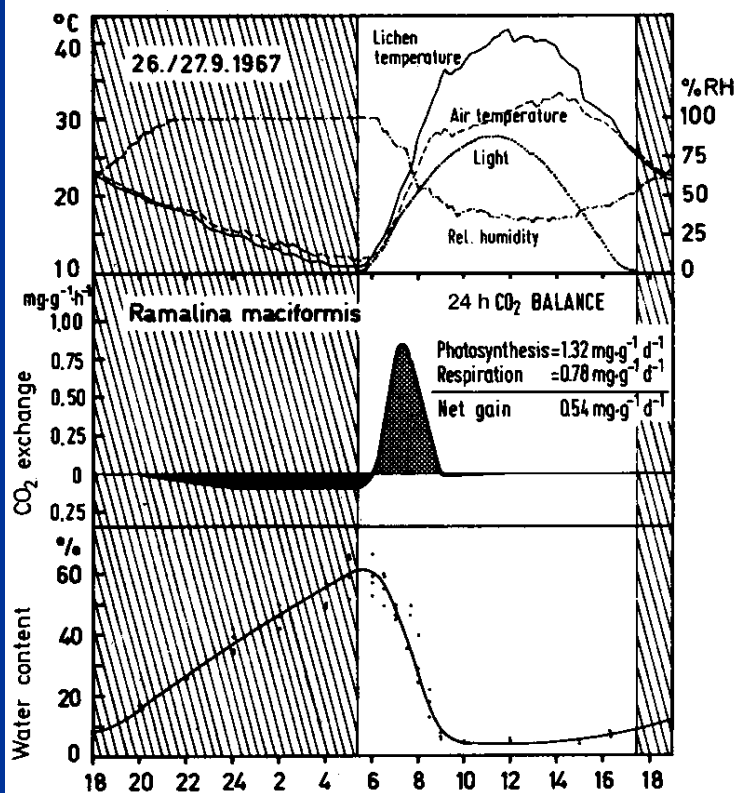
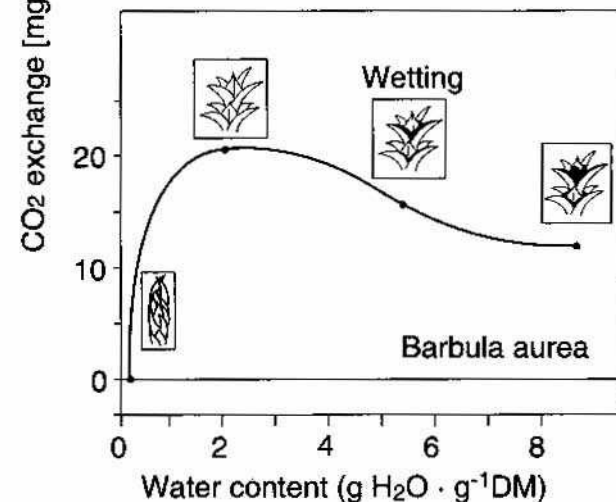
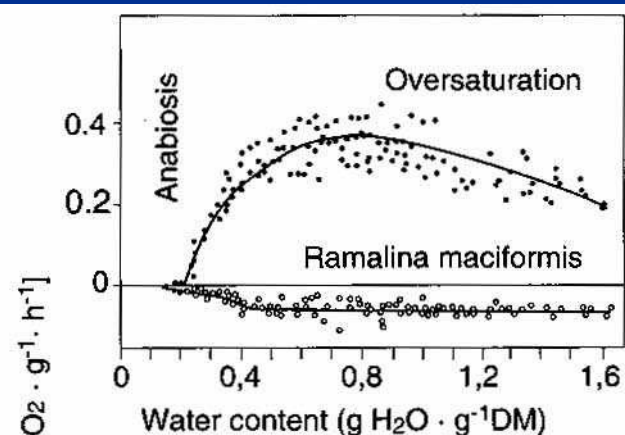
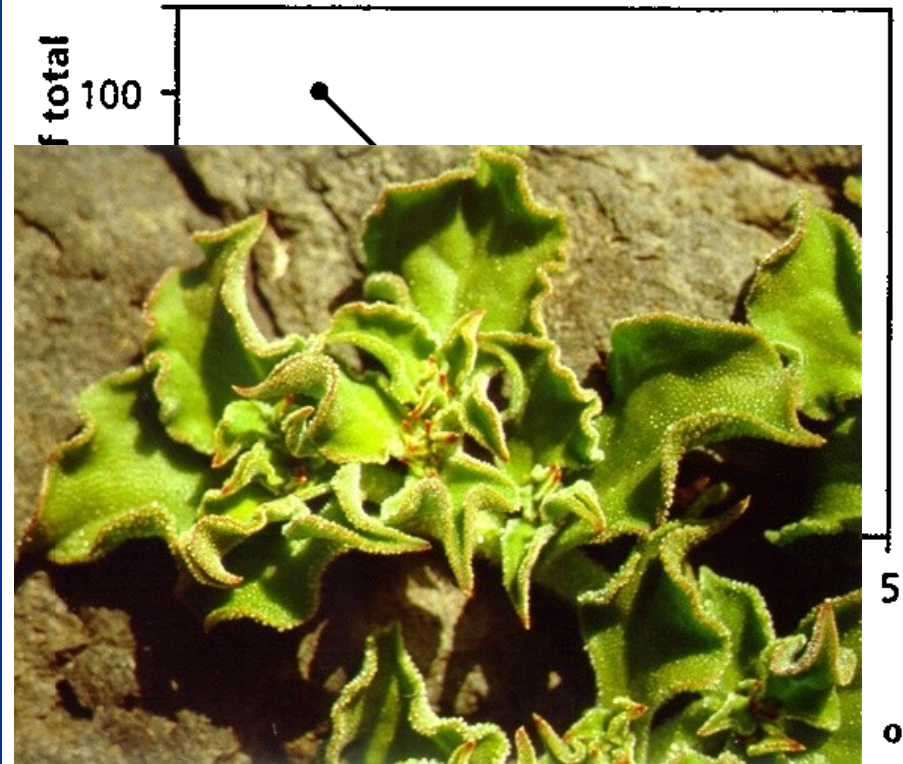


Fig. 2.46. CO<sub>2</sub> exchange and water content of the desert lichen *Ramalina maciformis* during the course of the day. Upper frame: irradiance, temperature and air humidity. The nighttime dew supplies the lichen with moisture, but in the morning it rapidly dries out again. Stippled area CO<sub>2</sub> uptake; black area CO<sub>2</sub> release; hatched night-time. (Lange et al. 1970)



# Evoluce CAM rostlin

- Deficit vlhkosti – suchozemské r.
- deficit CO<sub>2</sub> – vodní makrofyta



epiphytic bromeliad species with CAM metabolism and mean annual rainfall in Trinidad (Winter & Smith 1996).

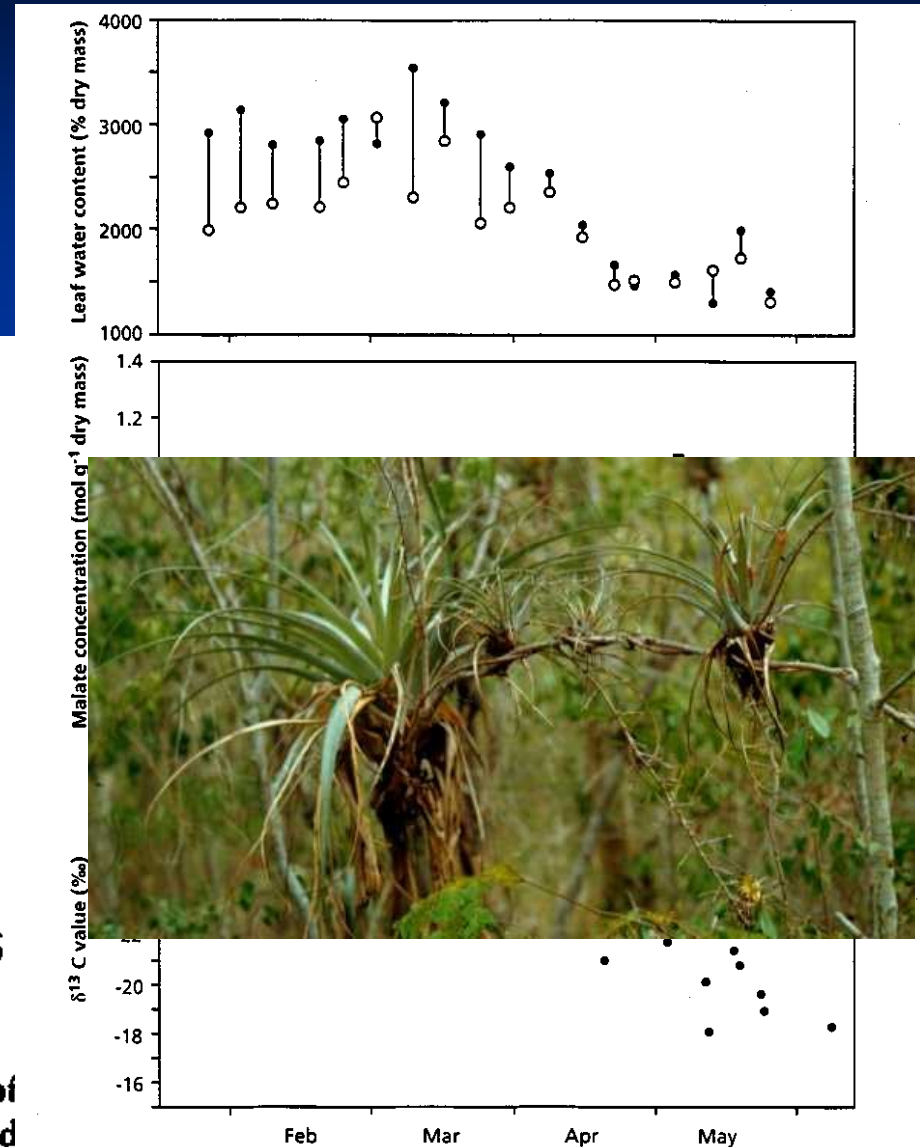


FIGURE 49. Induction of CAM in the facultative CAM species *Mesembryanthemum crystallinum*, growing in its natural habitat on rocky coastal cliffs of the Mediterranean Sea. There is a shift from the C<sub>3</sub> mode to CAM, coinciding

with less discrimination against the heavy carbon isotope. Filled symbols and bars represent the end of the night; open symbols and bars represent end-of day values (Osmond et al. 1982).

# Ekologie fotosyntézy - výživa

**Přímo** – dostupnost prvků, které jsou součástí enzymů dílčích procesů fotosyntézy.

**Nepřímo** – vliv na pohyb průduchů, anatomickou strukturu listů, apod.

**Koeficient využití dusíku ve fotosyntéze:**  $NUE_{ph} = \text{fotosyntéza} / \text{obsah N na jednotku plochy listu}$  [ $\mu\text{mol CO}_2 / \text{mmol N}$ ].

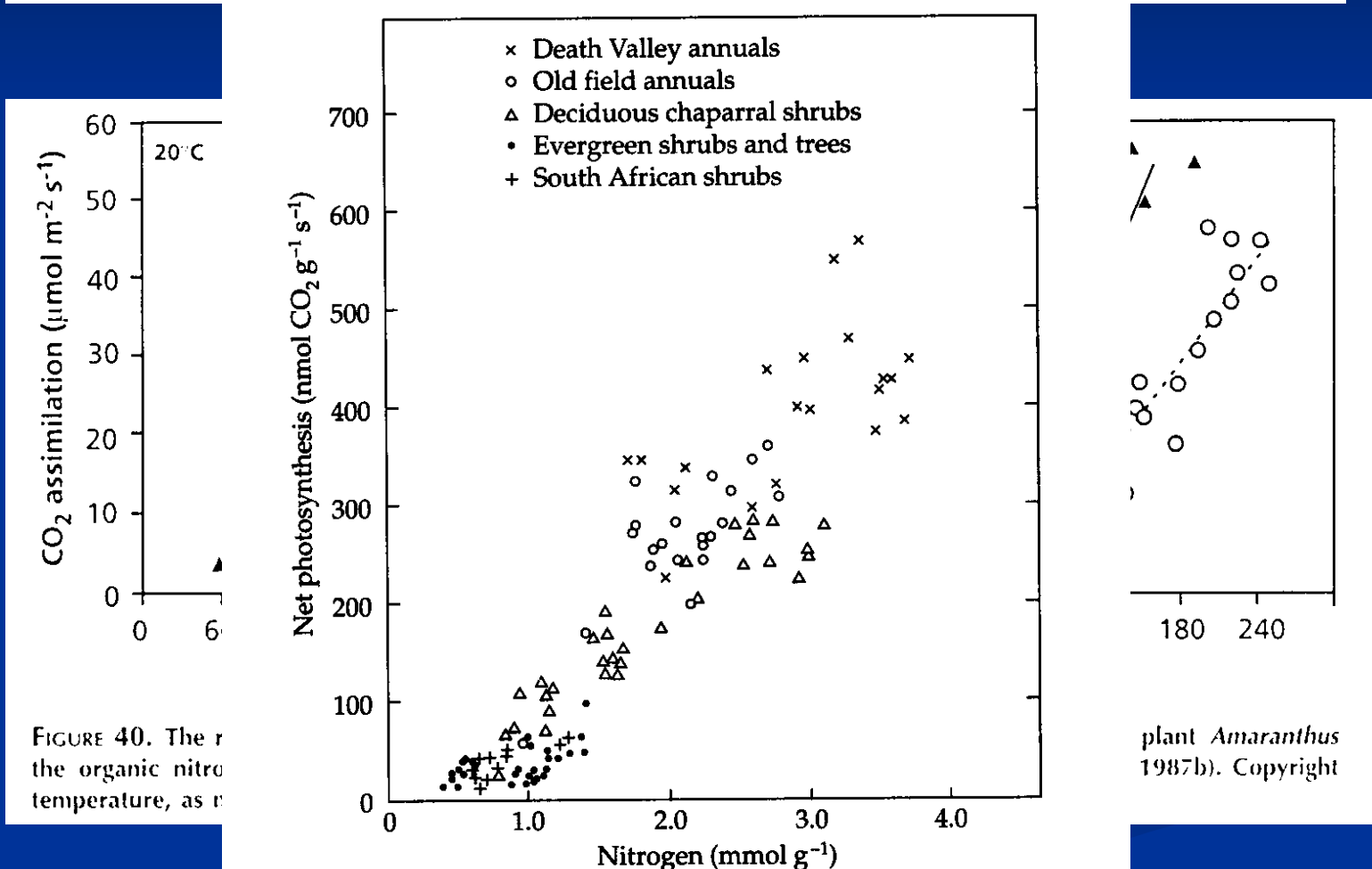


FIGURE 40. The r...  
the organic nitro...  
temperature, as r...

**Figure 15-11** Maximum photosynthesis and nitrogen per unit leaf weight for 21 species grown under natural conditions. From Field and Mooney (1986).

# Evoluce fotosyntézy

- Prokaryotické organismy - anoxygenní formy fotosyntézy, zdroj elektronů  $\text{H}_2\text{S}$ ,  $\text{H}_2$ , organické látky
- *Halobacterium halobium* - nejjednodušší forma fotosyntézy, absorpce záření (pigmentoproteinový komplex), gradient  $\text{H}^+ \rightarrow$  syntéza ATP
- oxygenní fotosyntéza - před ca 2.5 mld lety
  - sinice, řasy, vyšší rostliny - zdroj elektronů voda, produkce  $\text{O}_2$

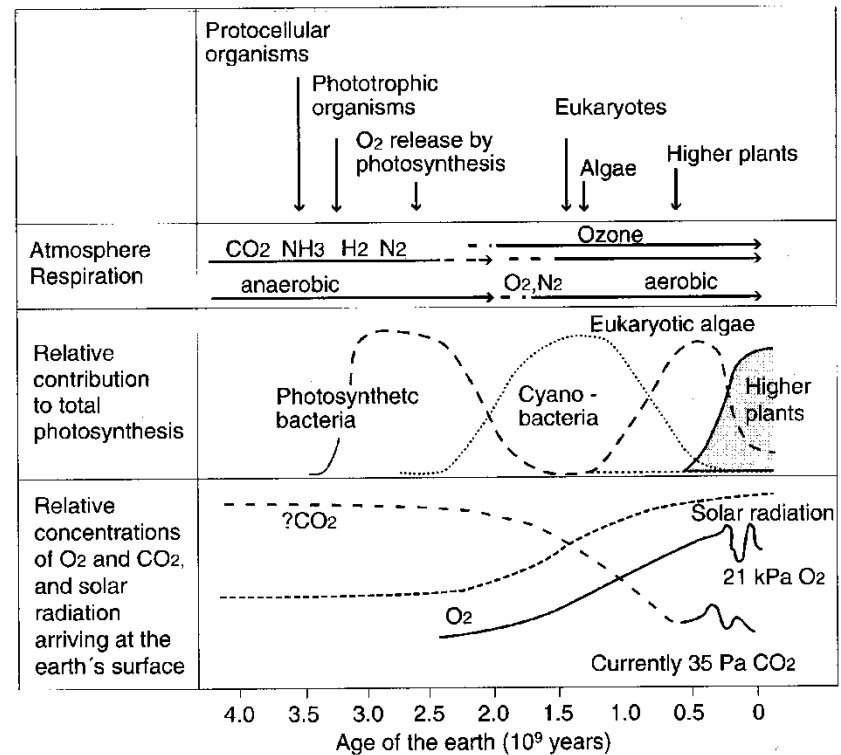
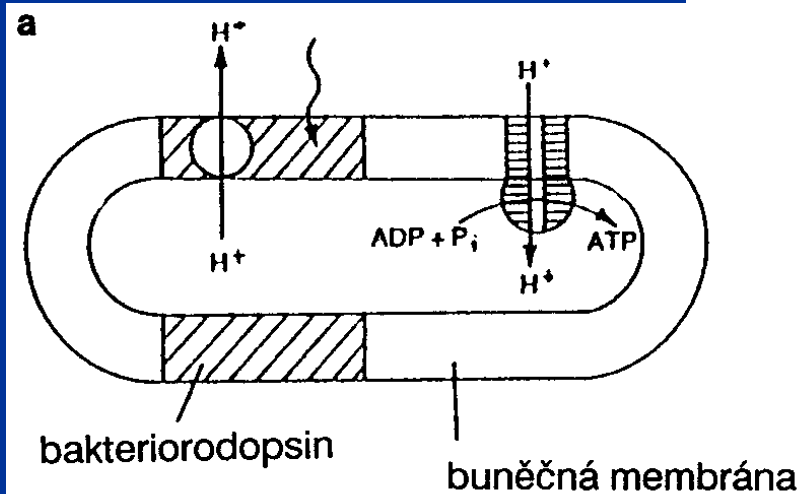


Fig. 2.1. Possible steps in the evolution of photosynthesis and their global consequences. (Lawlor 1993)

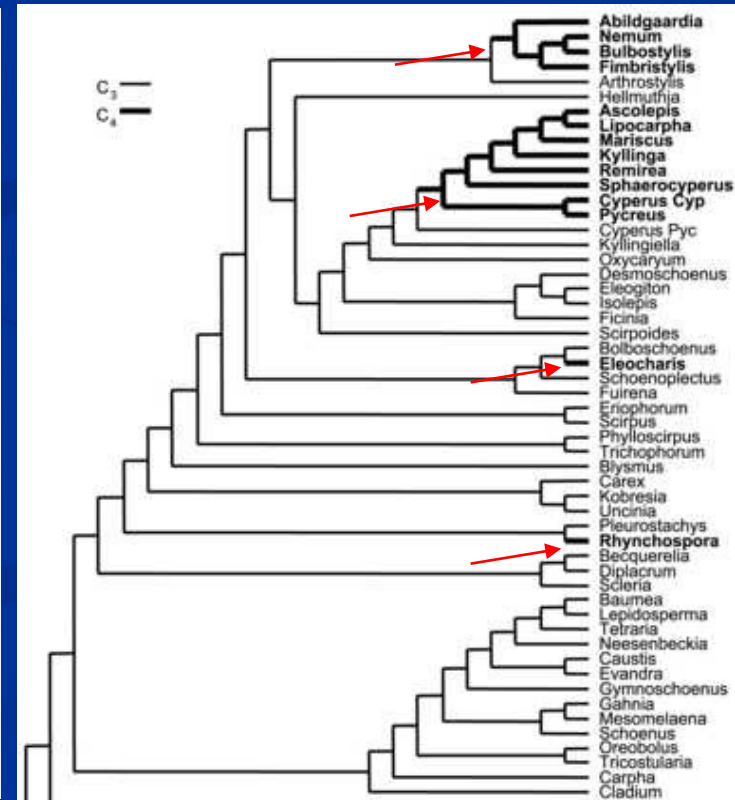
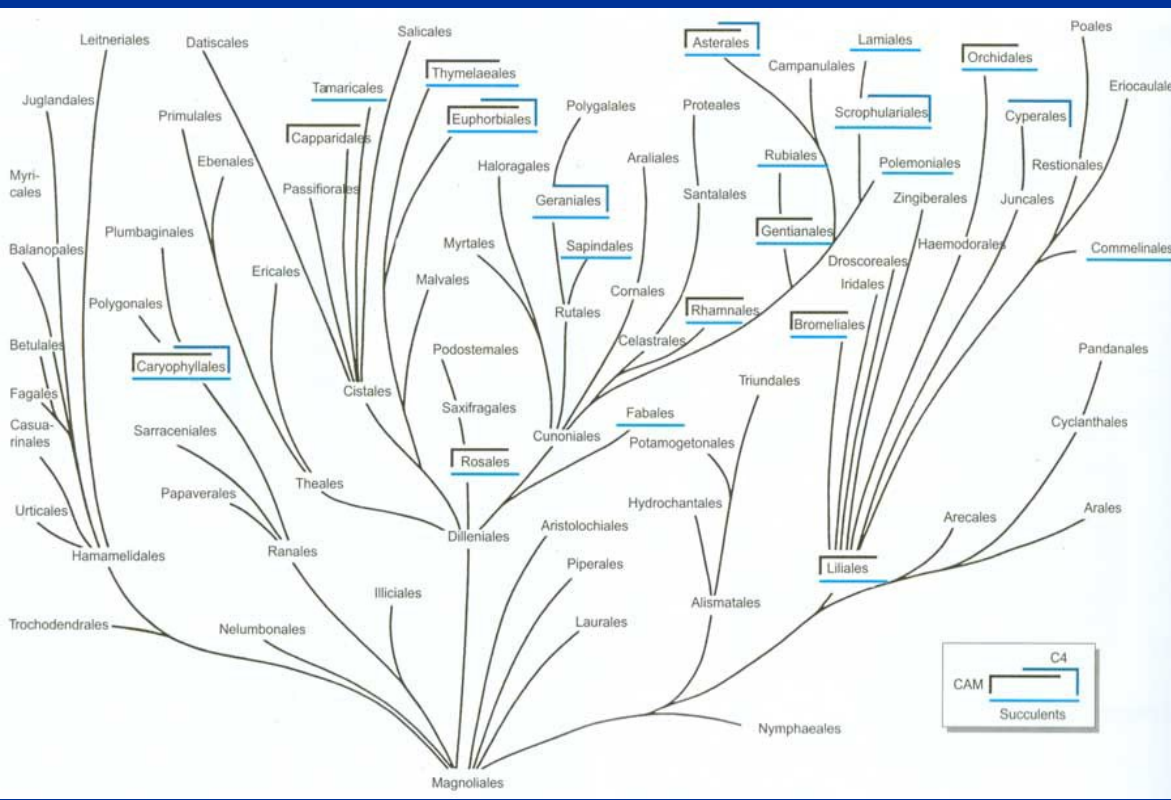


# Evoluce metabolických cest uhlíku

- C<sub>4</sub> a CAM opakovaně v průběhu evoluce
- různé míry přechodu C<sub>3</sub>/C<sub>4</sub> → CAM, C<sub>3</sub> → C<sub>4</sub>, C<sub>3</sub> a C<sub>4</sub> ekotypy, C<sub>3</sub> a C<sub>4</sub> v pletivech téže rostliny (kukuřice), fakultativní CAM



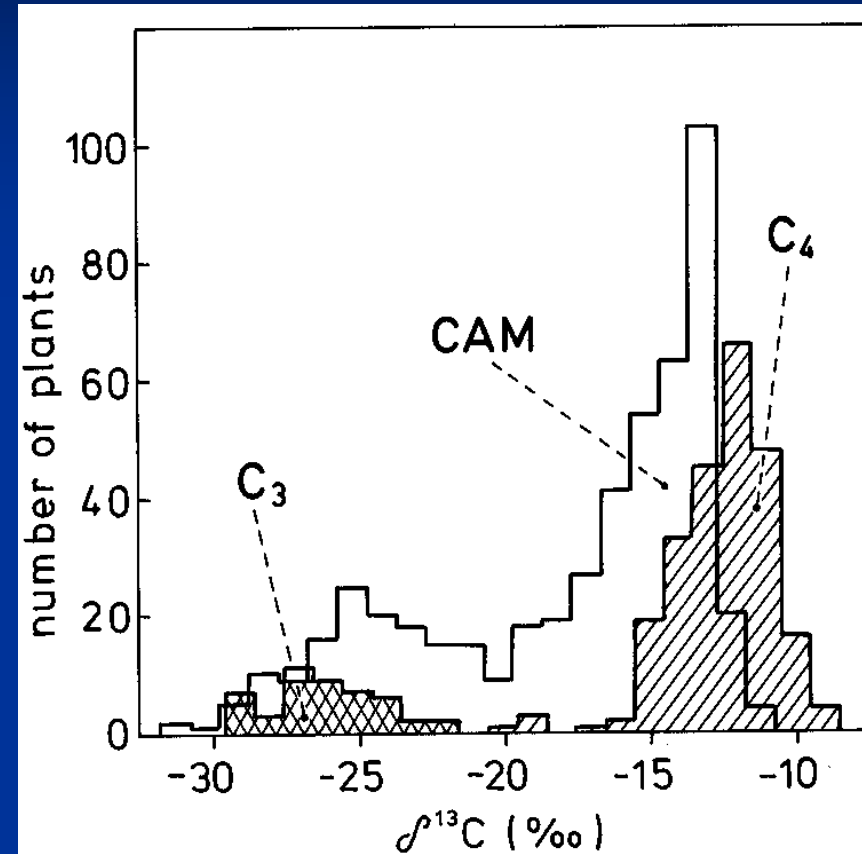
Figure 2.15 *Flaveria linearis* (Asteraceae), a species with a photosynthetic pathway that is intermediate between the C<sub>3</sub> and C<sub>4</sub> pathways. (Photo courtesy of P. Teese)



# Diskriminace izotopů uhlíku

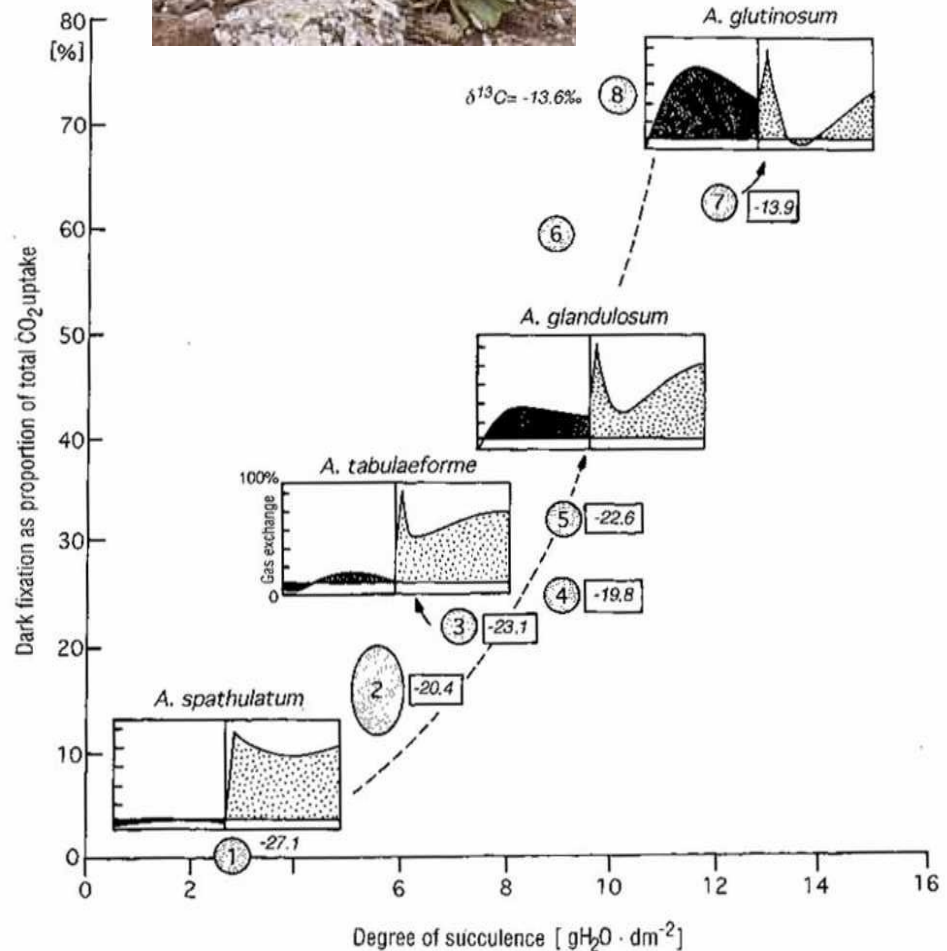
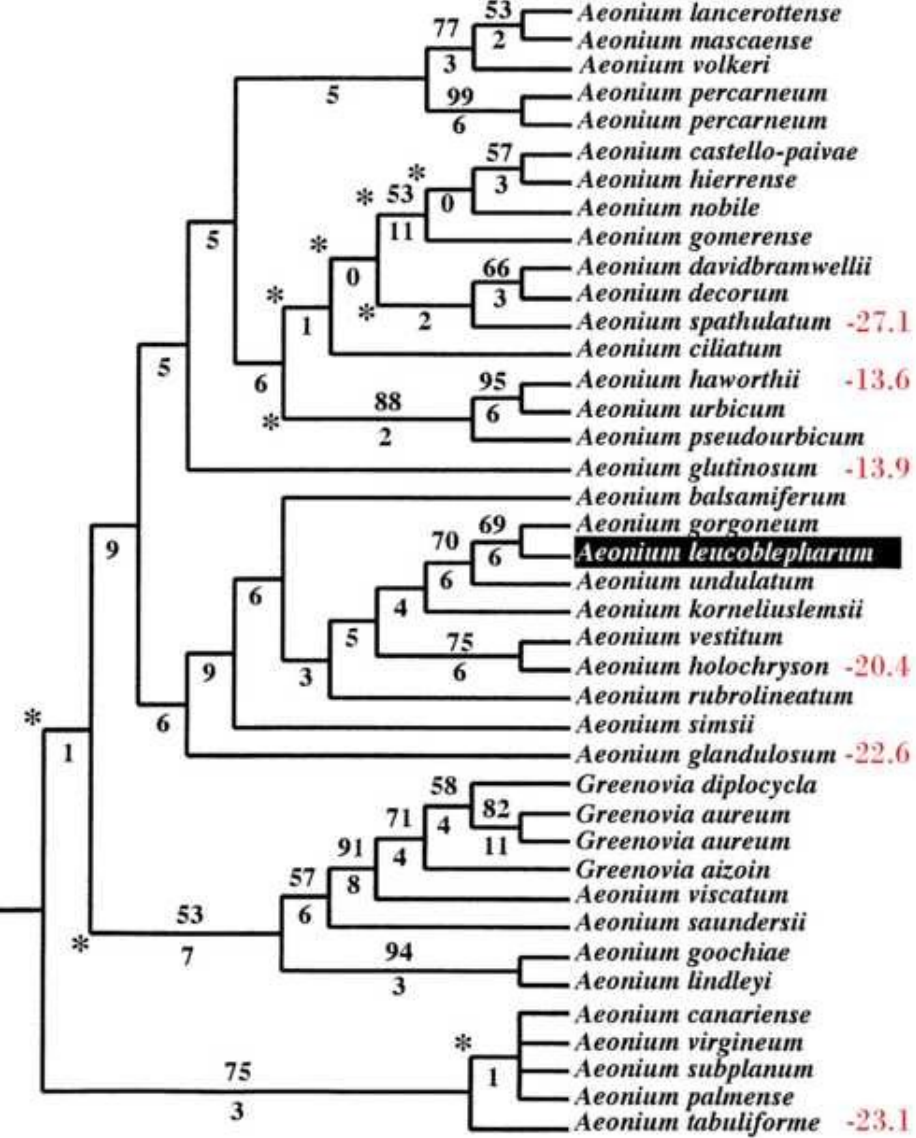
$$\delta^{13}\text{C}\text{‰} = \left( \frac{^{13}\text{C}/^{12}\text{C sample}}{^{13}\text{C}/^{12}\text{C standard}} - 1 \right) \cdot 1000$$

- $\delta^{13}\text{C}$  neznečištěného vzduchu = -7‰
- rozdílná diskriminace Rubisco a PEP-karboxylázy stabilních izotopů  $^{13}\text{C}$  a  $^{12}\text{C}$ 
  - C3 rostliny v průměru  $\delta^{13}\text{C}$  = -27‰ (rozpětí -23‰ až -36‰)
  - C4 rostliny v průměru  $\delta^{13}\text{C}$  = -13‰ (rozpětí -10‰ až -18‰)
  - CAM rostliny v rozpětí  $\delta^{13}\text{C}$  C3 až C4 rostlin
  - vodní rostliny  $\delta^{13}\text{C}$  v rozpětí -11‰ až -50‰
- paleobotanika, analýza tkání herbivorů
- Barbour *et al.* – z křídly fosilní pletiva rostlin s  $^{13}\text{C}$  signálem ~C4/CAM



**Fig. 2.12.**

Ranges of carbon-isotope ratios for C<sub>3</sub>-, C<sub>4</sub>- and CAM species. Measurements from 285 grasses (Poaceae) with 47 C<sub>3</sub> species and 238 C<sub>4</sub> species and from 513 CAM plants. (Unpub. data sets of H. Ziegler)



# Aeonium

Fig. 2.10. Variant forms of crassulacean acid metabolism in the genus *Aeonium*. 1: *A. spathulatum*; 2: *A. holochryson*; 3: *A. tabulaeforme*; 4: *A. arboreum*; 5: *A. glandulosum*; 6: *A. undulatum*; 7: *A. glutinosum*; 8: *A. haworthii*. The greater the storage capacity of the leaves (degree of succulence), the greater is the proportion of dark fixation in the total 24 h  $CO_2$  uptake.

# Ekologie C3 a C4 rostlin

- Různá odpověď na prostředí, především záření a teplotu
  - geografické rozšíření
  - kompetiční schopnosti
  - fenologie

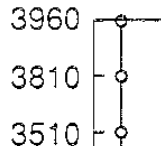
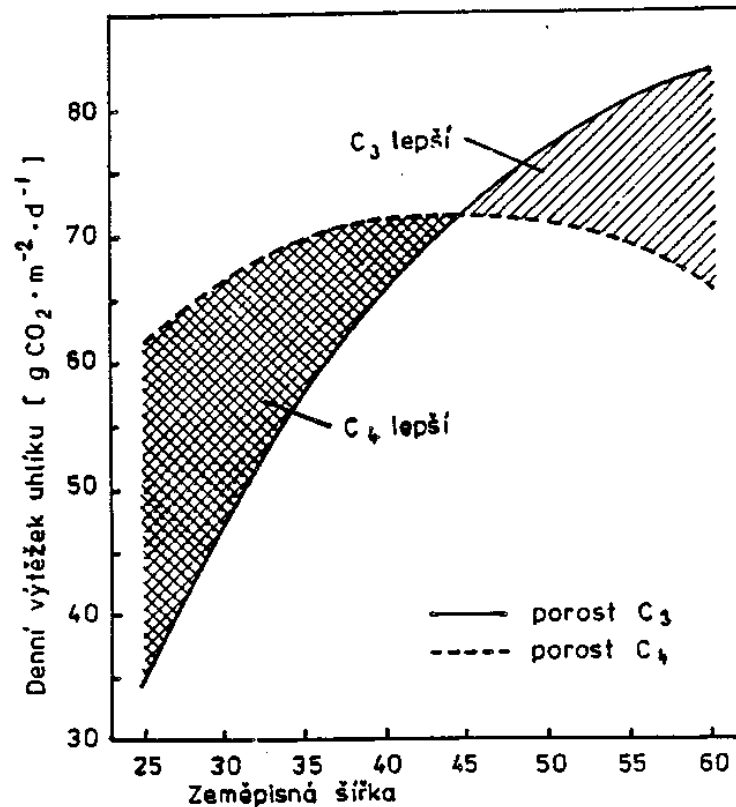


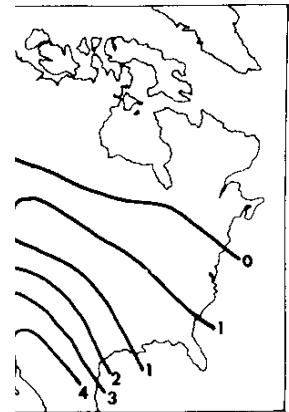
Figure 20-33 Relative percent biomass of C<sub>3</sub> (cool-season) and C<sub>4</sub> (warm-season) grasses as a function of latitude in the mid-prairie region of North America. From Sims and Risser (1998).

Composition of biomass (percent)



Obr. 3.53. Celkový denní výtěžek uhlíku stejně hustých porostů C<sub>3</sub> a C<sub>4</sub>-trav v různých zeměpisných šířkách severní polokoule v průběhu července. Výpočet byl proveden na základě výsledků terénních měření (Ehleringer 1978). Přehled rozšíření C<sub>3</sub> a C<sub>4</sub>-trav v závislosti na podnebí uvádí Hattersley (1983).

Dicotyledons



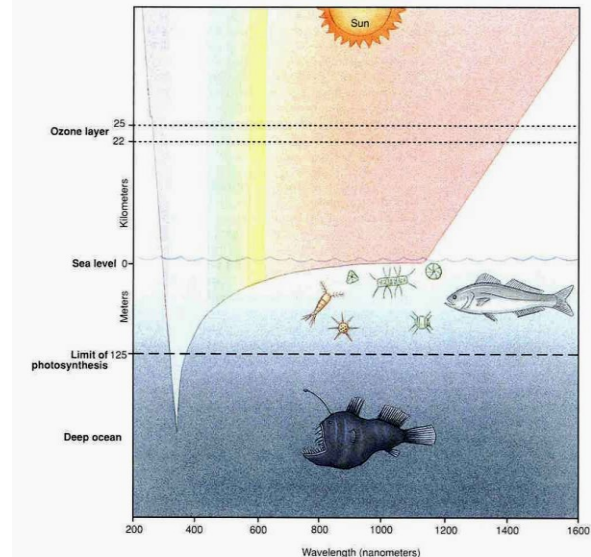
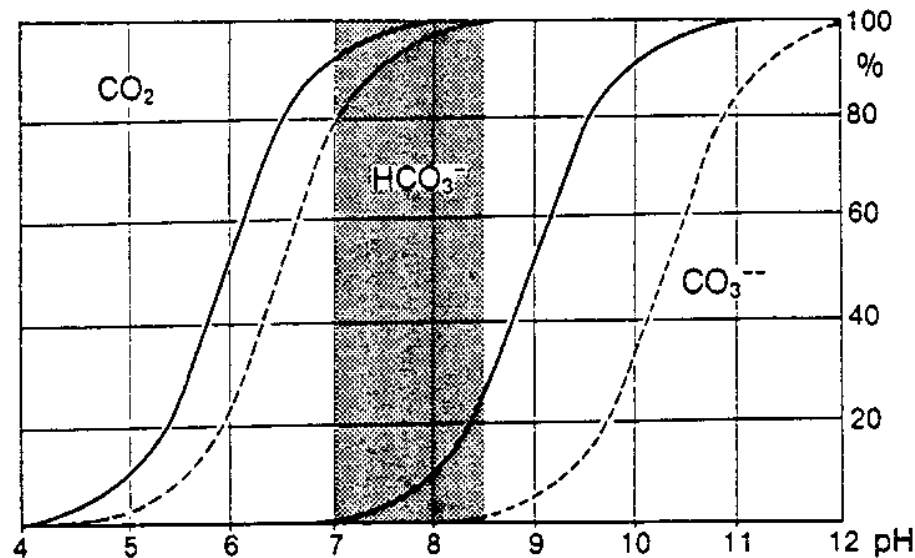
N. America. Percent C<sub>4</sub> (right). (After Teeri and proportions of C<sub>4</sub> plants of N. Africa (Batanouny 1983) 40–90% of the Argentine, 35% of the the montane belt (up to

Fig. 11.15. The percent C<sub>3</sub>, along an altitudinal (1979)



# Fotosyntéza vodních rostlin

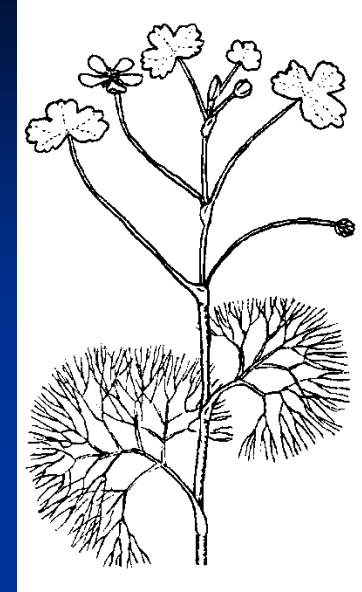
- Nízký příkon radiace (eufotická zóna)
- koncentrace plynů roste s tlakem nad hladinou a klesající teplotou, klesá s obsahem rozpuštěných solí
- $\text{CO}_2$  ve vodě snadno rozpustný, ale difúze asi 10,000x pomalejší oproti vzduchu ■ nedostatečné zásobování  $\text{CO}_2$  k listům
- s rostoucím pH vody se posouvá doprava rovnováha ( $\text{H}_2\text{CO}_3$ ) ■  $\text{H}_2\text{O} + \text{CO}_2$  ■  $\text{H}^+ + \text{HCO}_3^-$  ■  $\text{H}^+ + \text{CO}_3^{2-}$ , při  $\text{pH} > 9$  schází volný  $\text{CO}_2$



**Fig. 1.3.** The effect of pH on the carbonate system in seawater (solid line) and freshwater (broken line). Shaded area: Average pH values of seawater. (Ott 1988). The ordinate indicates the percent of the total  $\text{CO}_2$  or  $\text{CO}_3^{2-}$  present at particular pH values

# Adaptace vodních rostlin na příjem uhlíku

- Příjem celým povrchem stélky - maximálně dělené listy (*Myriophyllum*, *Ceratophyllum*, *Batrachium*)
- redukce hraniční vrstvy - snižuje ji proudění vody, zmenšení plochy listů
- příjem  $\text{HCO}_3^-$ 
  - aktivní transport (sinice, řada zelených řas)
  - převod na  $\text{CO}_2$  v buněčné stěně pomocí enzymu karbonát-anhydrázy (*Elodea canadensis*)
  - protonový polární transport - vylučování  $\text{H}^+$  → lokální zvýšení acidity → posun rovnováhy směrem k volnému  $\text{CO}_2$  (*Characeae*, makrofyta)
- využití  $\text{CO}_2$  z organického sedimentu - příjem kořeny a rozvod skrze kanálky k listům (*Isoetes*, *Litorella uniflora*, *Lobelia dortmana*)



# CAM vodních makrofyt

- CAM submerzních makrofyt
  - cirkadiální změny koncentrace malátu a pH v buňkách
  - popsáno u *Isoetes howellii*
  - CAM jako dodatečný zdroj

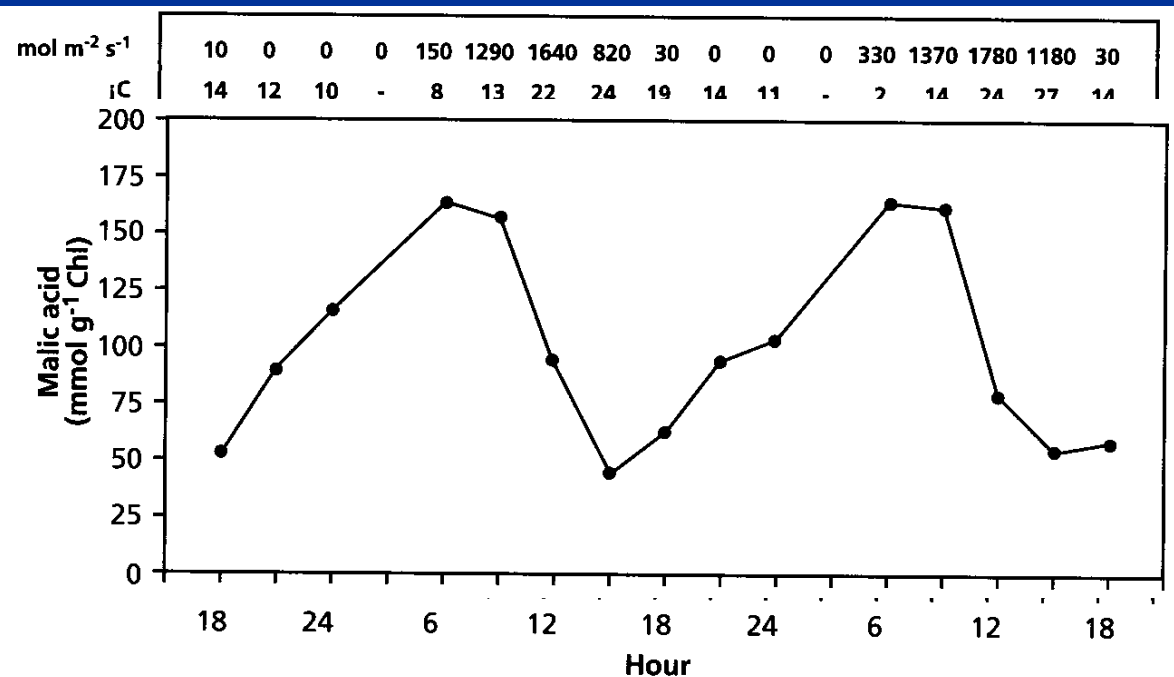


FIGURE 53. Malic acid levels, rates of CO<sub>2</sub> uptake, irradiance at the water surface, water temperatures, and concentrations of CO<sub>2</sub> and O<sub>2</sub> in the dark (filled symbol) and in the light (open symbols) for submerged *Isoetes howellii*

leaves in a pool. The numbers near the symbols in the bottom figure give the pH values (Keeley & Busch 1984). Copyright American Society of Plant Physiology.

# Isoetes andicola

- Semiterestrická rostlina - listy bez průduchů, velmi silná kutikula [redacted]alová výměna plynů s atmosférou
- příjem CO<sub>2</sub> kořeny z organického sedimentu
- CAM v noci - malý příjem CO<sub>2</sub> ze sedimentu a recyklace respiračního CO<sub>2</sub>, dodatečný metabolismus k dennímu C<sub>3</sub>

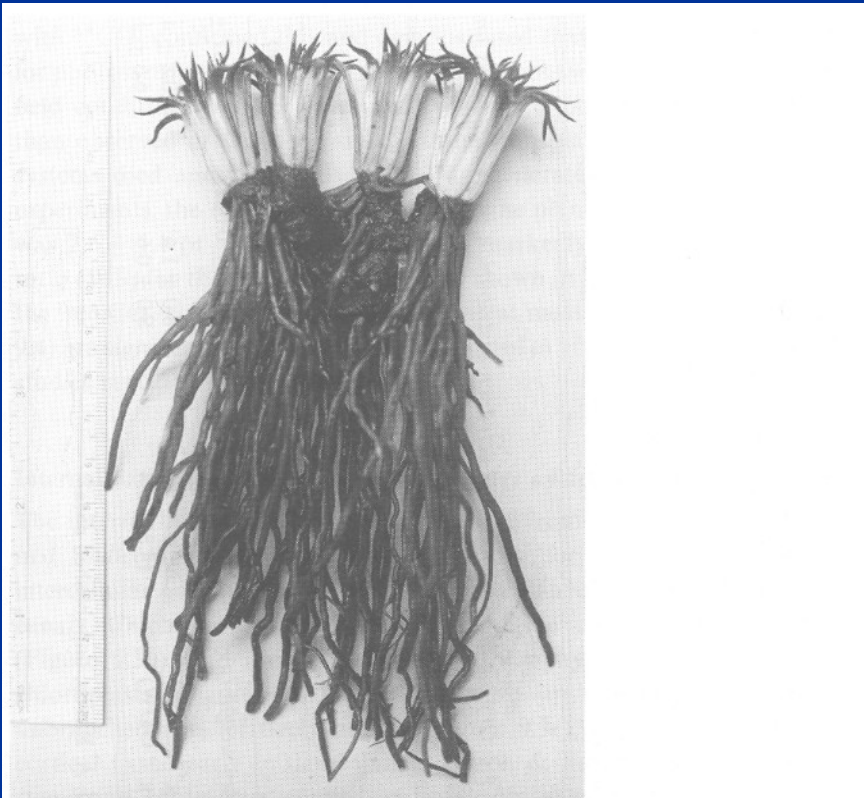


Figure 9.1. *Isoetes andicola*, 'stylites', collected near Junin, Peru; scale is a 15 cm ruler.

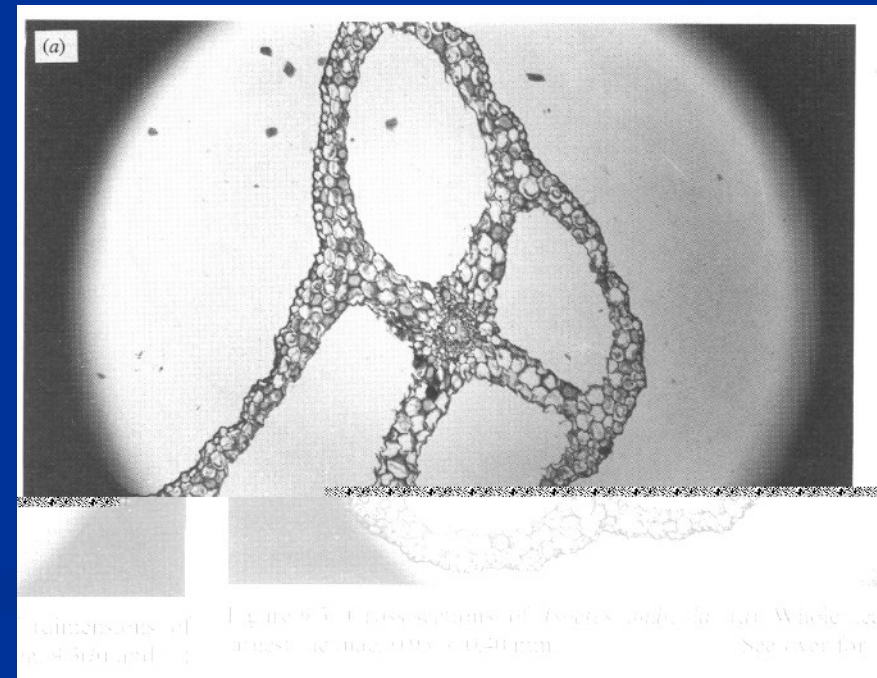
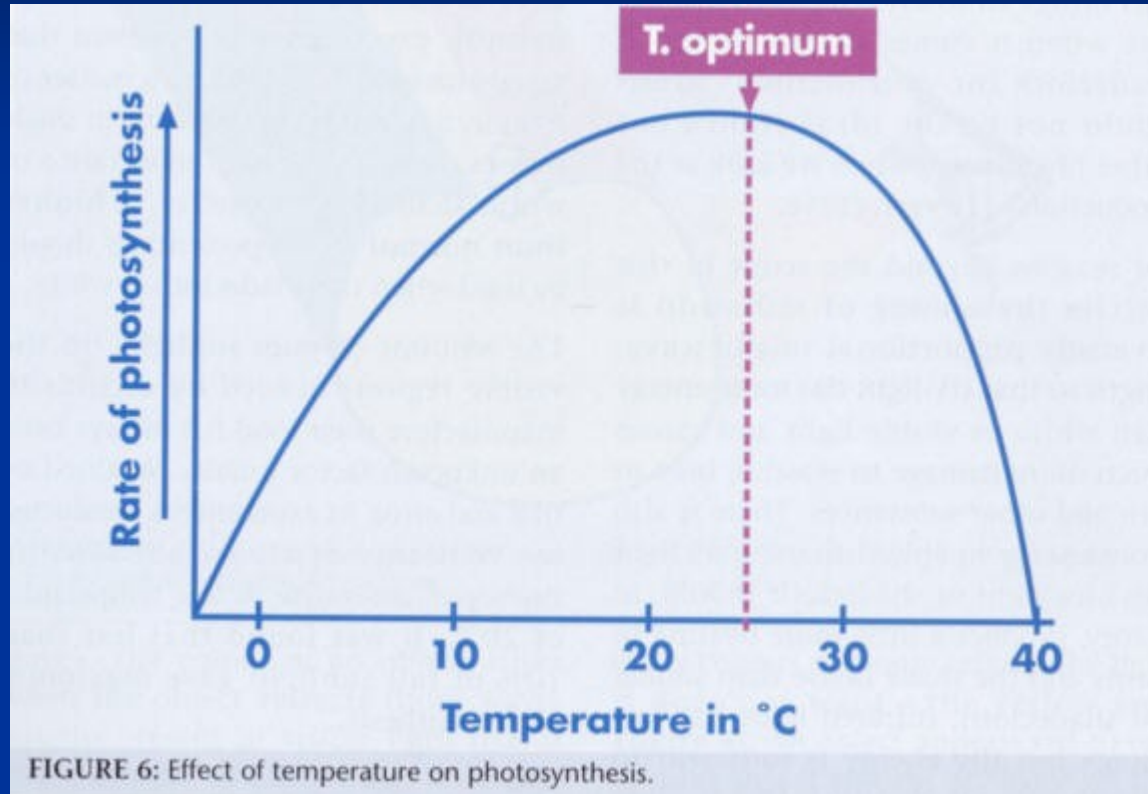


Figure 9.3. Cross sections of *Isoetes andicola* (a) Whole (a) (b) (c) (d) (e) (f) (g) (h) (i) (j) (k) (l) (m) (n) (o) (p) (q) (r) (s) (t) (u) (v) (w) (x) (y) (z) (aa) (ab) (ac) (ad) (ae) (af) (ag) (ah) (ai) (aj) (ak) (al) (am) (an) (ao) (ap) (aq) (ar) (as) (at) (au) (av) (aw) (ax) (ay) (az) (ba) (bb) (bc) (bd) (be) (bf) (bg) (bh) (bi) (bj) (bk) (bl) (bm) (bn) (bo) (bp) (bq) (br) (bs) (bt) (bu) (bv) (bw) (bx) (by) (bz) (ca) (cb) (cc) (cd) (ce) (cf) (cg) (ch) (ci) (cj) (ck) (cl) (cm) (cn) (co) (cp) (cq) (cr) (cs) (ct) (cu) (cv) (cw) (cx) (cy) (cz) (da) (db) (dc) (dd) (de) (df) (dg) (dh) (di) (dj) (dk) (dl) (dm) (dn) (do) (dp) (dq) (dr) (ds) (dt) (du) (dv) (dw) (dx) (dy) (dz) (ea) (eb) (ec) (ed) (ee) (ef) (eg) (eh) (ei) (ej) (ek) (el) (em) (en) (eo) (ep) (eq) (er) (es) (et) (eu) (ev) (ew) (ex) (ey) (ez) (fa) (fb) (fc) (fd) (fe) (ff) (fg) (fh) (fi) (fj) (fk) (fl) (fm) (fn) (fo) (fp) (fq) (fr) (fs) (ft) (fu) (fv) (fw) (fx) (fy) (fz) (ga) (gb) (gc) (gd) (ge) (gf) (gg) (gh) (gi) (gj) (gk) (gl) (gm) (gn) (go) (gp) (gq) (gr) (gs) (gt) (gu) (gv) (gw) (gx) (gy) (gz) (ha) (hb) (hc) (hd) (he) (hf) (hg) (hh) (hi) (hj) (hk) (hl) (hm) (hn) (ho) (hp) (hq) (hr) (hs) (ht) (hu) (hv) (hw) (hx) (hy) (hz) (ia) (ib) (ic) (id) (ie) (if) (ig) (ih) (ii) (ij) (ik) (il) (im) (in) (io) (ip) (iq) (ir) (is) (it) (iu) (iv) (iw) (ix) (iy) (iz) (ja) (jb) (jc) (jd) (je) (jf) (jg) (jh) (ji) (jj) (jk) (jl) (jm) (jn) (jo) (jp) (jq) (jr) (js) (jt) (ju) (jv) (jw) (jx) (jy) (jz) (ka) (kb) (kc) (kd) (ke) (kf) (kg) (kh) (ki) (kj) (kk) (kl) (km) (kn) (ko) (kp) (kq) (kr) (ks) (kt) (ku) (kv) (kw) (kx) (ky) (kz) (la) (lb) (lc) (ld) (le) (lf) (lg) (lh) (li) (lj) (lk) (ll) (lm) (ln) (lo) (lp) (lq) (lr) (ls) (lt) (lu) (lv) (lw) (lx) (ly) (lz) (ma) (mb) (mc) (md) (me) (mf) (mg) (mh) (mi) (mj) (mk) (ml) (mm) (mn) (mo) (mp) (mq) (mr) (ms) (mt) (mu) (mv) (mw) (mx) (my) (mz) (na) (nb) (nc) (nd) (ne) (nf) (ng) (nh) (ni) (nj) (nk) (nl) (nm) (nn) (no) (np) (nq) (nr) (ns) (nt) (nu) (nv) (nw) (nx) (ny) (nz) (oa) (ob) (oc) (od) (oe) (of) (og) (oh) (oi) (oj) (ok) (ol) (om) (on) (oo) (op) (oq) (or) (os) (ot) (ou) (ov) (ow) (ox) (oy) (oz) (pa) (pb) (pc) (pd) (pe) (pf) (pg) (ph) (pi) (pj) (pk) (pl) (pm) (pn) (po) (pp) (pq) (pr) (ps) (pt) (pu) (pv) (pw) (px) (py) (pz) (qa) (qb) (qc) (qd) (qe) (qf) (qg) (qh) (qi) (qj) (qk) (ql) (qm) (qn) (qo) (qp) (qq) (qr) (qs) (qt) (qu) (qv) (qw) (qx) (qy) (qz) (ra) (rb) (rc) (rd) (re) (rf) (rg) (rh) (ri) (rj) (rk) (rl) (rm) (rn) (ro) (rp) (rq) (rr) (rs) (rt) (ru) (rv) (rw) (rx) (ry) (rz) (sa) (sb) (sc) (sd) (se) (sf) (sg) (sh) (si) (sj) (sk) (sl) (sm) (sn) (so) (sp) (sq) (sr) (ss) (st) (su) (sv) (sw) (sx) (sy) (sz) (ta) (tb) (tc) (td) (te) (tf) (tg) (th) (ti) (tj) (tk) (tl) (tm) (tn) (to) (tp) (tq) (tr) (ts) (tt) (tu) (tv) (tw) (tx) (ty) (tz) (ua) (ub) (uc) (ud) (ue) (uf) (ug) (uh) (ui) (uj) (uk) (ul) (um) (un) (uo) (up) (uq) (ur) (us) (ut) (uu) (uv) (uw) (ux) (uy) (uz) (va) (vb) (vc) (vd) (ve) (vf) (vg) (vh) (vi) (vj) (vk) (vl) (vm) (vn) (vo) (vp) (vq) (vr) (vs) (vt) (vu) (vv) (vw) (vx) (vy) (vz) (wa) (wb) (wc) (wd) (we) (wf) (wg) (wh) (wi) (wj) (wk) (wl) (wm) (wn) (wo) (wp) (wq) (wr) (ws) (wt) (wu) (wv) (ww) (wx) (wy) (wz) (xa) (xb) (xc) (xd) (xe) (xf) (xg) (xh) (xi) (xj) (xk) (xl) (xm) (xn) (xo) (xp) (xq) (xr) (xs) (xt) (xu) (xv) (xw) (xx) (xy) (xz) (ya) (yb) (yc) (yd) (ye) (yf) (yg) (yh) (yi) (yj) (yk) (yl) (ym) (yn) (yo) (yp) (yq) (yr) (ys) (yt) (yu) (yv) (yw) (yx) (yy) (yz) (za) (zb) (zc) (zd) (ze) (zf) (zg) (zh) (zi) (zj) (zk) (zl) (zm) (zn) (zo) (zp) (zq) (zr) (zs) (zt) (zu) (zv) (zw) (zx) (zy) (zz)

Figure 9.3. Cross sections of *Isoetes andicola* (a) Whole (a) (b) (c) (d) (e) (f) (g) (h) (i) (j) (k) (l) (m) (n) (o) (p) (q) (r) (s) (t) (u) (v) (w) (x) (y) (z) (aa) (ab) (ac) (ad) (ae) (af) (ag) (ah) (ai) (aj) (ak) (al) (am) (an) (ao) (ap) (aq) (ar) (as) (at) (au) (av) (aw) (ax) (ay) (az) (ba) (bb) (bc) (bd) (be) (bf) (bg) (bh) (bi) (bj) (bk) (bl) (bm) (bn) (bo) (bp) (bq) (br) (bs) (bt) (bu) (bv) (bw) (bx) (by) (bz) (ca) (cb) (cc) (cd) (ce) (cf) (cg) (ch) (ci) (cj) (ck) (cl) (cm) (cn) (co) (cp) (cq) (cr) (cs) (ct) (cu) (cv) (cw) (cx) (cy) (cz) (da) (db) (dc) (dd) (de) (df) (dg) (dh) (di) (dj) (dk) (dl) (dm) (dn) (do) (dp) (dq) (dr) (ds) (dt) (du) (dv) (dw) (dx) (dy) (dz) (ea) (eb) (ec) (ed) (ee) (ef) (eg) (eh) (ei) (ej) (ek) (el) (em) (en) (eo) (ep) (eq) (er) (es) (et) (eu) (ev) (ew) (ex) (ey) (ez) (fa) (fb) (fc) (fd) (fe) (ff) (fg) (fh) (fi) (fj) (fk) (fl) (fm) (fn) (fo) (fp) (fq) (fr) (fs) (ft) (fu) (fv) (fw) (fx) (fy) (fz) (ga) (gb) (gc) (gd) (ge) (gf) (gg) (gh) (gi) (gj) (gk) (gl) (gm) (gn) (go) (gp) (gq) (gr) (gs) (gt) (gu) (gv) (gw) (gx) (gy) (gz) (ha) (hb) (hc) (hd) (he) (hf) (hg) (hh) (hi) (hj) (hk) (hl) (hm) (hn) (ho) (hp) (hq) (hr) (hs) (ht) (hu) (hv) (hw) (hx) (hy) (hz) (ia) (ib) (ic) (id) (ie) (if) (ig) (ih) (ii) (ij) (ik) (il) (im) (in) (io) (ip) (iq) (ir) (is) (it) (iu) (iv) (iw) (ix) (iy) (iz) (ja) (jb) (jc) (jd) (je) (jf) (jg) (jh) (ji) (jj) (jk) (jl) (jm) (jn) (jo) (jp) (jq) (jr) (js) (jt) (ju) (jv) (jw) (jx) (jy) (jz) (ka) (kb) (kc) (kd) (ke) (kf) (kg) (kh) (ki) (kj) (kk) (kl) (km) (kn) (ko) (kp) (kq) (kr) (ks) (kt) (ku) (kv) (kw) (kx) (ky) (kz) (la) (lb) (lc) (ld) (le) (lf) (lg) (lh) (li) (lj) (lk) (ll) (lm) (ln) (lo) (lp) (lq) (lr) (ls) (lt) (lu) (lv) (lw) (lx) (ly) (lz) (ma) (mb) (mc) (md) (me) (mf) (mg) (mh) (mi) (mj) (mk) (ml) (mm) (mn) (mo) (mp) (mq) (mr) (ms) (mt) (mu) (mv) (mw) (mx) (my) (mz) (na) (nb) (nc) (nd) (ne) (nf) (ng) (nh) (ni) (nj) (nk) (nl) (nm) (nn) (no) (np) (nq) (nr) (ns) (nt) (nu) (nv) (nw) (nx) (ny) (nz) (oa) (ob) (oc) (od) (oe) (of) (og) (oh) (oi) (oj) (ok) (ol) (om) (on) (oo) (op) (oq) (or) (os) (ot) (ou) (ov) (ow) (ox) (oy) (oz) (pa) (pb) (pc) (pd) (pe) (pf) (pg) (ph) (pi) (pj) (pk) (pl) (pm) (pn) (po) (pp) (pq) (pr) (ps) (pt) (pu) (pv) (pw) (px) (py) (pz) (qa) (qb) (qc) (qd) (qe) (qf) (qg) (qh) (qi) (qj) (qk) (ql) (qm) (qn) (qo) (qp) (qq) (qr) (qs) (qt) (qu) (qv) (qw) (qx) (qy) (qz) (ra) (rb) (rc) (rd) (re) (rf) (rg) (rh) (ri) (rj) (rk) (rl) (rm) (rn) (ro) (rp) (rq) (rr) (rs) (rt) (ru) (rv) (rw) (rx) (ry) (rz) (sa) (sb) (sc) (sd) (se) (sf) (sg) (sh) (si) (sj) (sk) (sl) (sm) (sn) (so) (sp) (sq) (sr) (ss) (st) (su) (sv) (sw) (sx) (sy) (sz) (ta) (tb) (tc) (td) (te) (tf) (tg) (th) (ti) (tj) (tk) (tl) (tm) (tn) (to) (tp) (tq) (tr) (ts) (tt) (tu) (tv) (tw) (tx) (ty) (tz) (ua) (ub) (uc) (ud) (ue) (uf) (ug) (uh) (ui) (uj) (uk) (ul) (um) (un) (uo) (up) (uq) (ur) (us) (ut) (uu) (uv) (uw) (ux) (uy) (uz) (va) (vb) (vc) (vd) (ve) (vf) (vg) (vh) (vi) (vj) (vk) (vl) (vm) (vn) (vo) (vp) (vq) (vr) (vs) (vt) (vu) (vv) (vw) (vx) (vy) (vz) (wa) (wb) (wc) (wd) (we) (wf) (wg) (wh) (wi) (wj) (wk) (wl) (wm) (wn) (wo) (wp) (wq) (wr) (ws) (wt) (wu) (wv) (ww) (wx) (wy) (wz) (xa) (xb) (xc) (xd) (xe) (xf) (xg) (xh) (xi) (xj) (xk) (xl) (xm) (xn) (xo) (xp) (xq) (xr) (xs) (xt) (xu) (xv) (xw) (xx) (xy) (xz) (ya) (yb) (yc) (yd) (ye) (yf) (yg) (yh) (yi) (yj) (yk) (yl) (ym) (yn) (yo) (yp) (yq) (yr) (ys) (yt) (yu) (yv) (yw) (yx) (yy) (yz) (za) (zb) (zc) (zd) (ze) (zf) (zg) (zh) (zi) (zj) (zk) (zl) (zm) (zn) (zo) (zp) (zq) (zr) (zs) (zt) (zu) (zv) (zw) (zx) (zy) (zz)



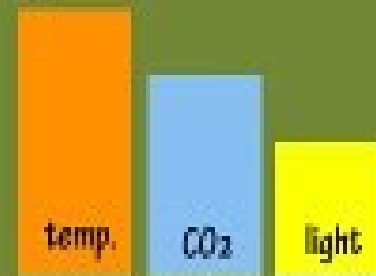
# Teplotní křivka fotosyntézy



## Limiting factors on photosynthesis



Assuming that the supply of nutrient and other environmental conditions are correct, three factors affect the rate of photosynthesis: temperature, carbon dioxide (CO<sub>2</sub>) and light.



If one factor is in short supply, photosynthesis will be restricted. Increasing the temperature and CO<sub>2</sub> content will not increase photosynthesis if the plants do not receive enough light.

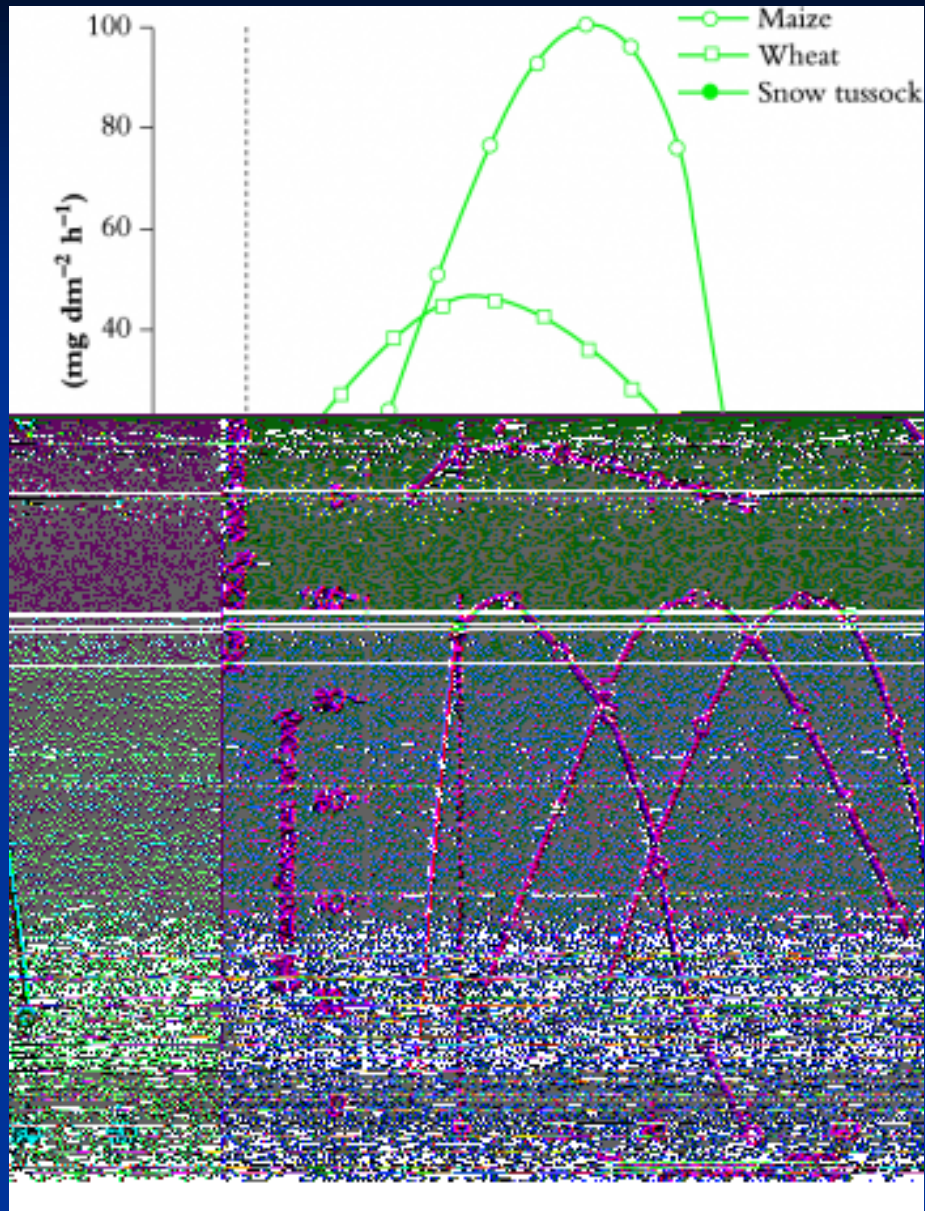


In most aquariums, the CO<sub>2</sub> content of water is limiting factor. even with the correct temperature and good lighting, plants will not grow well if they receive little CO<sub>2</sub>.

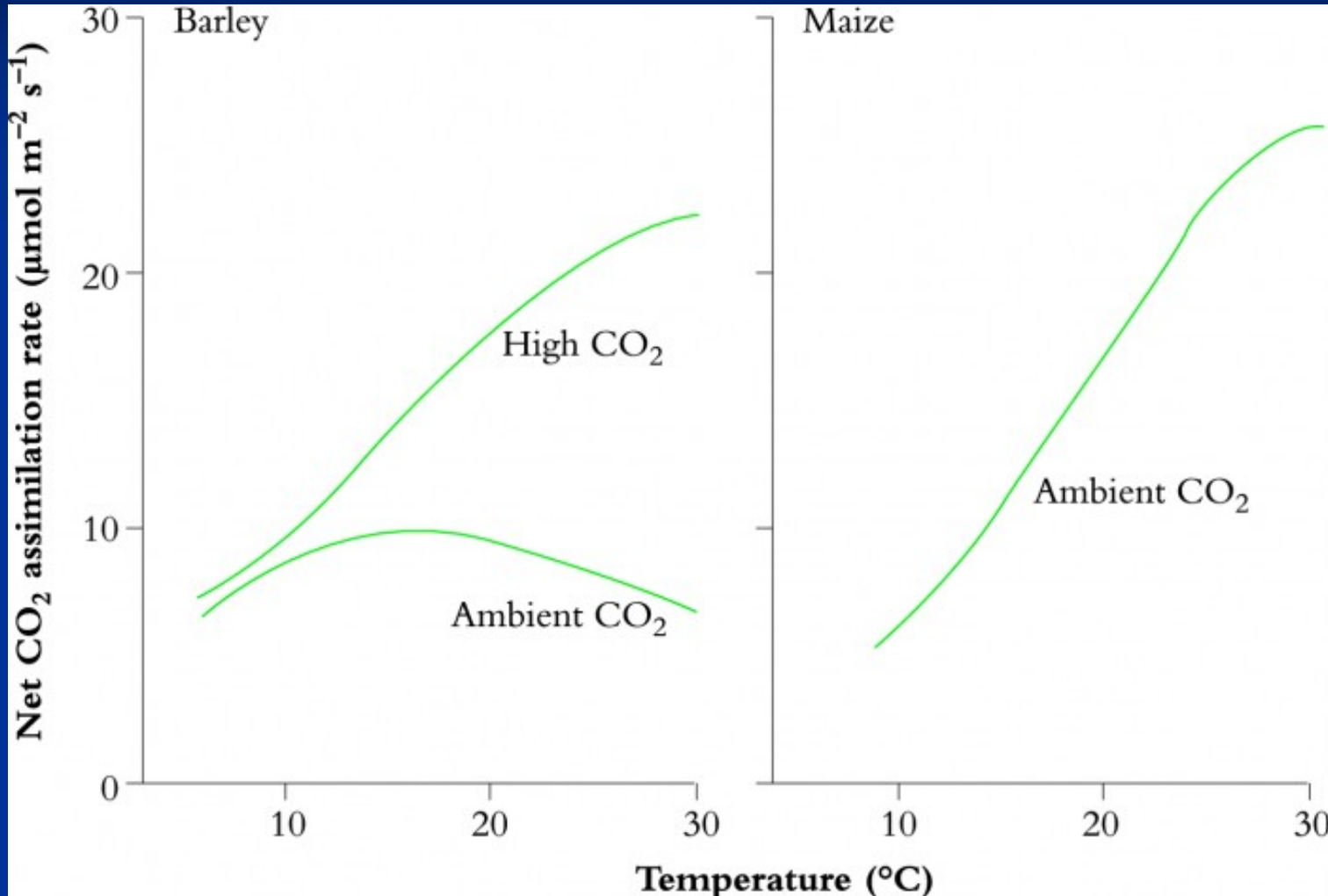


Once CO<sub>2</sub> and lighting levels are sufficiently high, and the temperature is at an optimum level, the rate of photosynthesis will increase rapidly. Mostly this will produce a healthier aquarium plant.

# Teplotní křivka – mezidruhové rozdíly

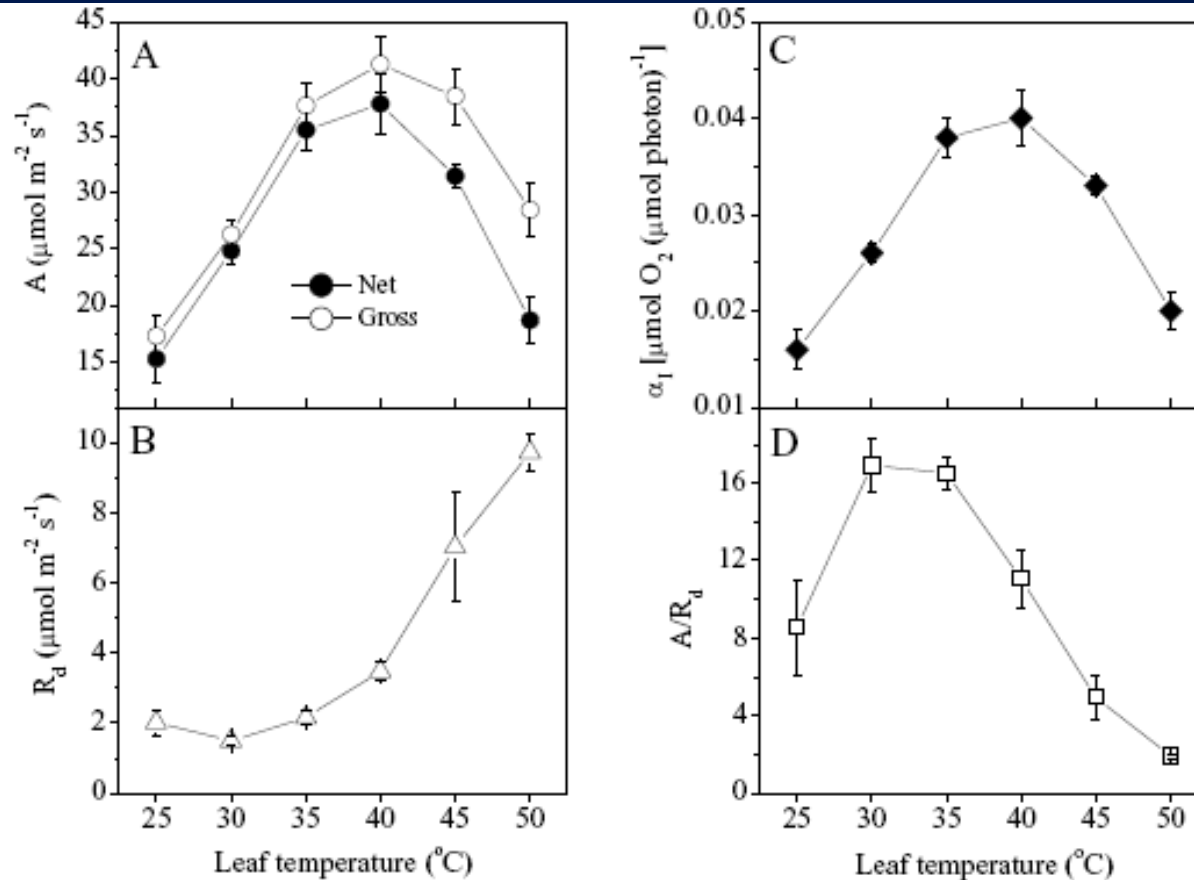


# Vysoká teplota v kombinaci s CO<sub>2</sub>





# Fotosyntéza a transpirace



**FIGURE 1** – Net and gross photosynthesis ( $A$ , A), dark respiration ( $R_d$ , B), instantaneous quantum efficiency of photosynthesis ( $\alpha_1$ , C) and relationship between photosynthesis and respiration ( $A/R_d$ , D) as a function of leaf temperature in sweet orange leaf discs under non-photorespiratory condition. Gross photosynthesis refers to the sum of net photosynthesis and respiration. Each point represents the mean value ( $n=5$ )  $\pm$  SE. Leaf discs were excised from plants grown under greenhouse conditions.

# Metody měření senzitivity fotosyntézy vůči vysokým teplotám

