Photosynthesis – Environment
Species Variability

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Photosynthesis and Environment

Species Variability and Application EPI Concept across Species

The learning objectives of this lecture are:

- Species variability in photosynthesis response to environmental conditions.
- Can we use environmental productivity index (EPI) concept across species?
- What do we need to apply this concept universally across species and regions?

Plant Responses to Environment
Models of Photosynthesis

Of the 250,000 higher plant species:

C_3 photosynthetic model	222,000 (89%)
C_4 photosynthetic model	8,000 (3.2%)
Crassulacean Acid Metabolic (CAM) photosynthetic model	20,000 (8%)

Can we apply EPI concept across species and and across environments?

Photosynthetic Carbon Fixation

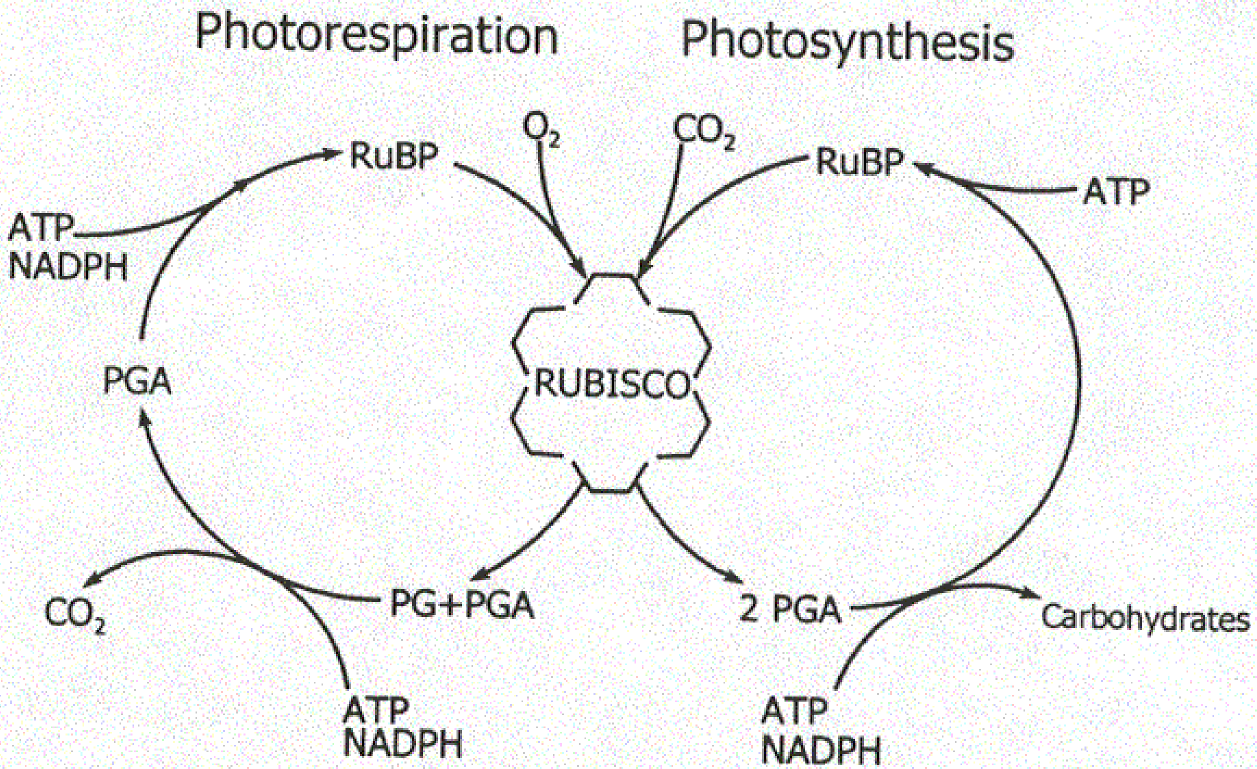
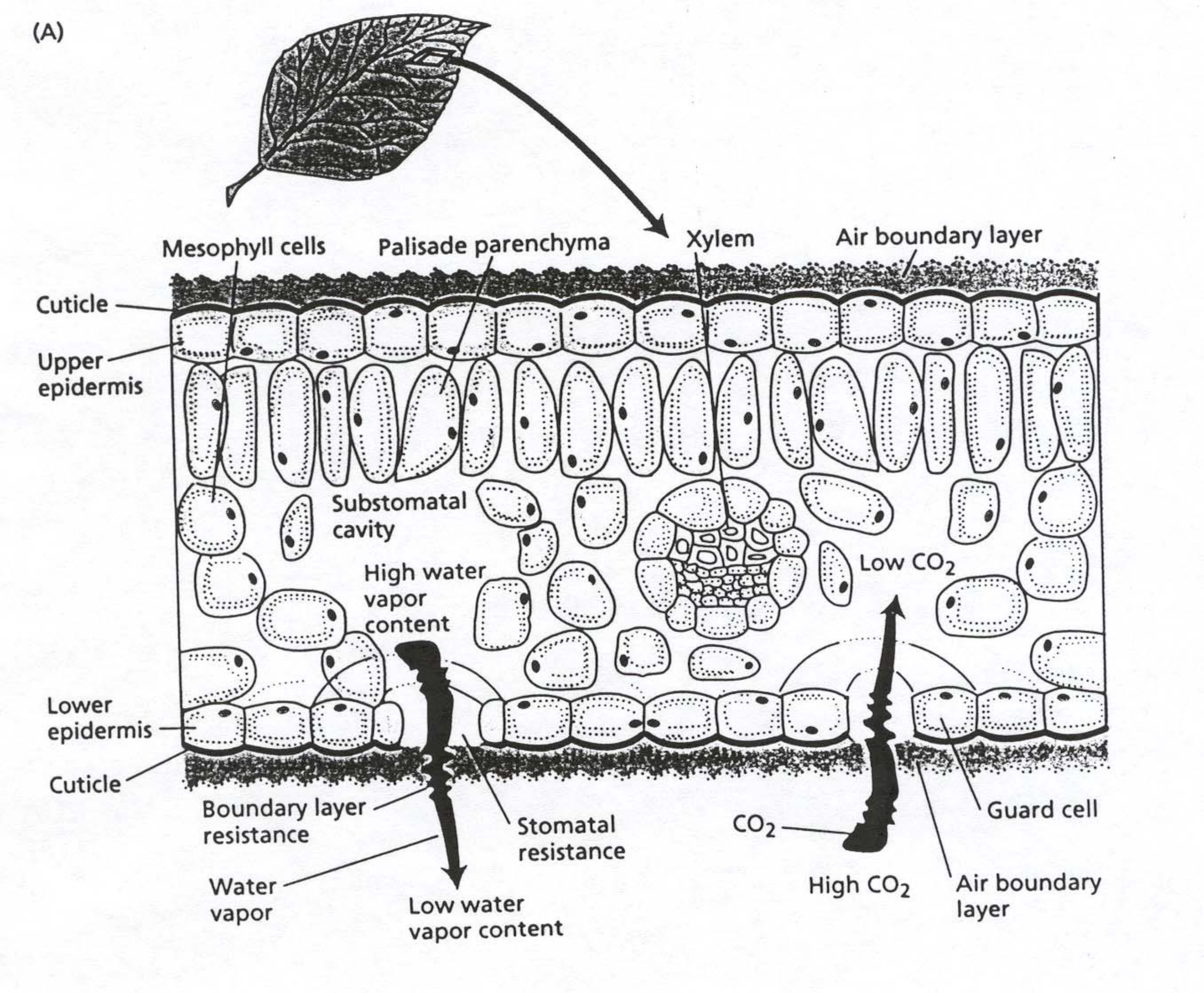
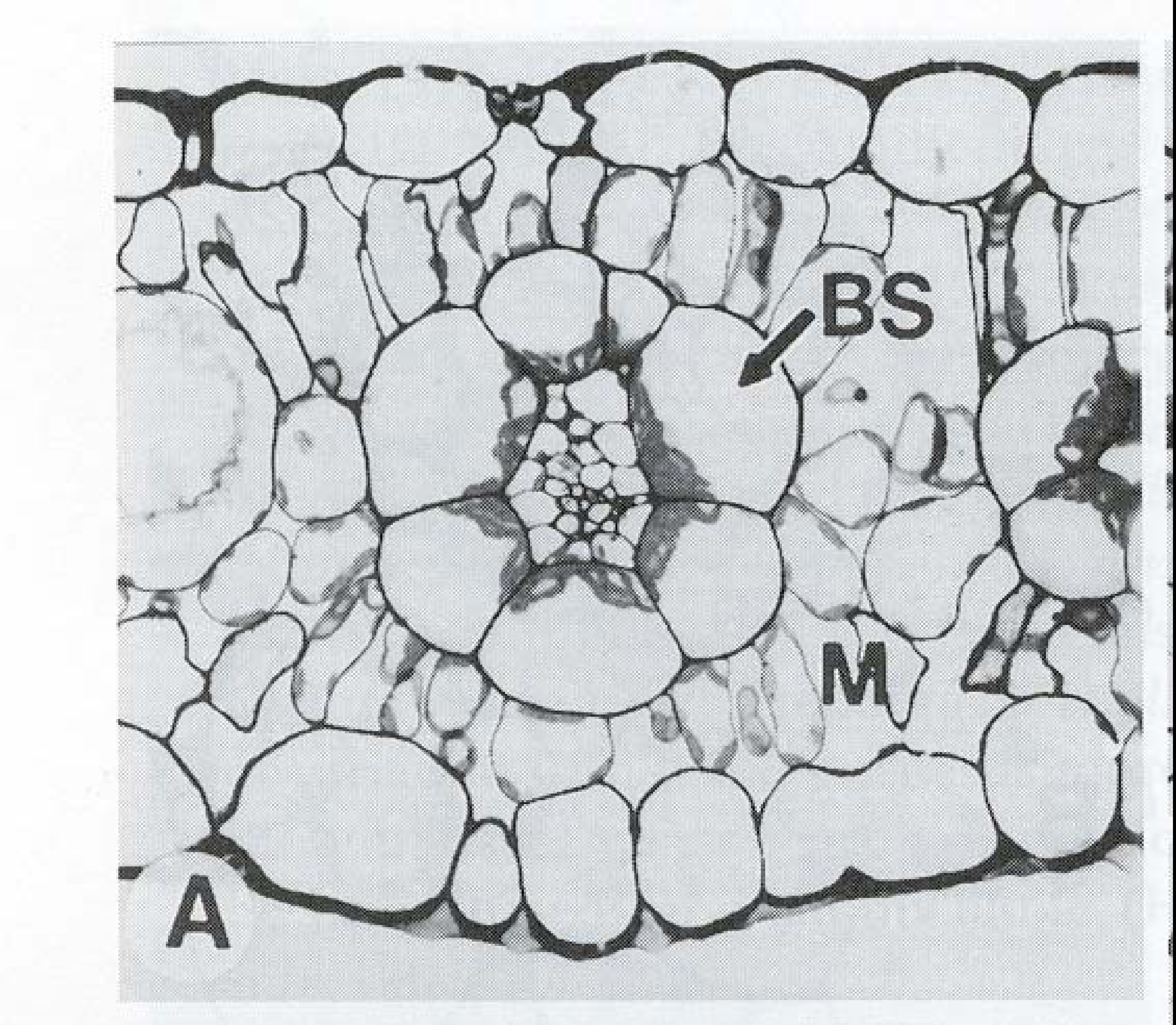


Figure 1 A schematic of the photorespiratory cycle and photosynthesis. Photosynthesis occurs when RuBP is carboxylated by Rubisco, and the products (two phosphoglyceric acid molecules; PGA) are processed into carbohydrates and used to regenerate RuBP in reaction sequences requiring ATP and NADPH. Photorespiration begins with the oxygenation of RuBP to form one phosphoglycolate (PG) and PGA, in a side reaction catalyzed by Rubisco. Processing the phosphoglycolate to PGA and eventually RuBP requires ATP and reducing power (indicated by NADPH).

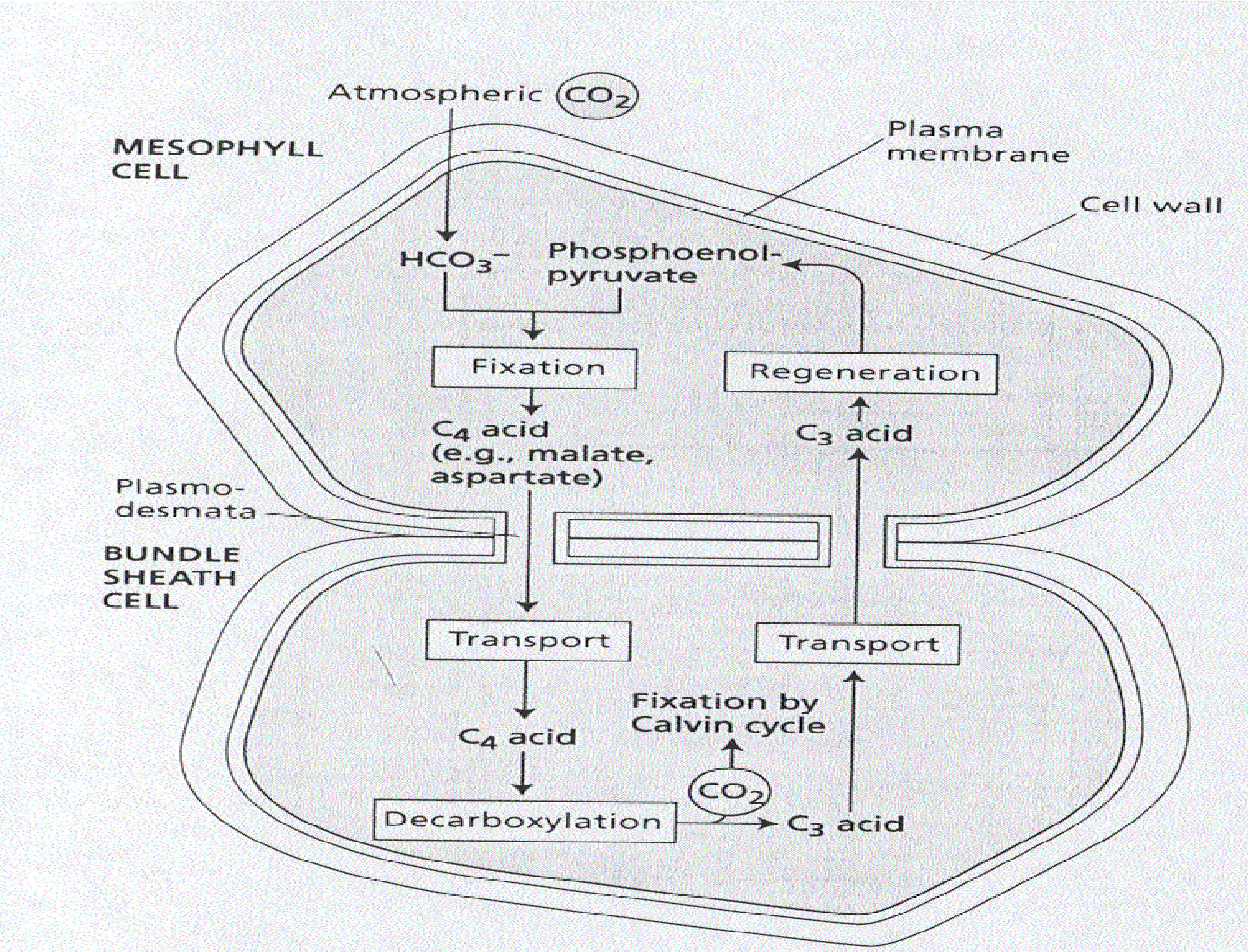
Photosynthetic Carbon Fixation – C3 Plants



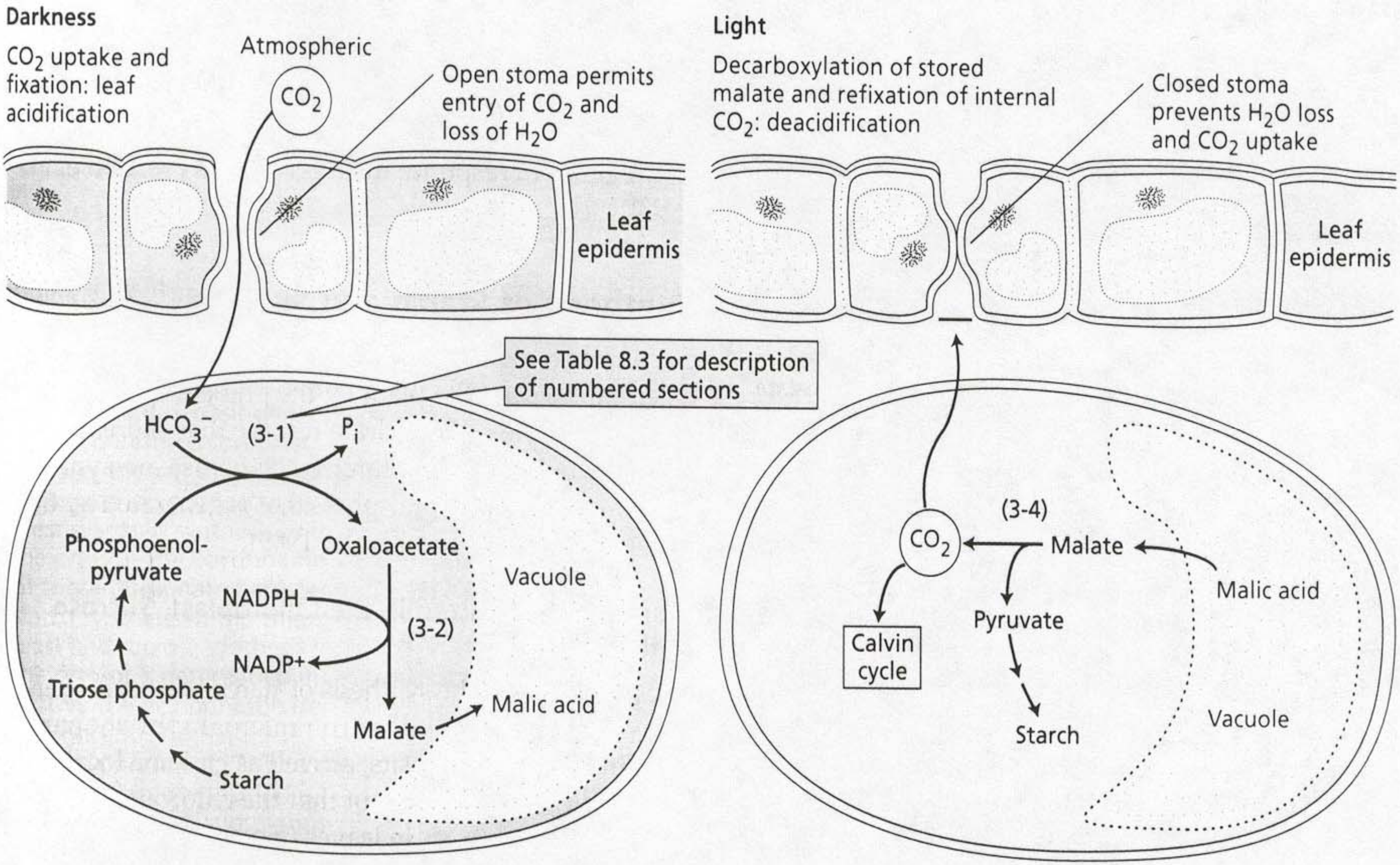
Photosynthetic Carbon Fixation – C4 Plants



Photosynthetic Carbon Fixation – C4 Plants



Photosynthetic Carbon Fixation – CAM Plants

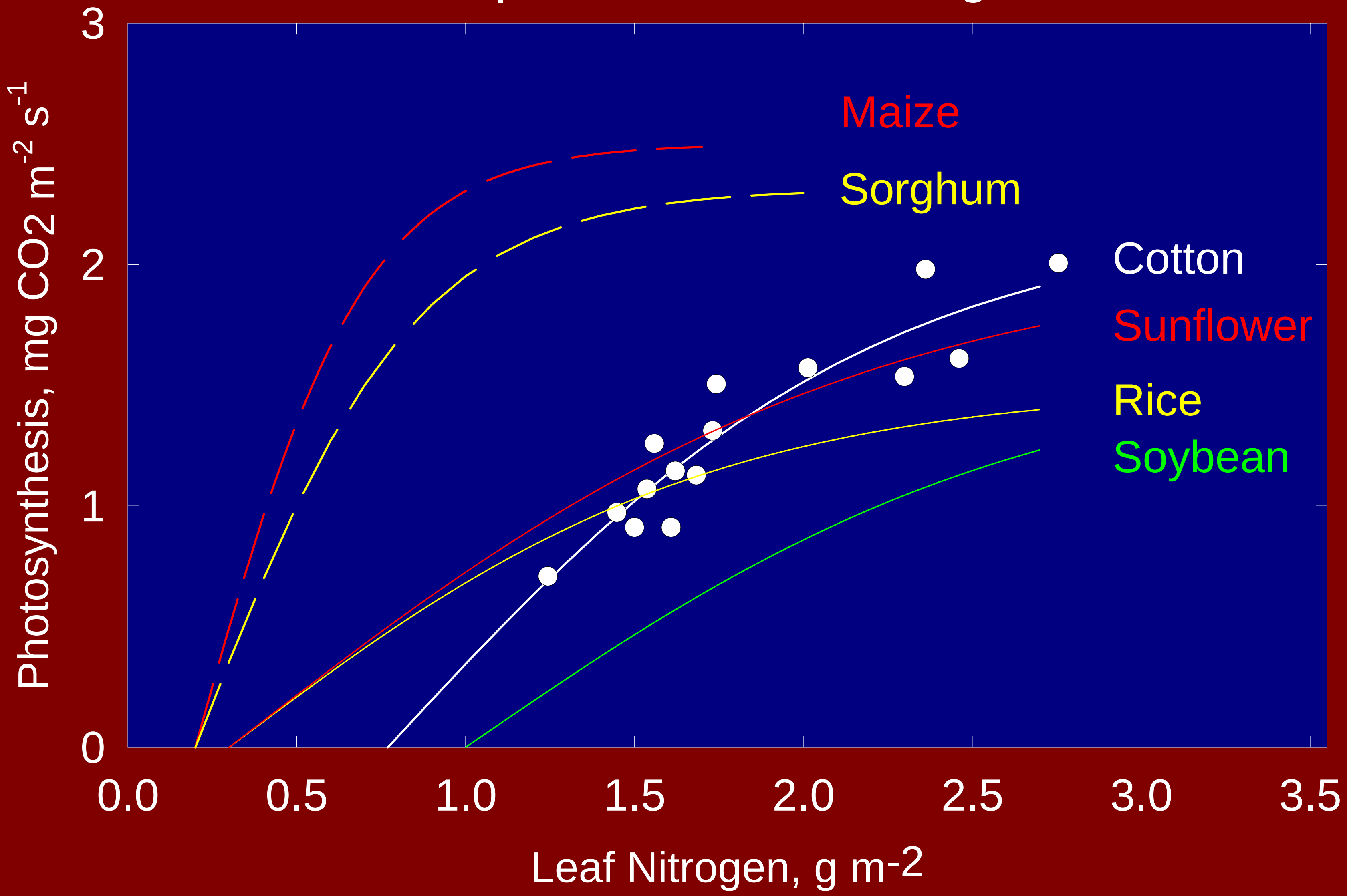


Response to Nitrogen

Variation among Species

Photosynthesis - Variability Among Species

Response to Leaf Nitrogen



Photosynthesis and Leaf Nitrogen

Species variability and temperature

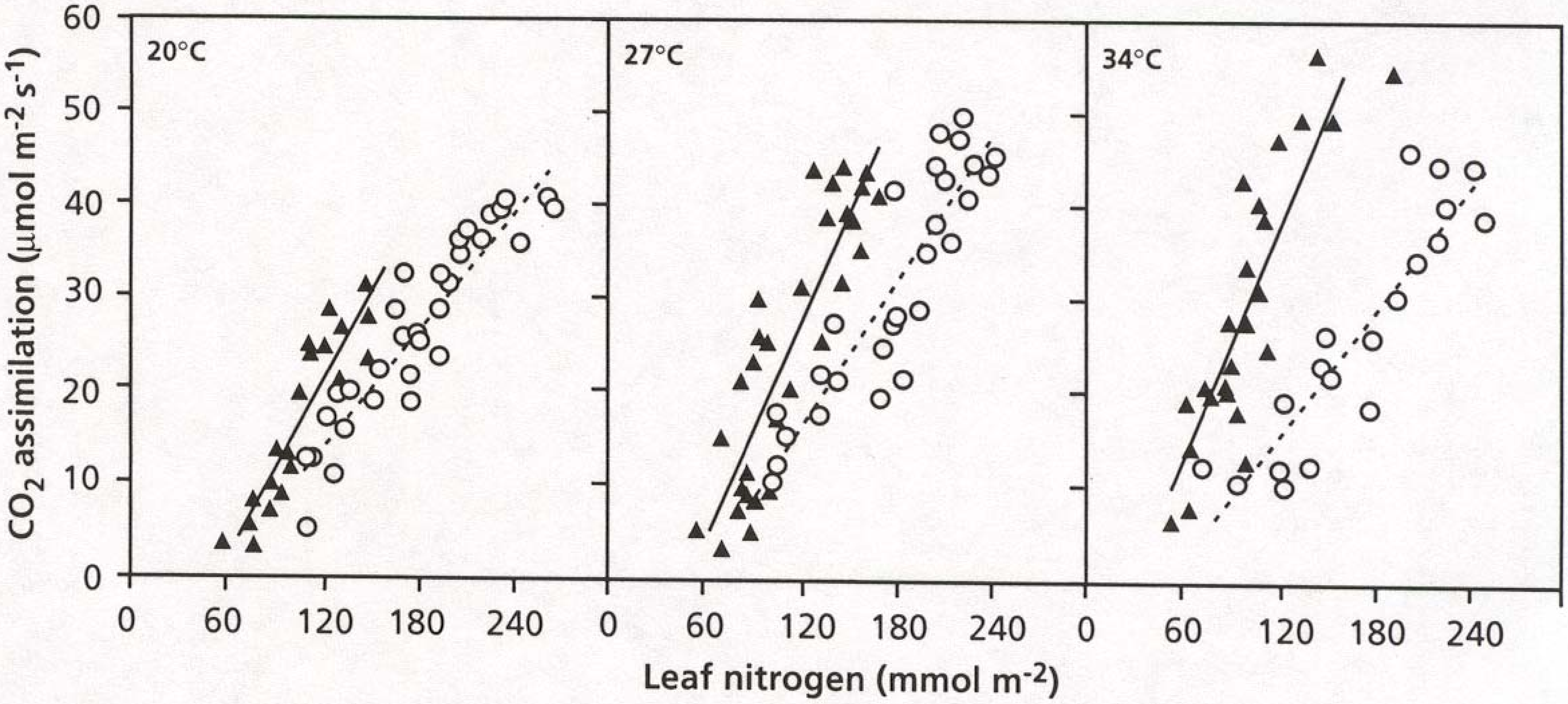


FIGURE 40. The rate of CO_2 assimilation as a function of the organic nitrogen concentration in the leaf and the temperature, as measured for the C_3 plant *Chenopodium album* (pigweed, circles) and the C_4 plant *Amaranthus retroflexus* (triangles) (Sage & Pearcy 1987b). Copyright American Society of Plant Physiology.

Nitrogen and Plant Growth

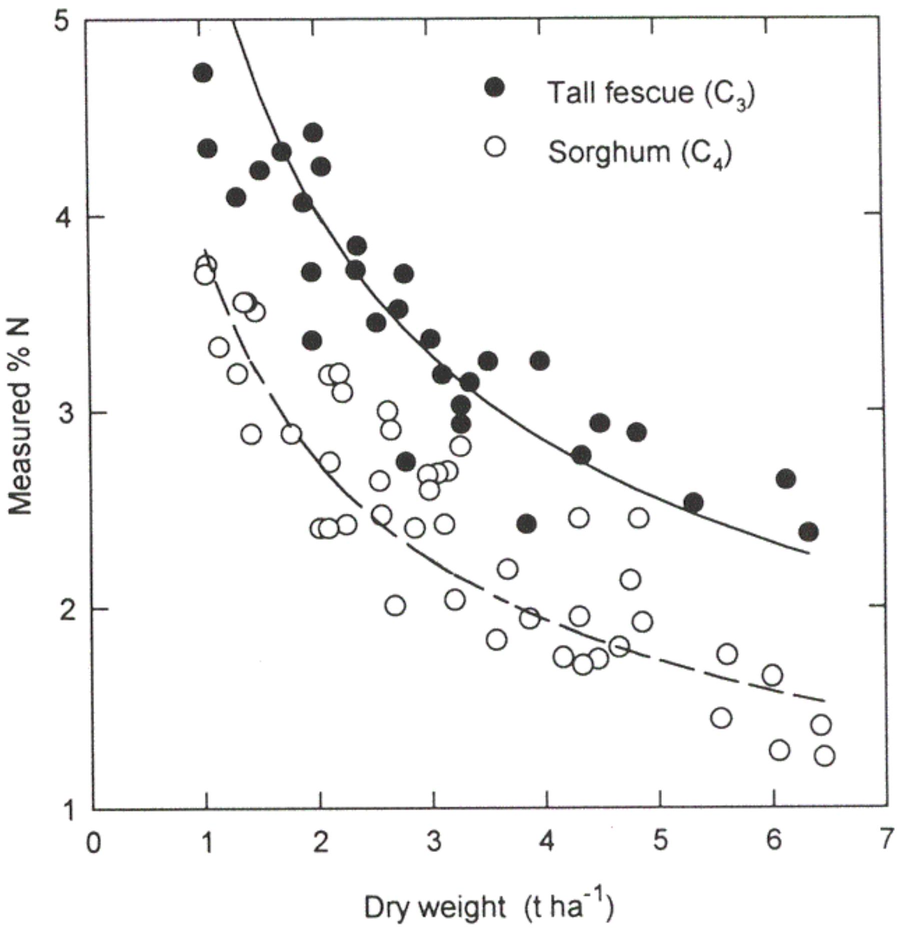
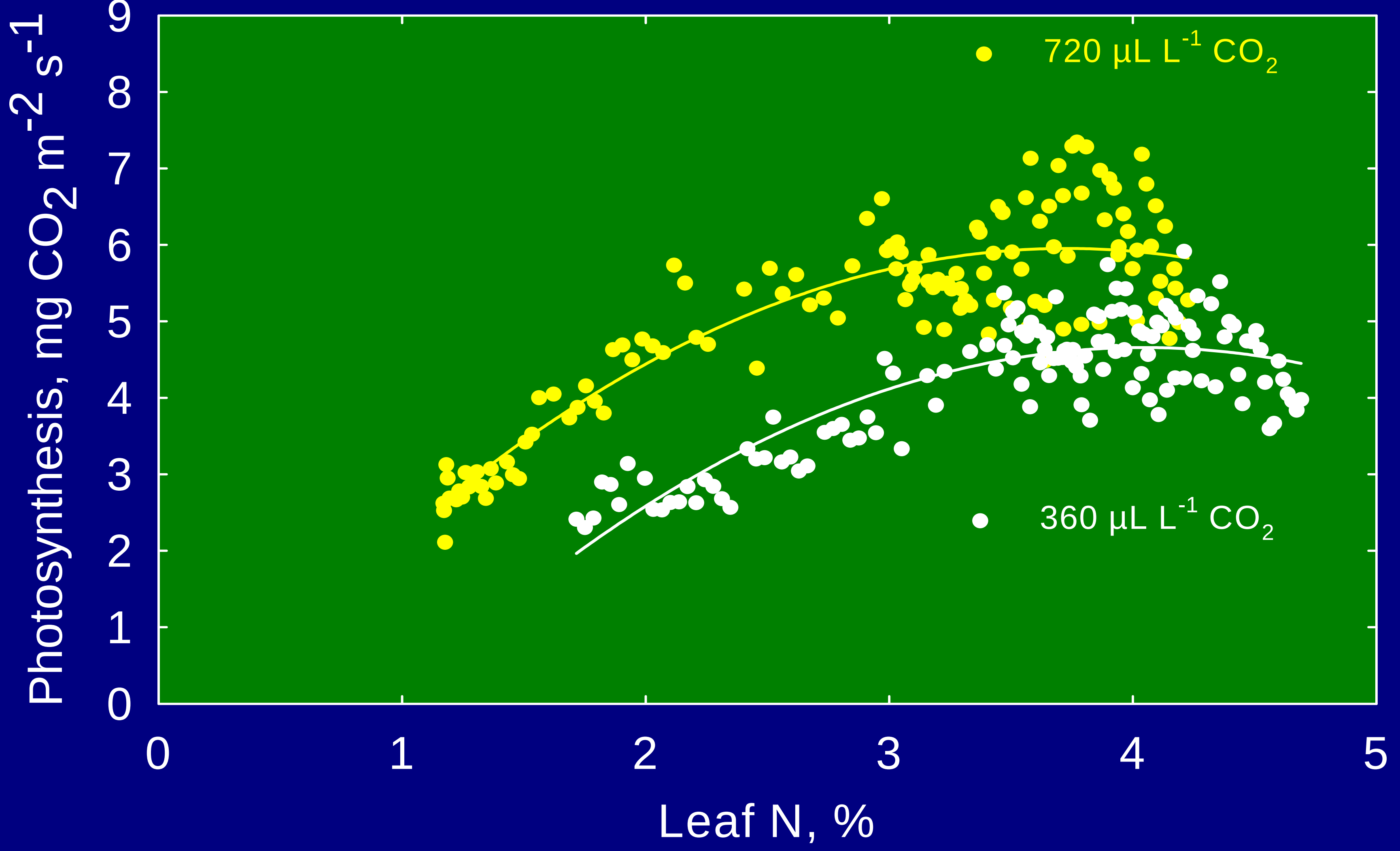


Figure 1 Relationships between plant dry weight and N concentration in foliage of tall fescue (C_3) and sorghum (C_4). [Redrawn with permission from Greenwood, D. J., Lemaire, G., Gosse, G., Cruz, P., Draycott, A., and Neeteson, J. J. (1990). Decline in percentage N of C_3 and C_4 crops with increasing plant mass. *Ann. Bot.* **66,**.425–436, using data points from their Fig. 3 A,B. Lines were drawn using their Eqs. 3 and 5 for C_3 and C_4 species, respectively.]

Photosynthesis - Seasonal Trends

Response to Nitrogen and Carbon Dioxide - Canopy-level



Response to Temperature and Carbon Dioxide

Variation among Species

Photosynthesis and environment

Response to Temperature – Species Variation

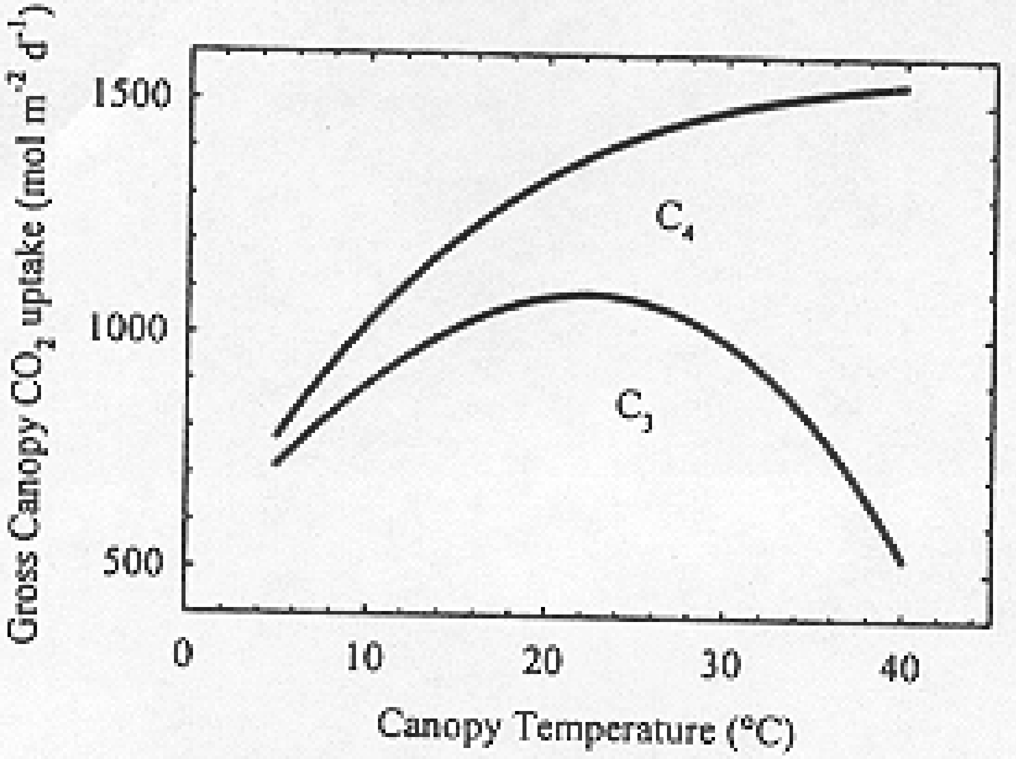


Figure 5 Predicted rates of gross canopy CO_2 uptake integrated over a diurnal course for a range of canopy temperatures. The simulation is for a leaf area index of three assuming a spherical distribution of foliar elements, on Julian day 190 and with clear sky conditions (atmospheric transmittance = 0.75) at a latitude of 52°N. Equations and parameter from Long (1991) and Humphries and Long (1995). Details of the modifications made to simulate the C_4 canopy are given in the text.

Photosynthesis and Temperature

Species variability

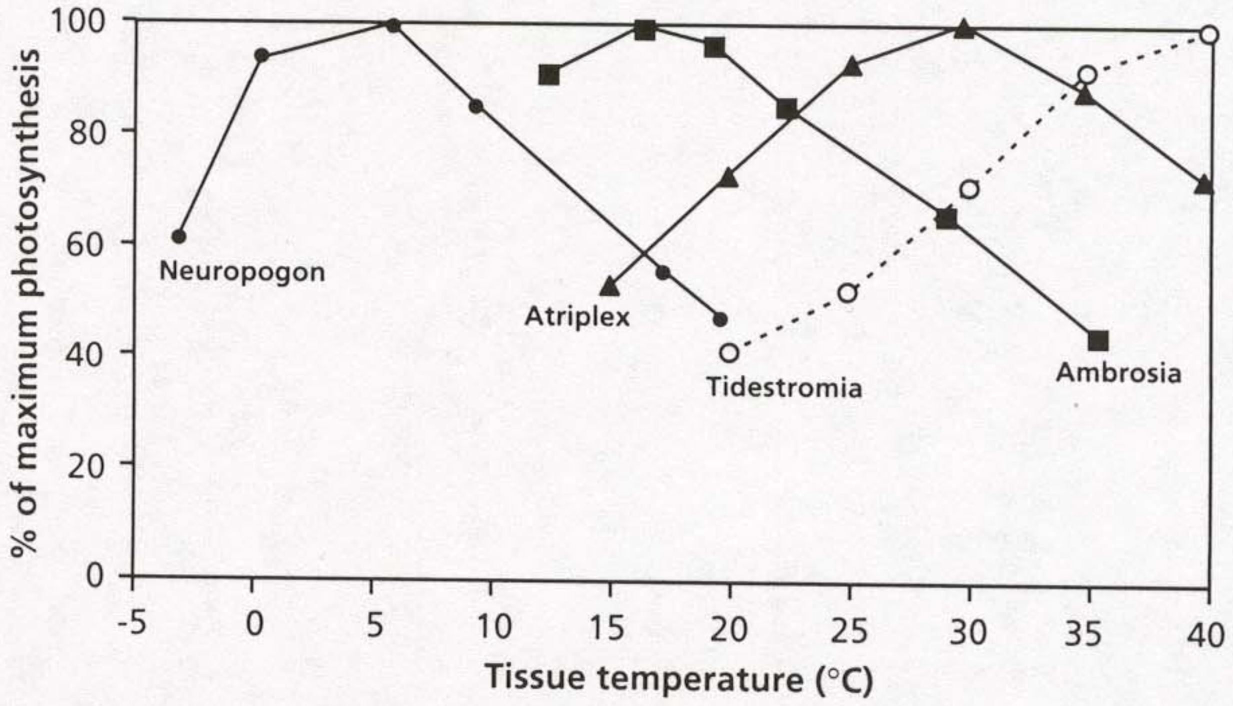
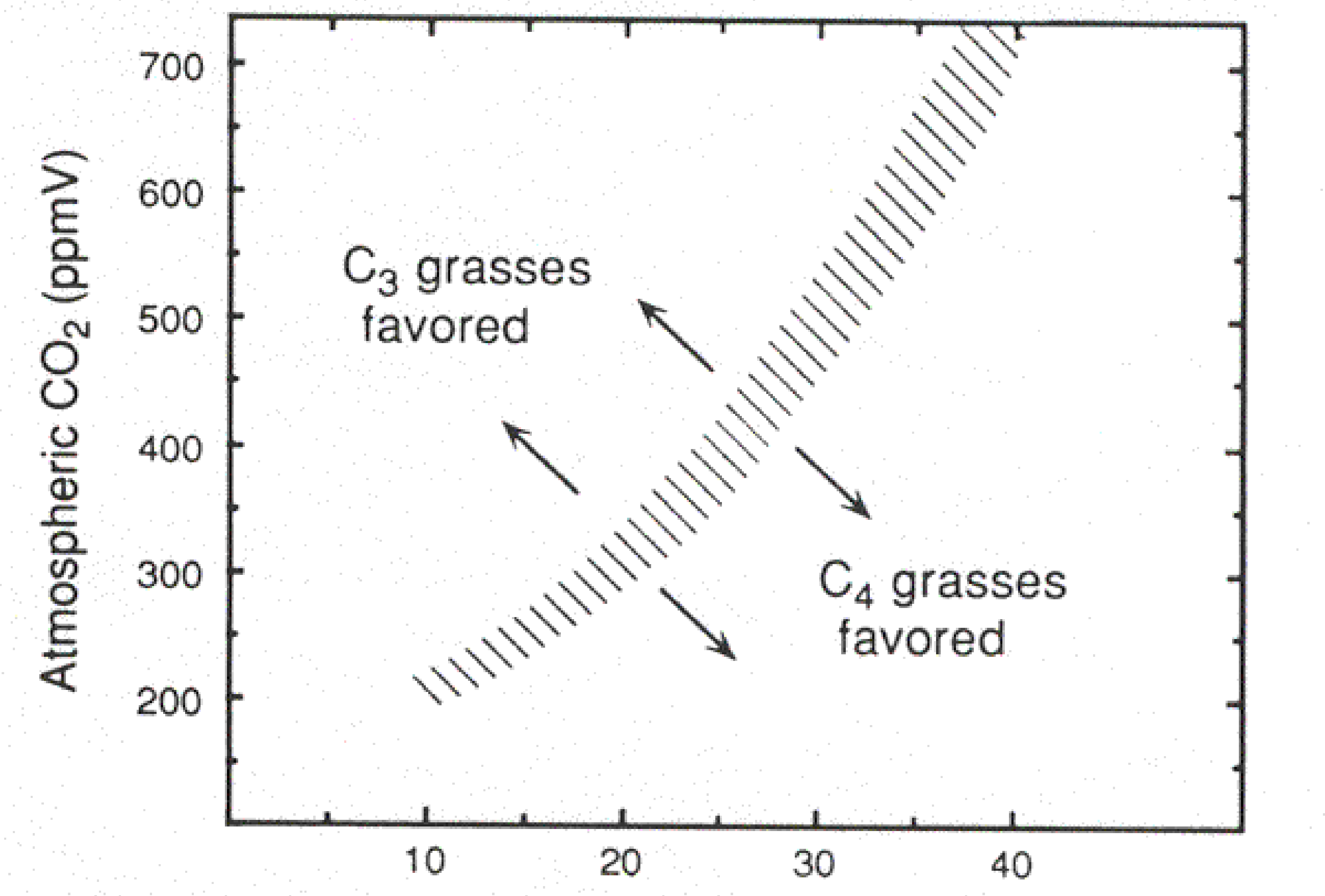


FIGURE 37. Photosynthetic response to temperature in plants from contrasting temperature regimes. Curves from left to right are for *Neuropogon acromelanus*, an antarctic lichen, *Ambrosia chamissonis*, a cool coastal dune plant, *Atriplex hymenelytra*, an evergreen desert shrub, and *Tidestromia obliongifolia*, a summer-active desert perennial (Mooney 1986). Copyright Blackwell Science Ltd.

Photosynthesis and Temperature

Species variability



Temperature, °C

Photosynthesis and Temperature

Species variability – CAM Crops

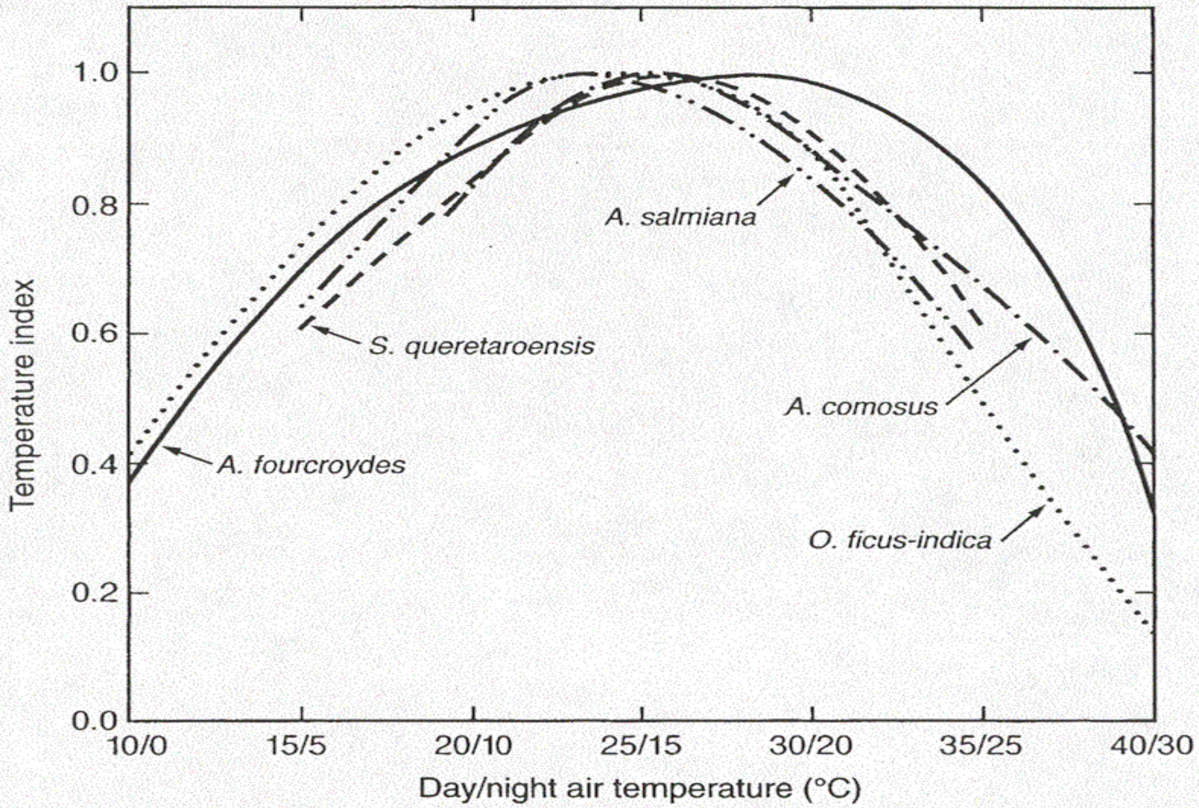
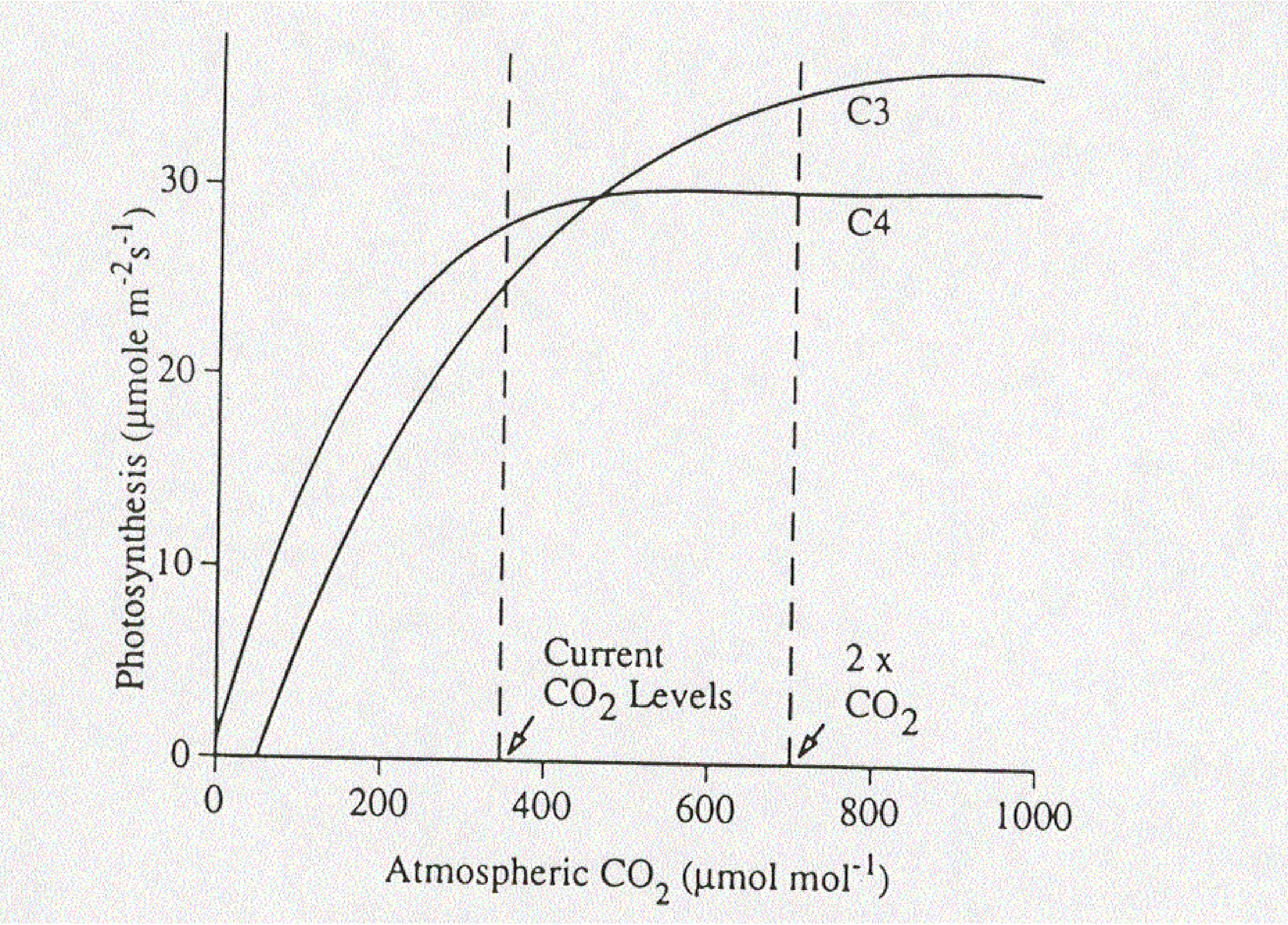


Fig. 14.3. Responses of the temperature index (see equation 14.1) to day/night air temperatures for *Agave fourcroydes, A. salmiana, Ananas comosus, O. ficus-indica* and *S. queretaroensis*. The plants were routinely kept at a particular day/night temperature regime for 10 days to allow for acclimation (Nobel, 1988). Data are for mean night temperatures for *S. queretaroensis* and for constant night temperatures for the other species. They are from the references cited in Fig. 14.2, plus Connelly (1972), Neales *et al.* (1980) and Bartholomew and Malézieux (1994) for *Ananas comosus*.

Photosynthesis and Carbon Dioxide

Species variability

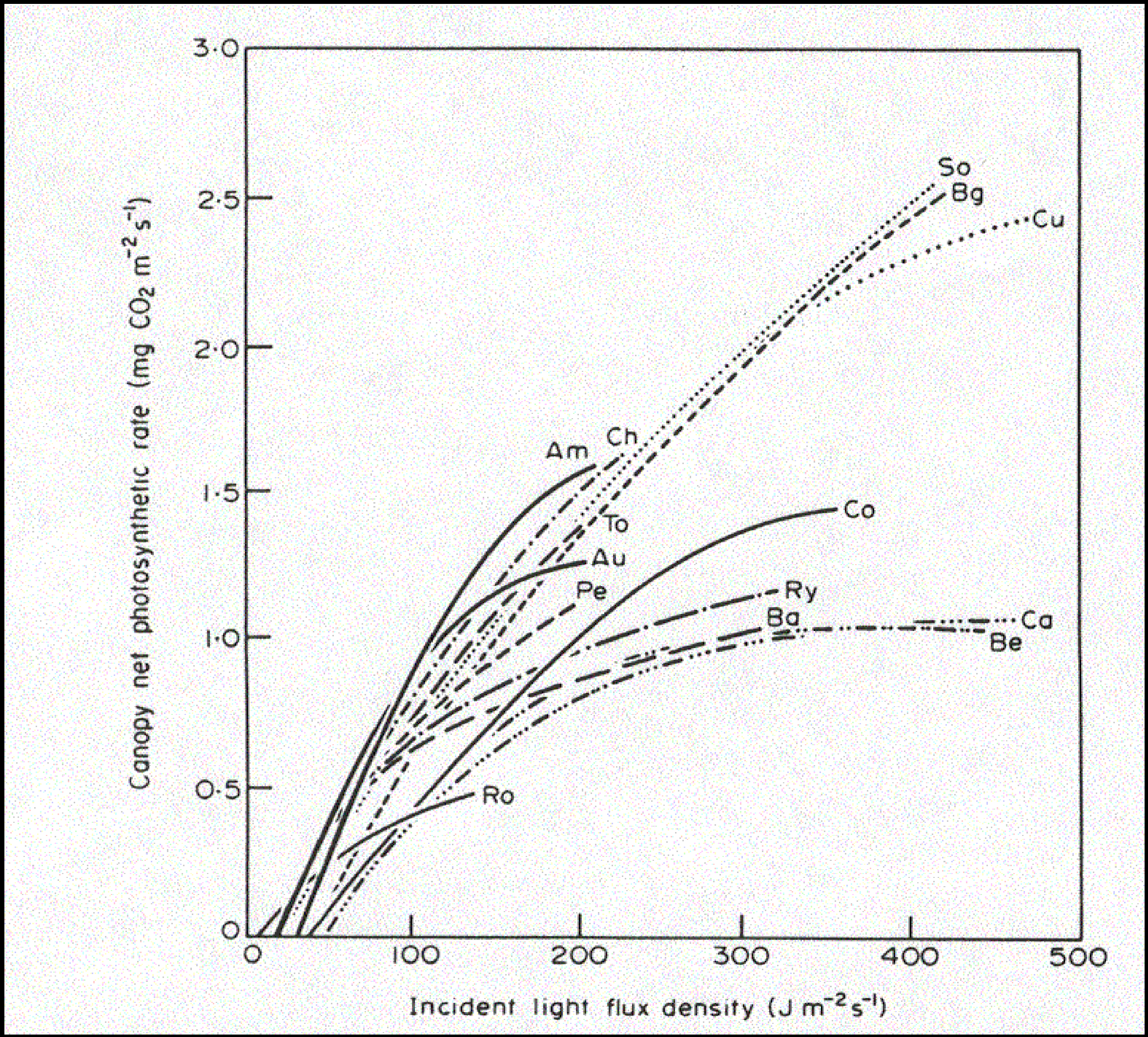


Crop responses to Solar Radiation

Species Variability

Photosynthesis and Solar Radiation

Species variability



Am – Amaranthus

Au – Aubergine

Ba – Barley

Be – Bean

Bg – Bermudagrass

Ca – Cabbage

Ch – Chrysanthimum

Co – Cotton

Cu – Cucumber

Pe – Pepper

Ro – Rose

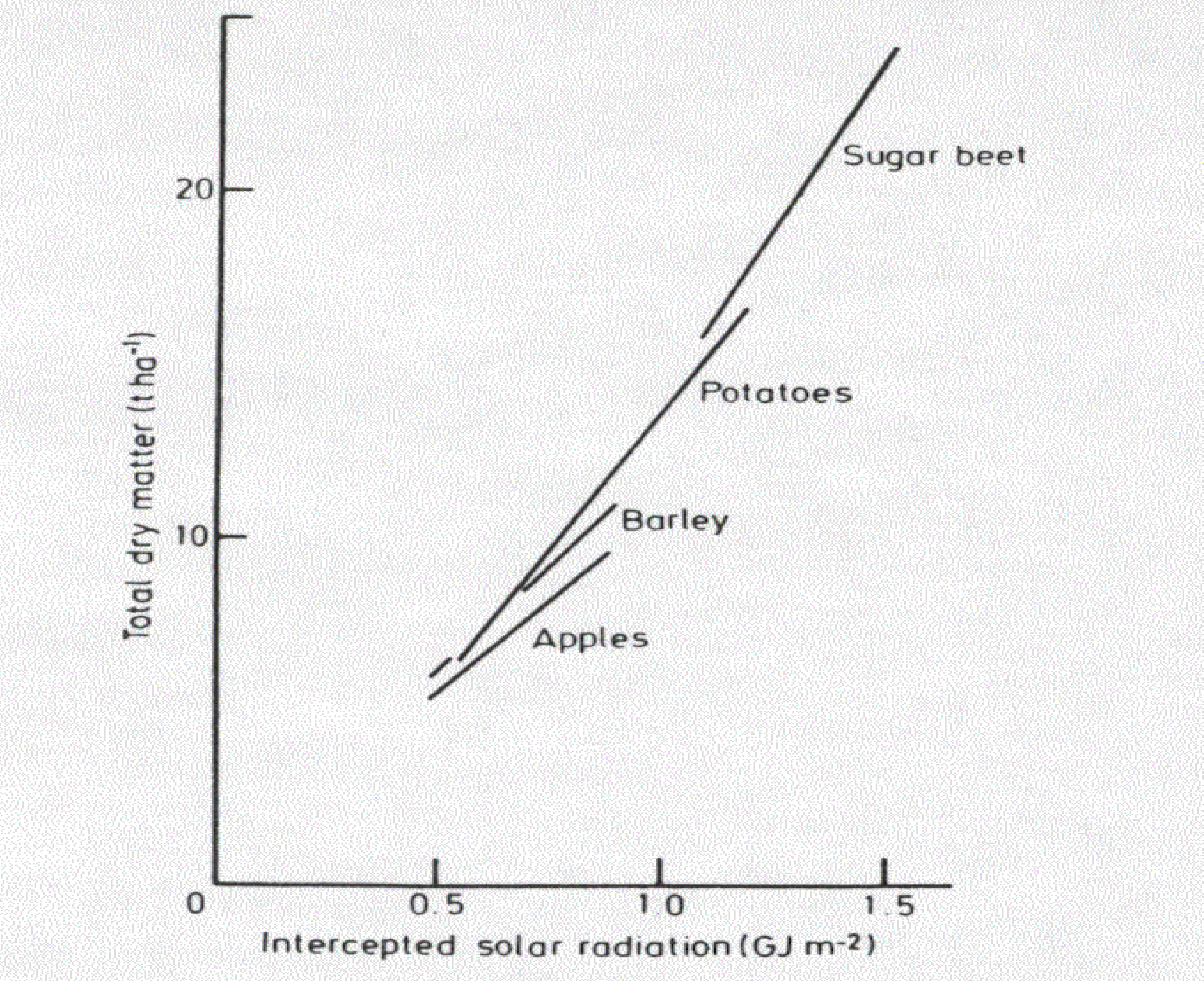
Ry – Ryegrass

So – Sobean

To - Tomato

Photosynthesis and Solar Radiation

Photosynthesis and Thus Dry Matter Production



Photosynthesis and Radiation

Light adaptation

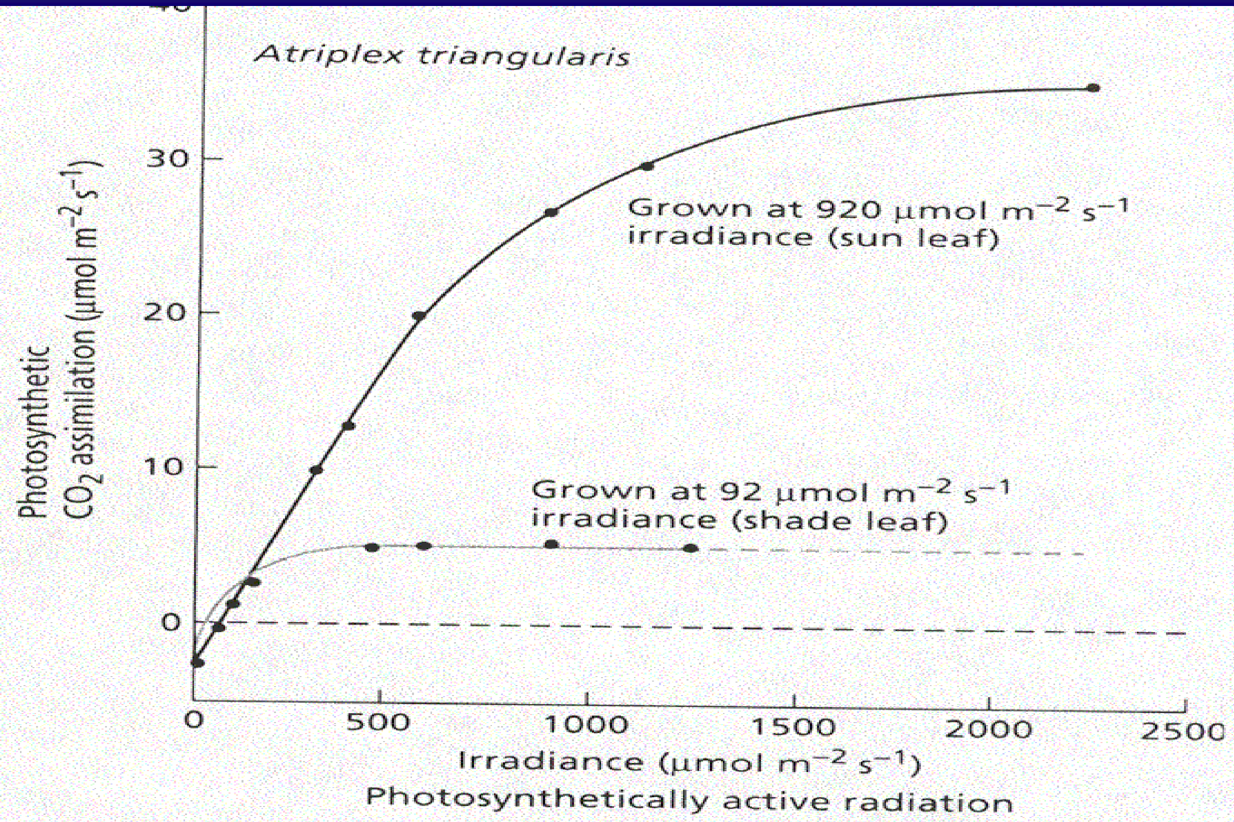


Figure 9.9 Changes in photosynthesis in leaves of *Atriplex triangularis* as a function of irradiance. The upper curve represents a leaf grown at an irradiance ten times higher than that of the lower curve. In the leaf grown at the lower light levels, photosynthesis saturates at a substantially lower irradiance, indicating that the photosynthetic properties of a leaf depend on its growing conditions. (From Björkman 1981.)

Photosynthesis and Solar Radiation

Sun and Shade adaptation

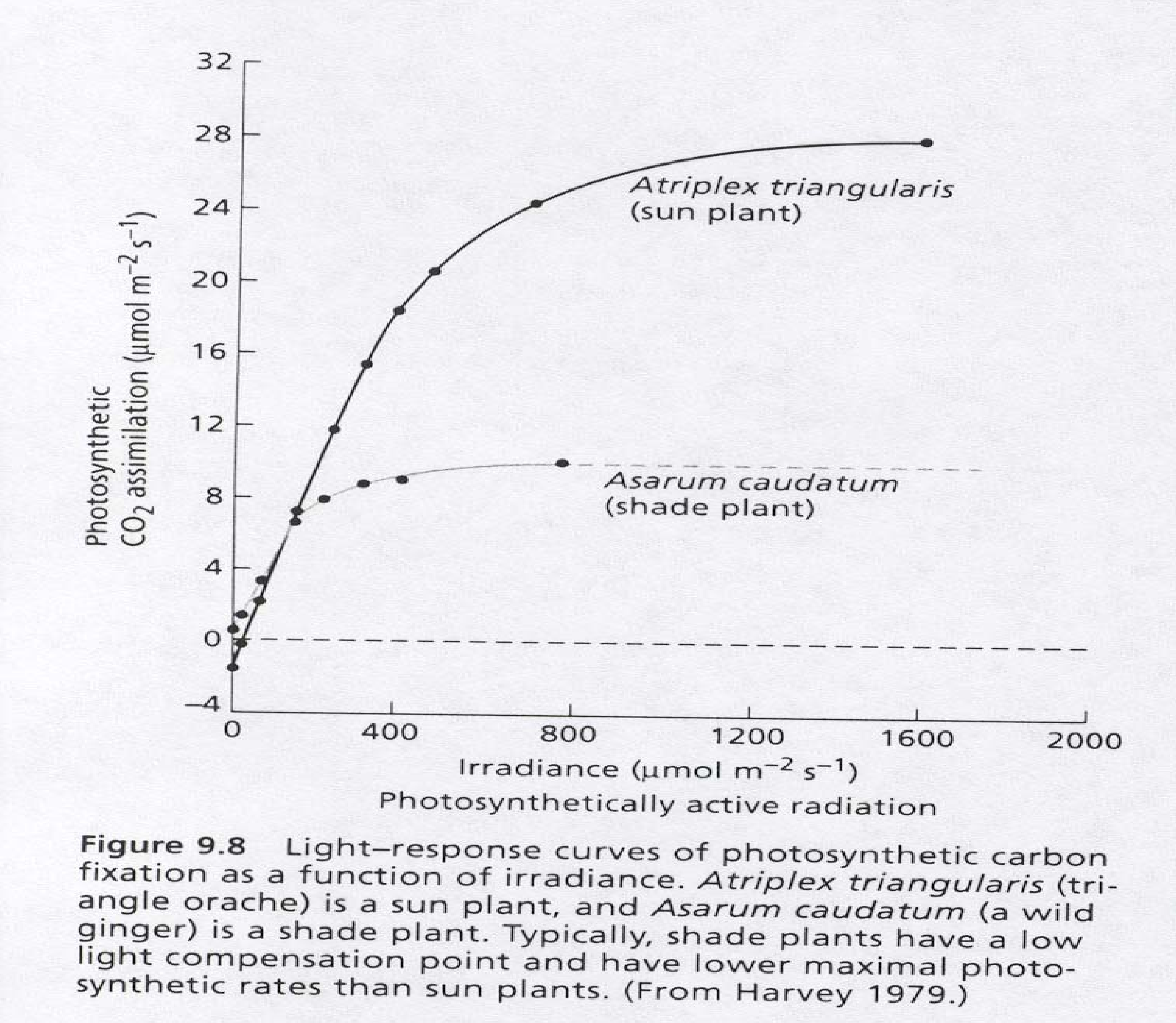


Figure 9.8 Light–response curves of photosynthetic carbon fixation as a function of irradiance. *Atriplex triangularis* (triangle orache) is a sun plant, and *Asarum caudatum* (a wild ginger) is a shade plant. Typically, shade plants have a low light compensation point and have lower maximal photosynthetic rates than sun plants. (From Harvey 1979.)

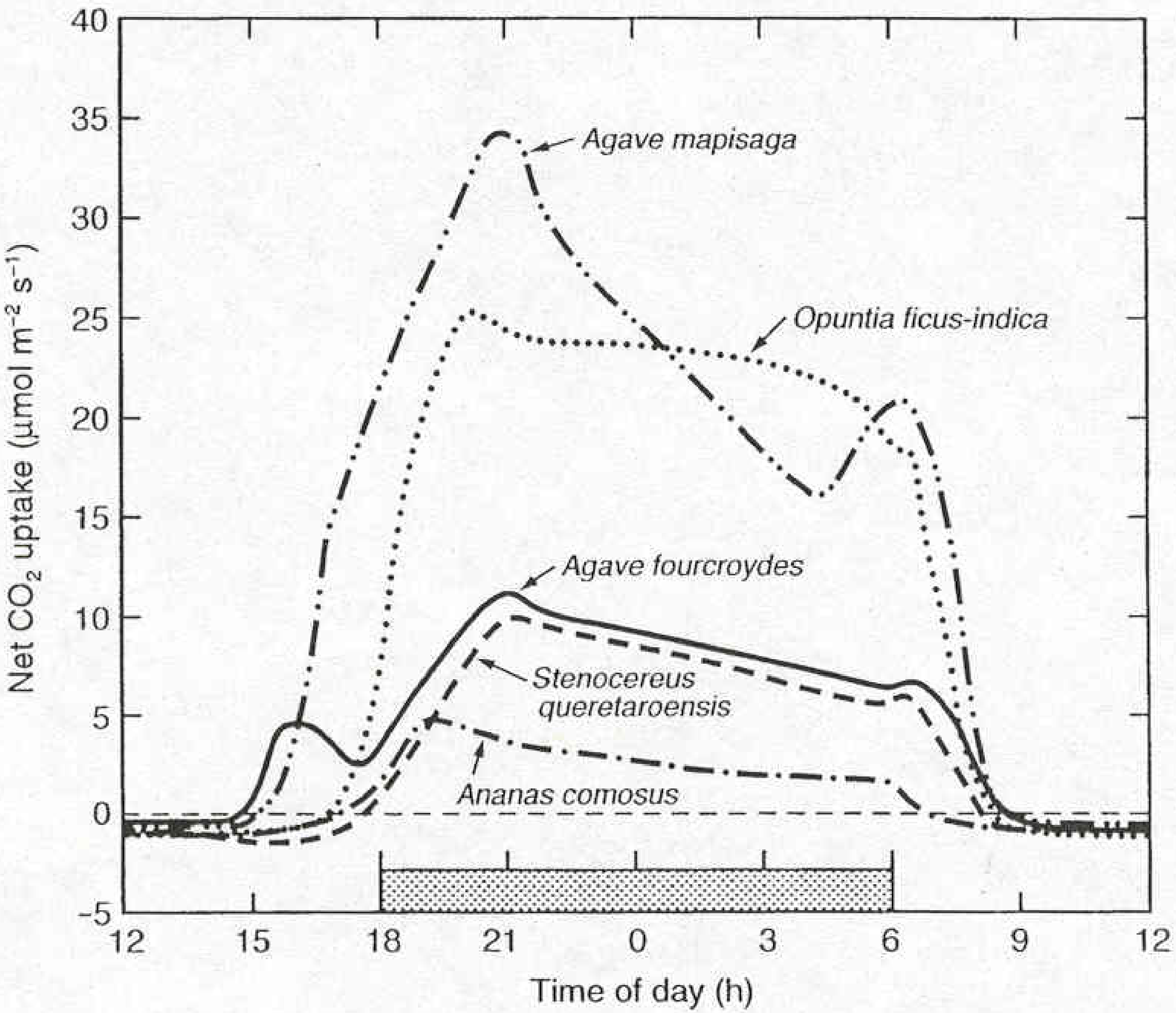


Fig. 14.1. Net CO$_2$ uptake over 24 h period for various cultivated CAM species under approximately optimal conditions. Data for leaves of *Agave mapisaga* are from Nobel *et al.* (1992); for leaves of *Agave fourcroydes* from Nobel (1985); for leaves of *Ananas comosus* at a suboptimal PPF averaging 360 μmol m^{-2} s^{-1} from Medina *et al.* (1991); for stems of *Opuntia ficus-indica* from Nobel (1988) and P.S. Nobel (unpublished observations); and for stems of *Stenocereus queretaroensis* from Nobel and Pimienta-Barrios (1995) and P. S. Nobel (unpublished observations).

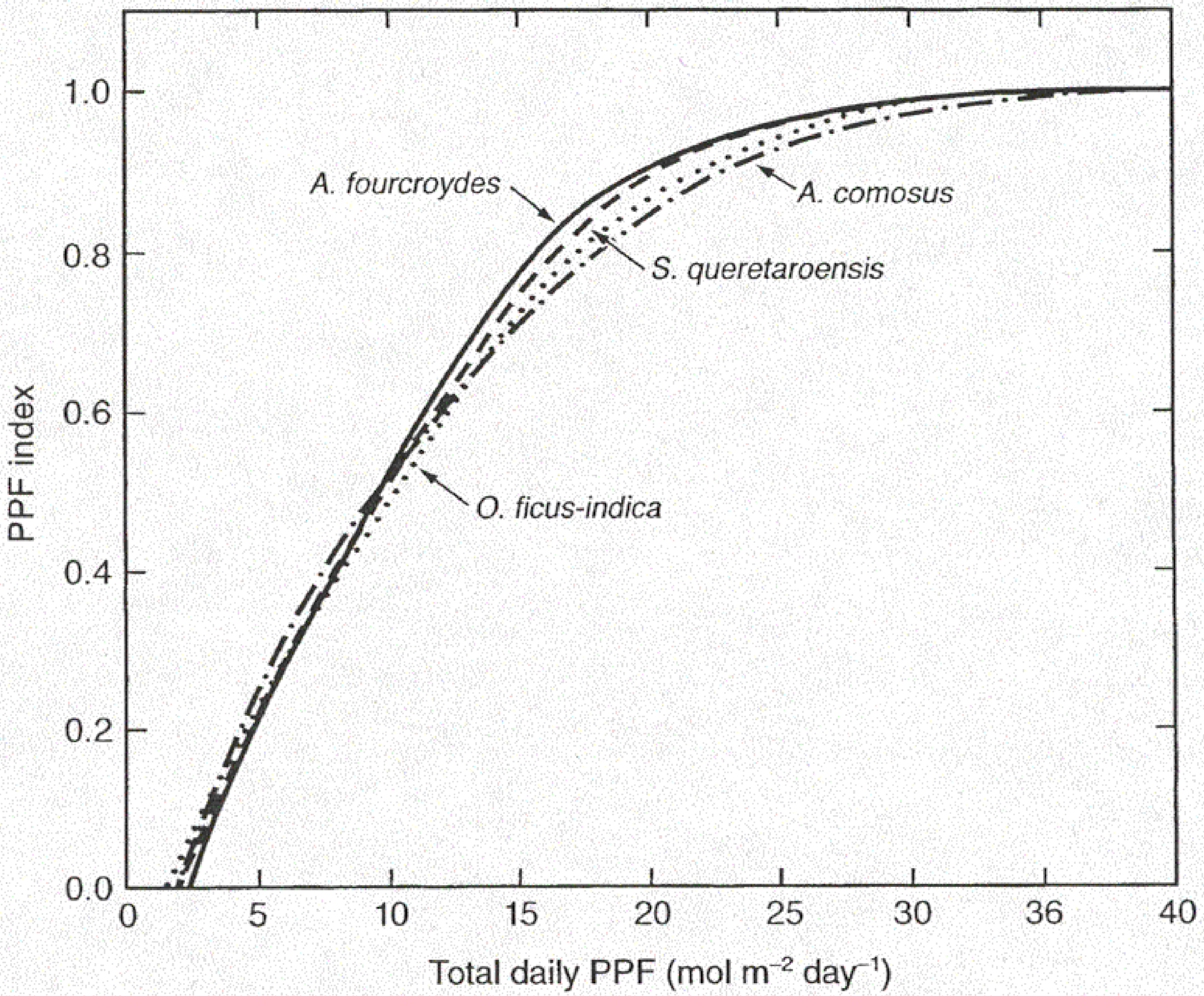


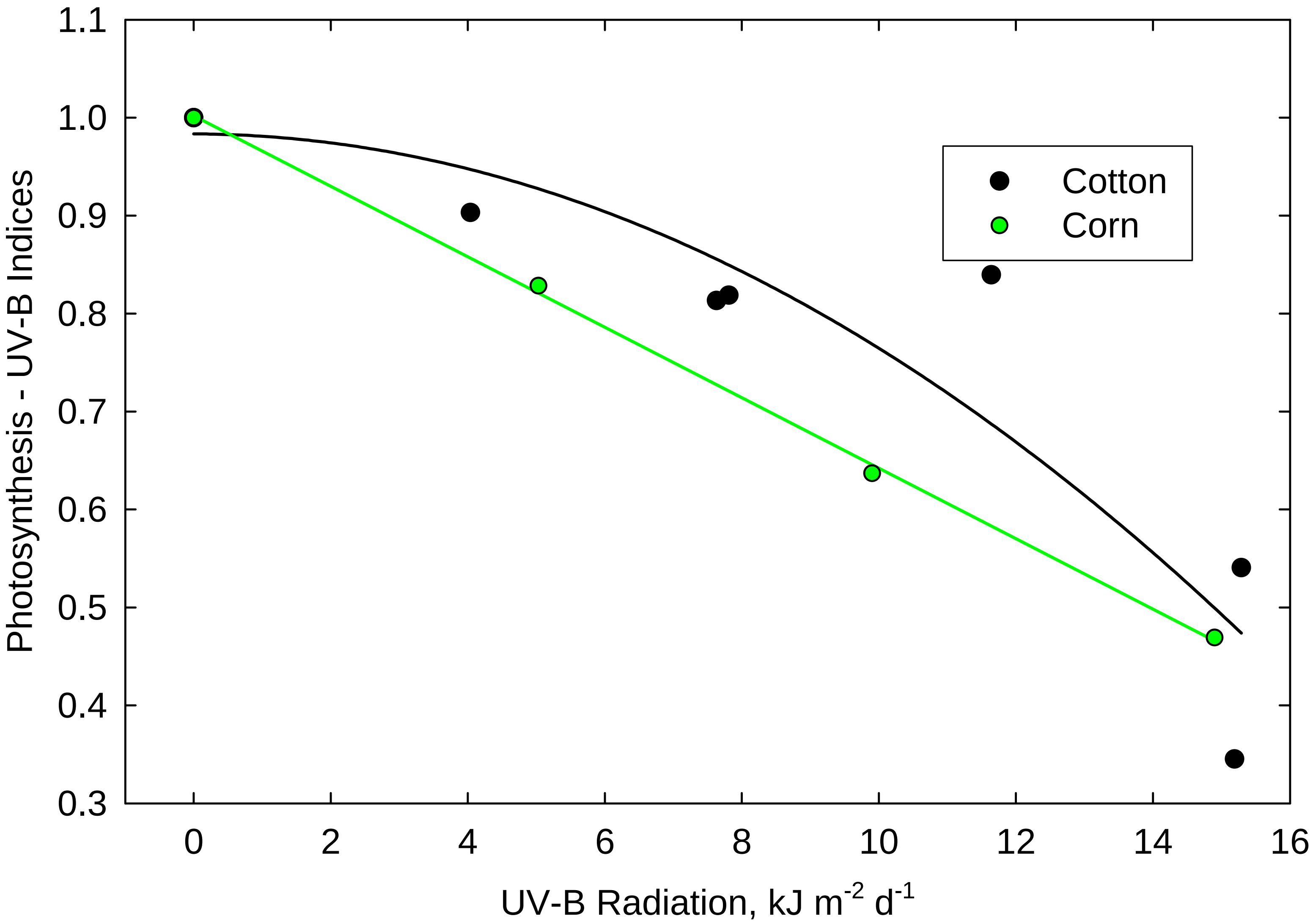
Fig. 14.4. Responses of the PPF Index (see equation 14.1) to the total daily PPF for *Agave fourcroydes, Ananas comosus, O. ficus-indica,* and *S. queretaroensis.* Data for the agave and the cacti are for the PPF in the planes of the photosynthetic surfaces and are from the references cited in Fig. 14.2. For pineapple, data are for the PPF in a horizontal plane incident on the canopy and are from Sale and Neales (1980) and Nose *et al.* (1986).

Crop responses to UV-B Radiation

Species Variability

Photosynthesis and UV-B Radiation

Species variability and Degree of UV-B stress

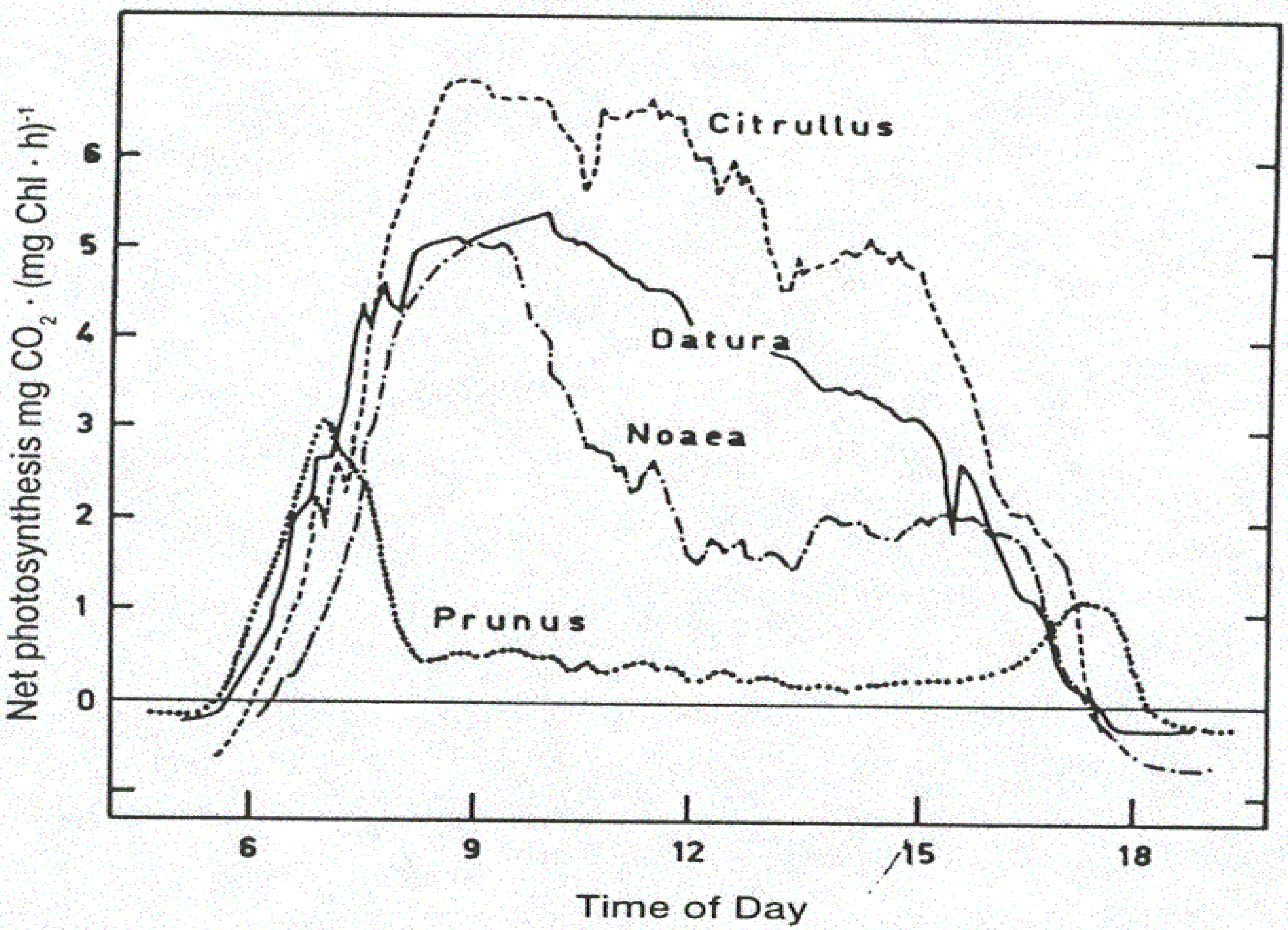


Crop responses to Water Stress

Species Variability

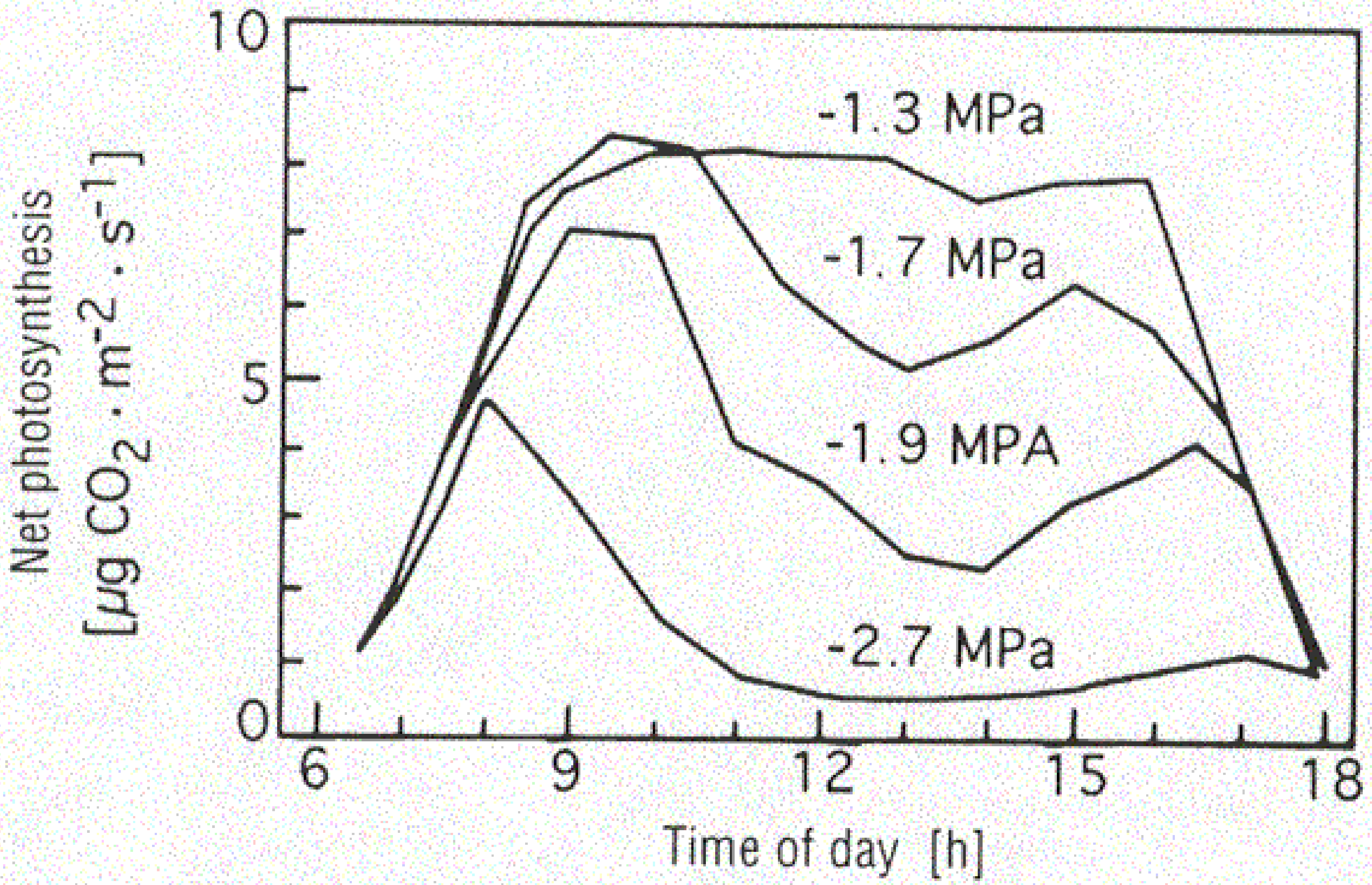
Photosynthesis and Water Deficits

Species variability and Degree of stress



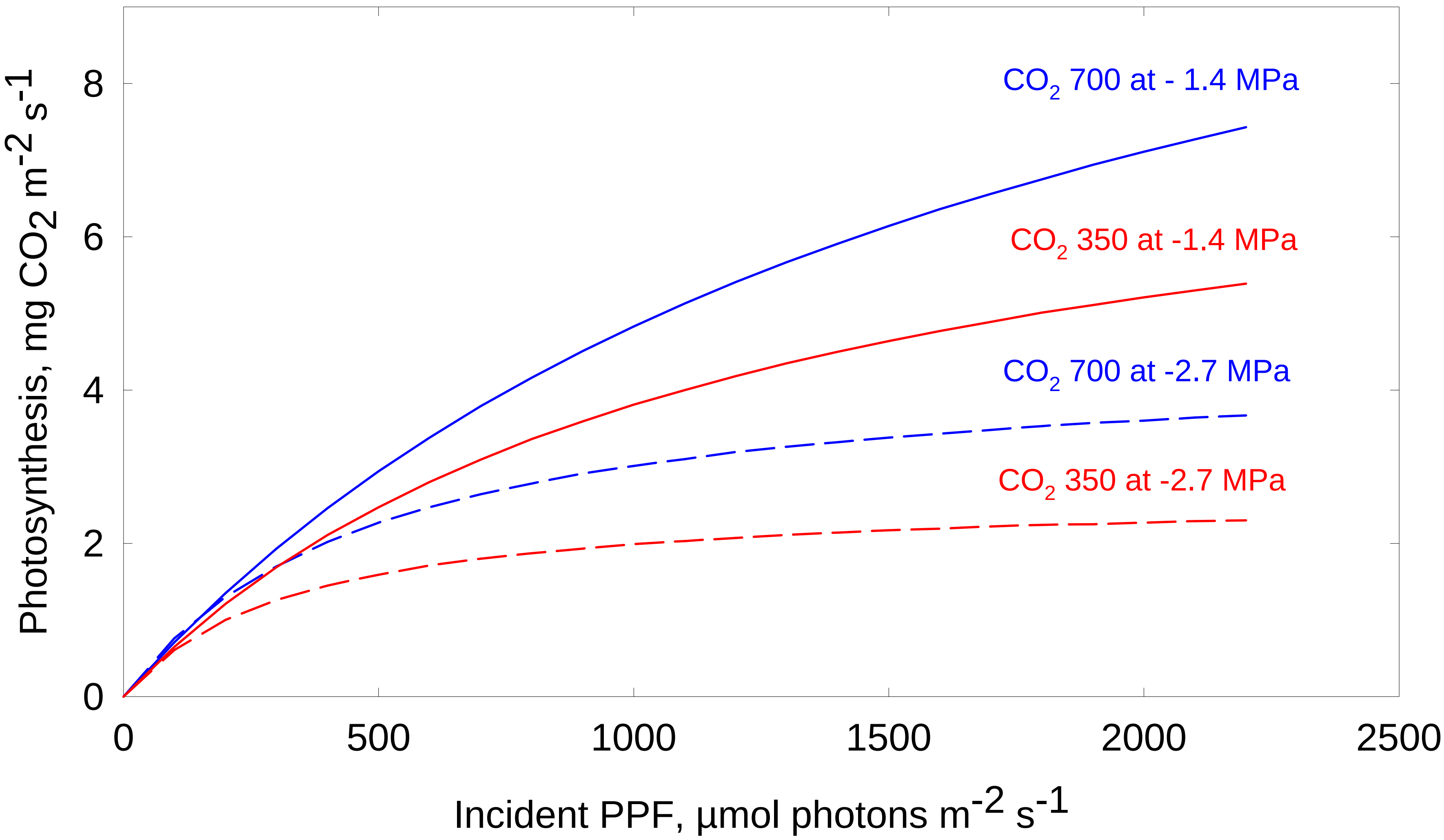
Photosynthesis and Water Deficits

Soybean-Diurnal trends - Response to degree of water stress



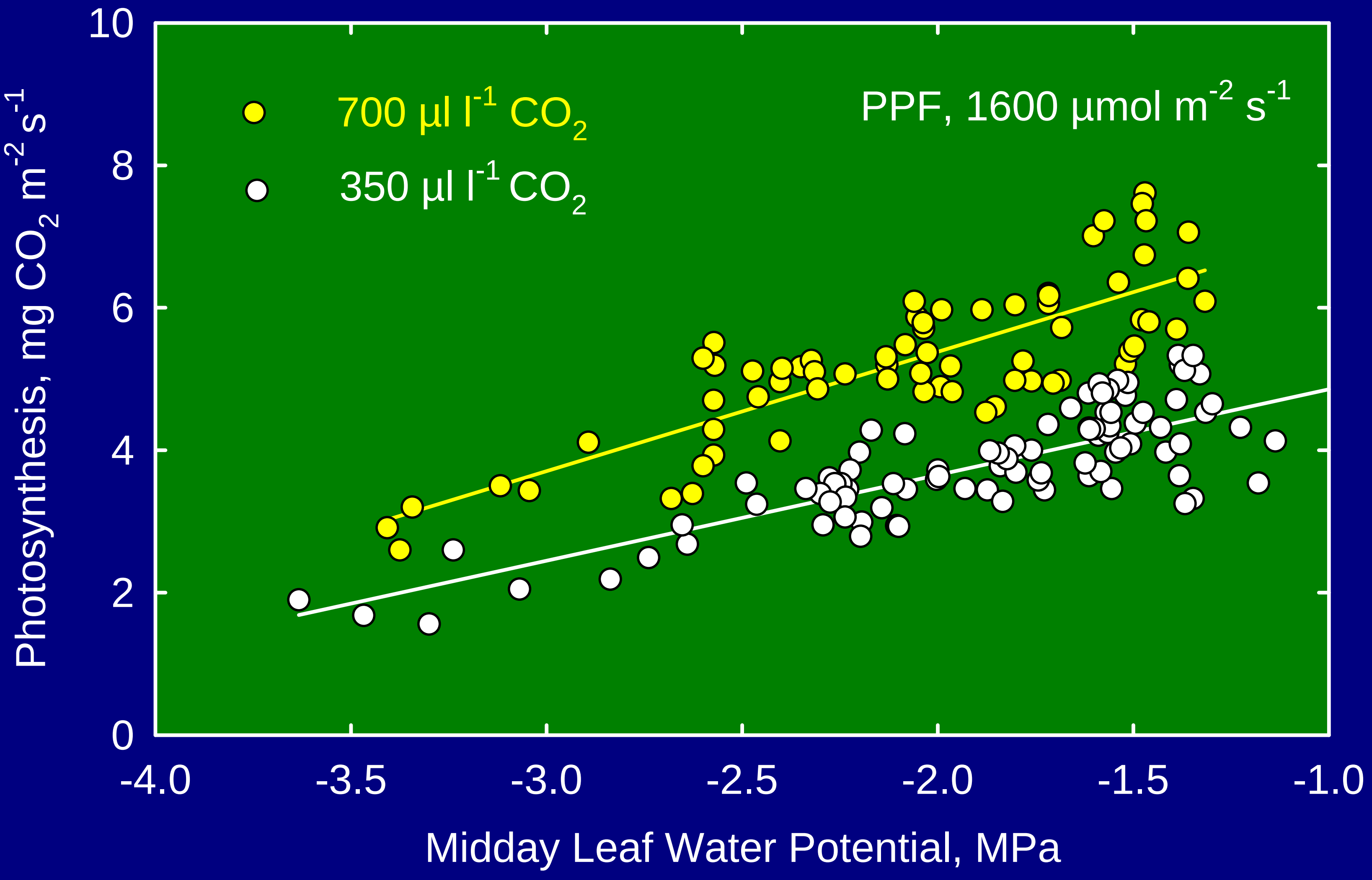
Photosynthesis - Environment

Response to Drought - Light Response Curves



Photosynthesis - Environment

Response to Water Deficits - Photosynthetic Rates



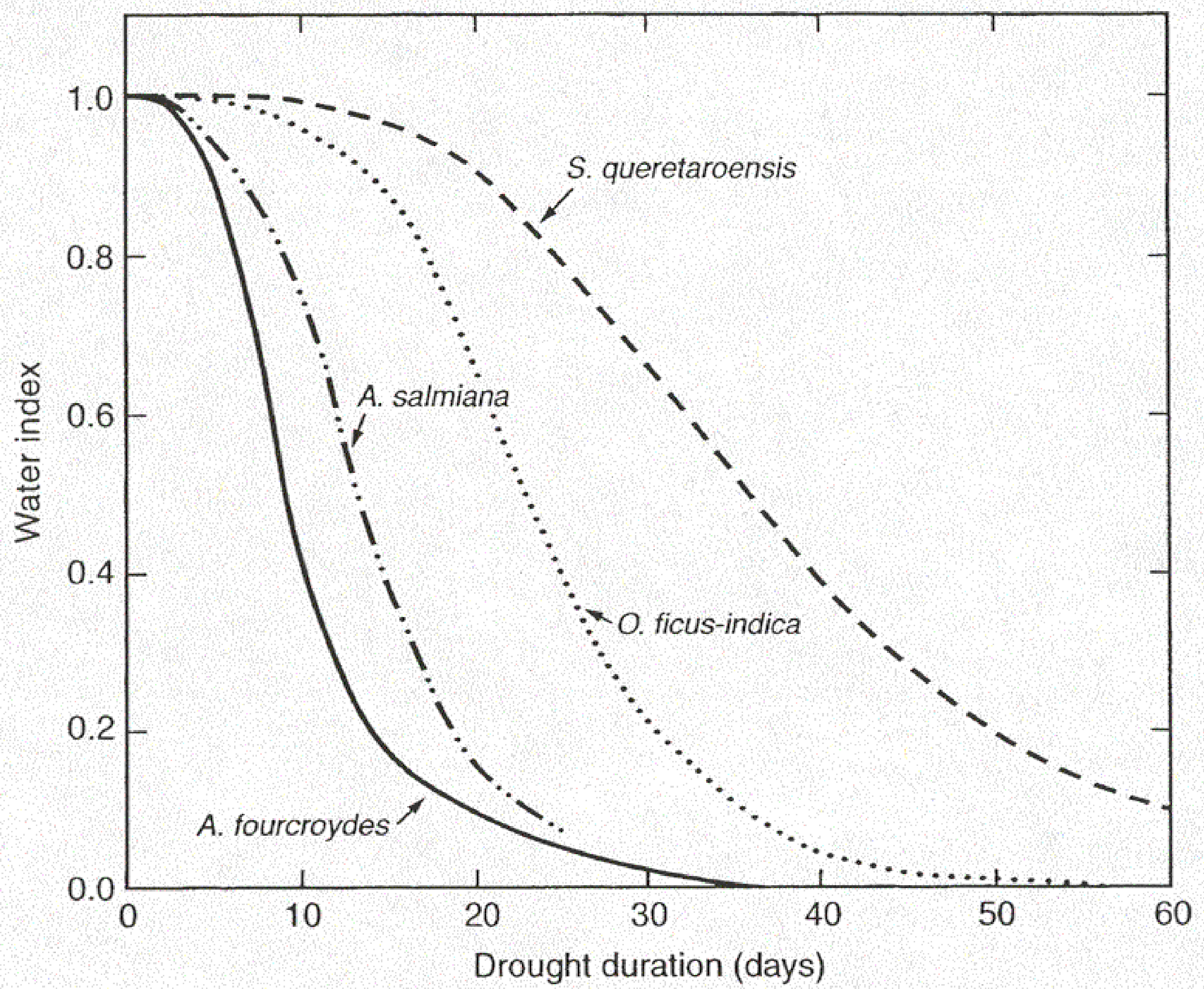
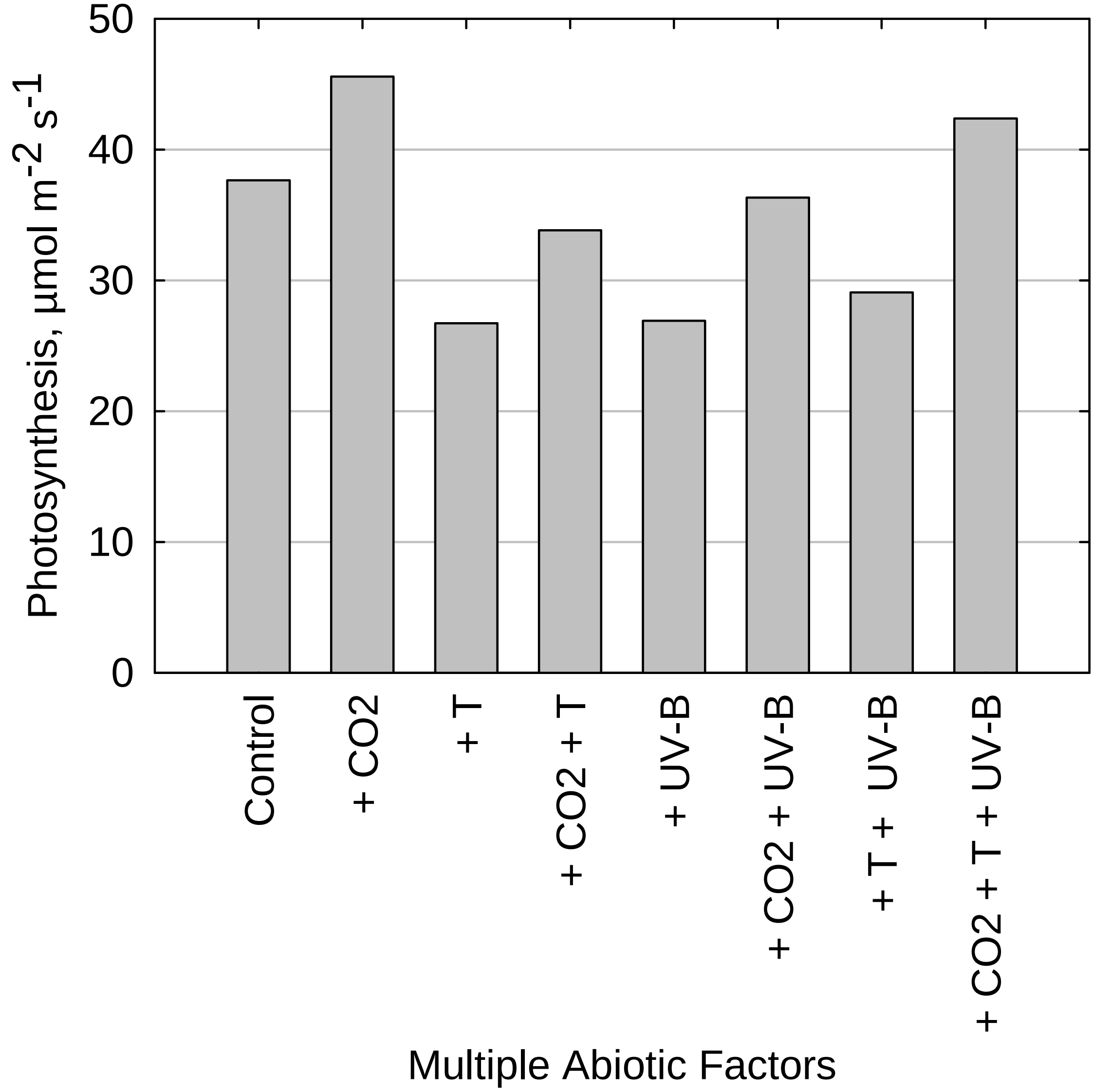


Fig. 14.2. Responses of the water index (see equation 14.1) to drought duration for *Agave fourcroydes, A. salmiana, O. ficus-indica,* and *S. queretaroensis.* Drought refers to the period when the shoot has a lower water potential than the soil just outside the roots in the centre of the root zone. Data for *A. fourcroydes* are from Nobel (1985); for *A. salmiana* from Nobel *et al.* (1996); for *O. ficus-indica* from Nobel and Hartsock (1983, 1984); and for *S. queretaroensis* from Nobel and Pimienta-Barrios (1995) and P.S. Nobel (unpublished observations).

Crop responses to multiple abiotic stresses

Photosynthesis and multiple abiotic stresses



Environmental Productivity Index Concept and Species Variability and Applicability

- ➢ What do we need:
- ✓ We need species-specific potential photosynthesis at maximum solar radiation levels.
- ✓ Then, we need species-specific functional algorithms for various environmental factor effects on photosynthesis (EPI's for various environmental stress factors).
- ✓ Physical inputs such as solar and UV-B radiation, and daily values of light interception (Light interception model), leaf nutrient (N,P, K) status (Models for nutrient uptake and leaf distribution model), leaf water potential as affected by precipitation and irrigation (Model for water uptake and leaf water potential) are also needed.

Environmental Productivity Index Concept and Species Variability and Applicability

- Then, one can apply environmental productivity index concept across species and environments.
- EPI also allows one to interpret and to understand stresses in the field situations.
- If we know the factor that is limiting most at any point of time during the growing season, then we can make appropriate management decisions to correct that limitation.