Environmental Factors
Solar Radiation

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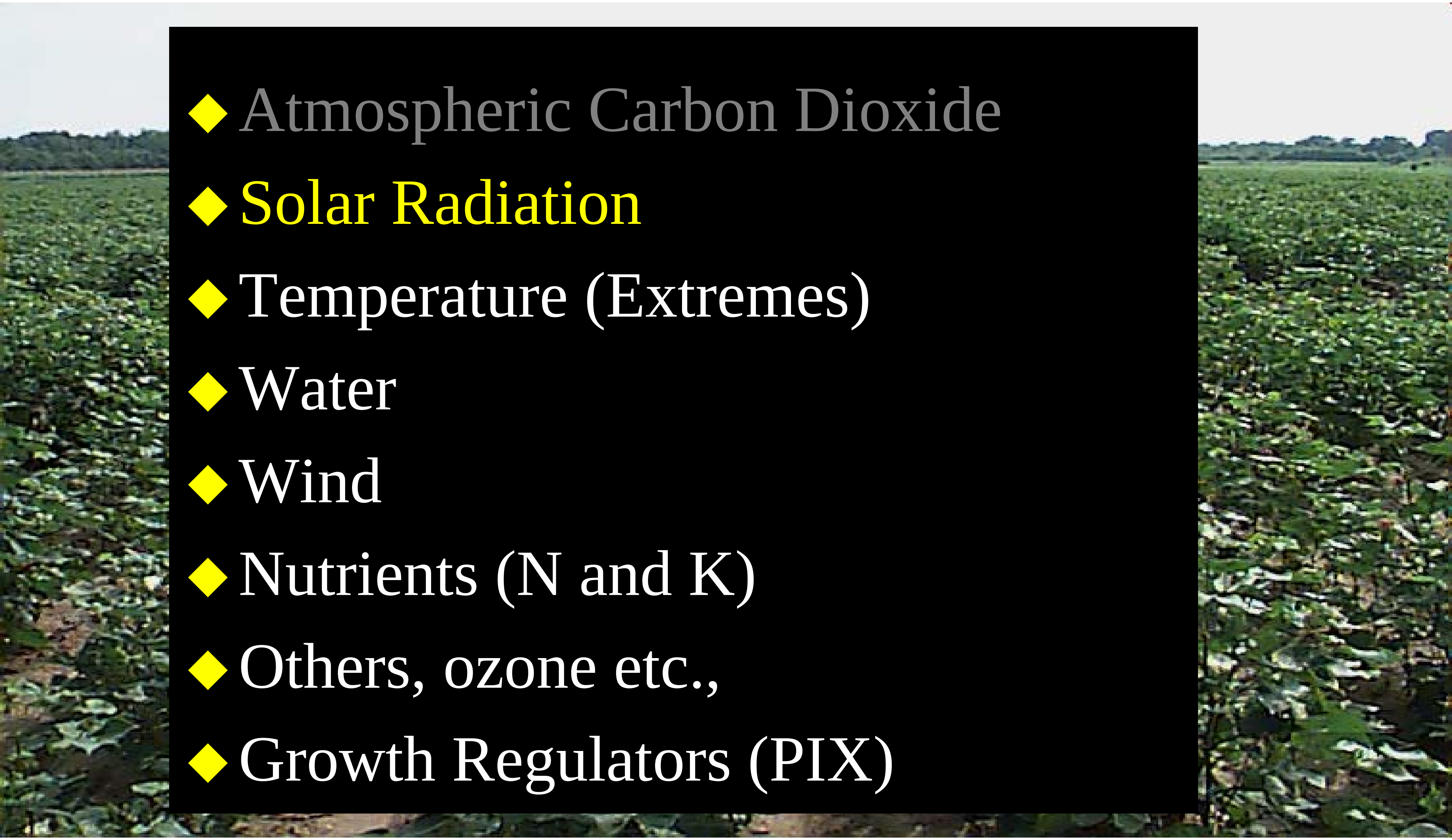
Environmental and Cultural Factors Limiting Potential Yields



- Atmospheric Carbon Dioxide
- Solar Radiation
- Temperature (Extremes)
- Water
- Wind
- Nutrients (N and K)
- Others, ozone etc.,
- Growth Regulators (PIX)

Radiation and Plant Growth

Total amount (duration or length), intensity and quality of light will have profound influence on the energy balance and flow of different components of Earth's ecosystems.

Solar Radiation - Objectives

The objectives of this lecture are:

- To learn global, regional and local spatial and temporal/diurnal trends in solar radiation.
- Radiation distribution in different plant canopies.
- The influence of solar radiation on plants and ecosystems in general.
- The relationship between solar radiation and remote sensing.

Solar Radiation

- All life on the earth is maintained by the flow of energy radiated by the Sun and entering the biosphere.
- Plants fix this energy through photosynthesis.
- Radiation is also the primary source for turnover of organic materials, and by regulating the heat and water balance of the earth it provides the energy condition essential for living organisms.
- For plants, radiation is:
  - A source of energy (photoenergetic effect).
  - Stimulus for development (photocybernetic effect).
  - Stress factor (photodestructive effect).

Light and Carbohydrates and Dry Matter Production

- Of the 100% total energy received by the leaf, only 5% is converted into carbohydrates and later for biomass production.
- Losses of energy by non-absorbed wavelengths: 60%
- Reflection and transmission: 8%
- Heat dissipation: 8%
- Metabolism: 19%

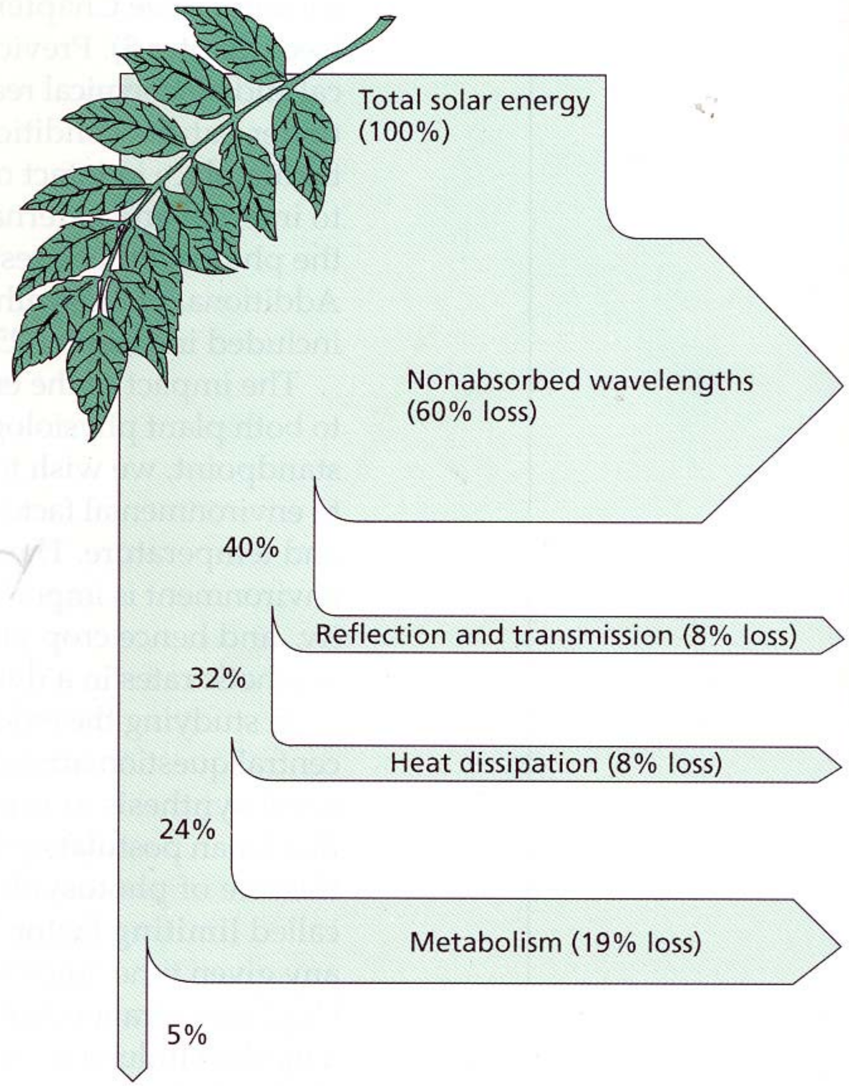


Figure 9.1 Conversion of solar energy into carbohydrates by a leaf. Of the total incident energy, only 5% is converted into carbohydrates.

Radiation and Photosynthesis
Leaf-level

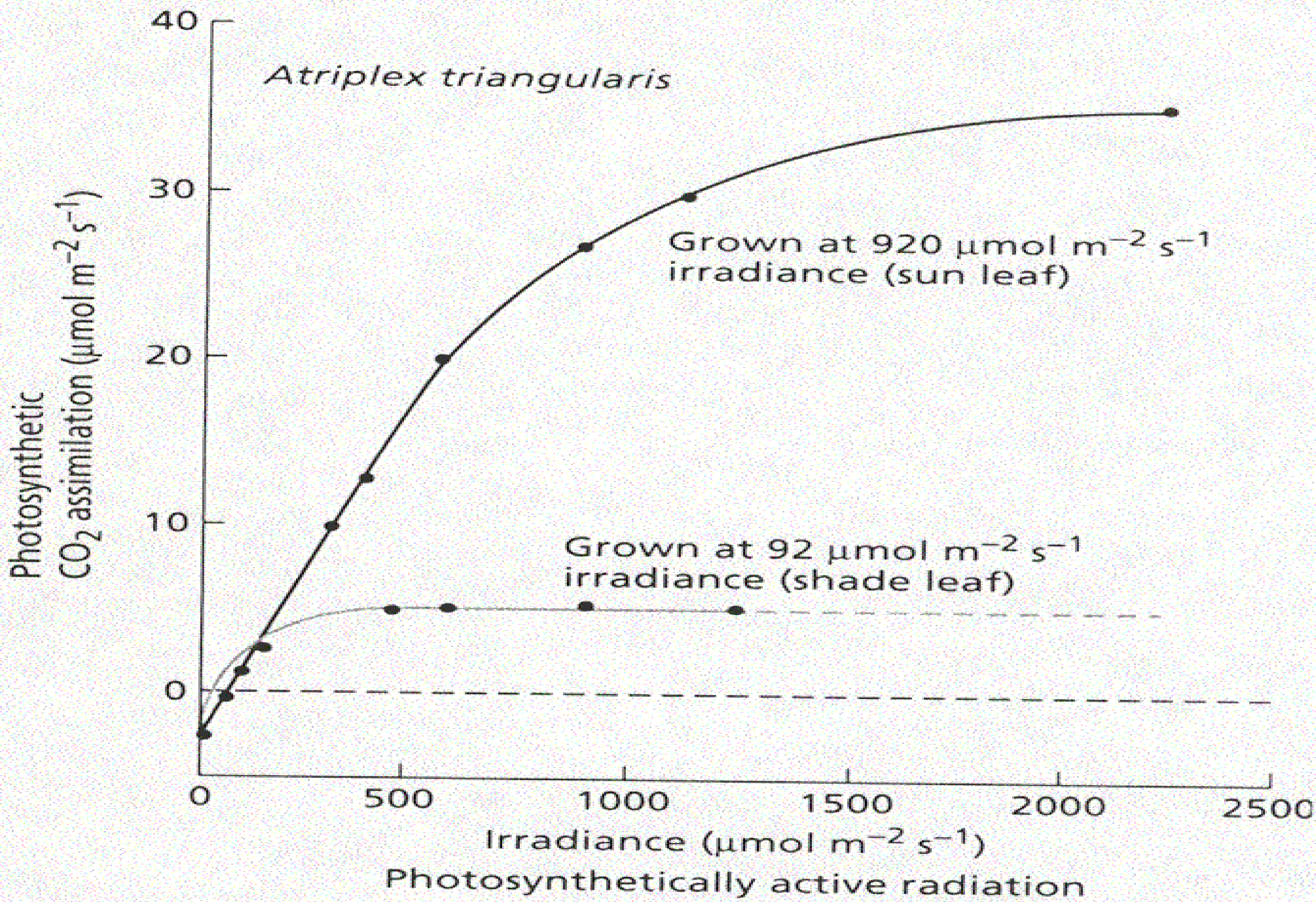
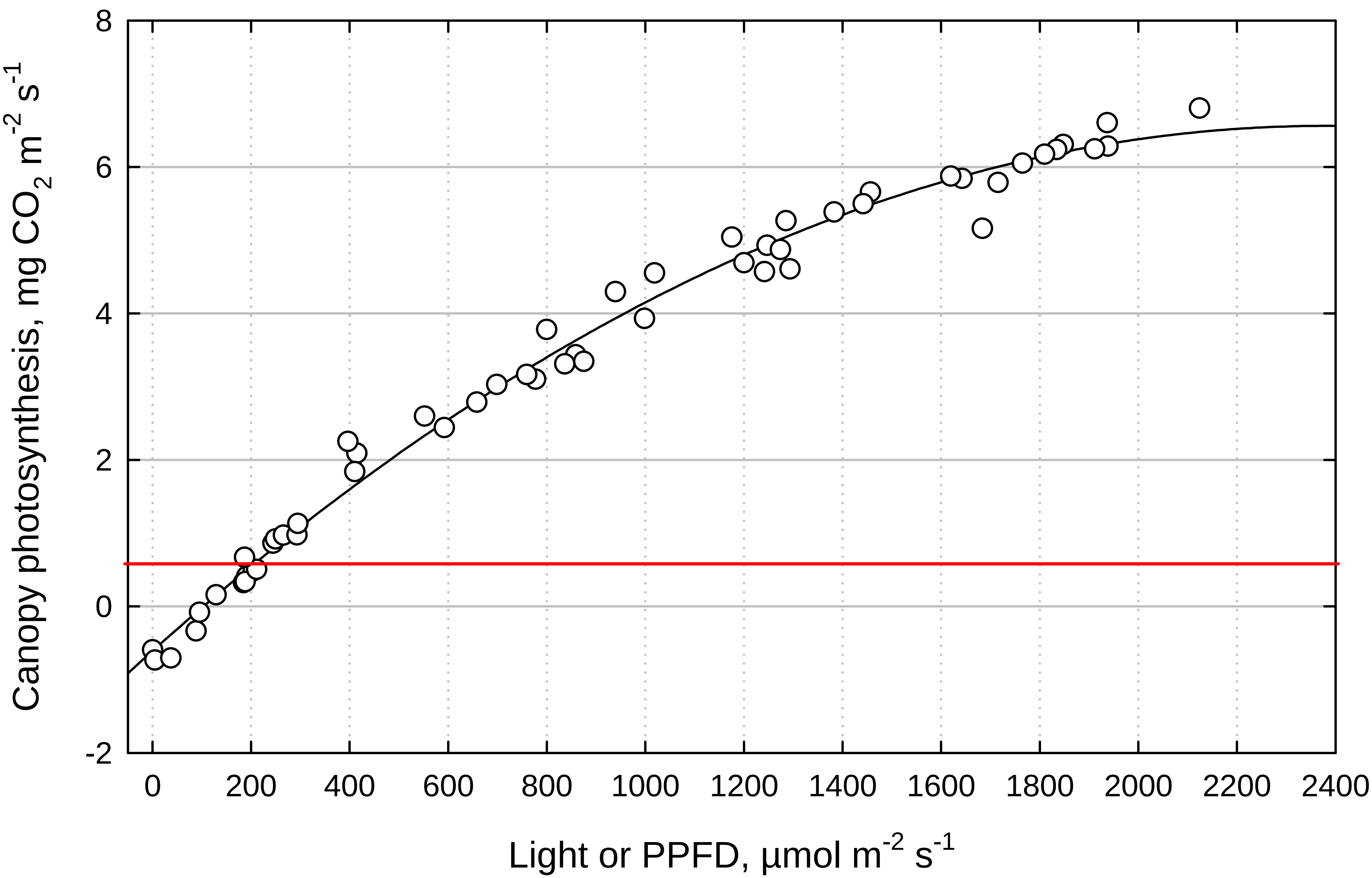


Figure 9.9 Changes in photosynthesis in leaves of *Atriplex triangularis* as a function of irradiance. The upper curve represents a leaf grown at an irradiance ten times higher than that of the lower curve. In the leaf grown at the lower light levels, photosynthesis saturates at a substantially lower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

Radiation and Photosynthesis
Canopy-level



Light and Dry Matter Production

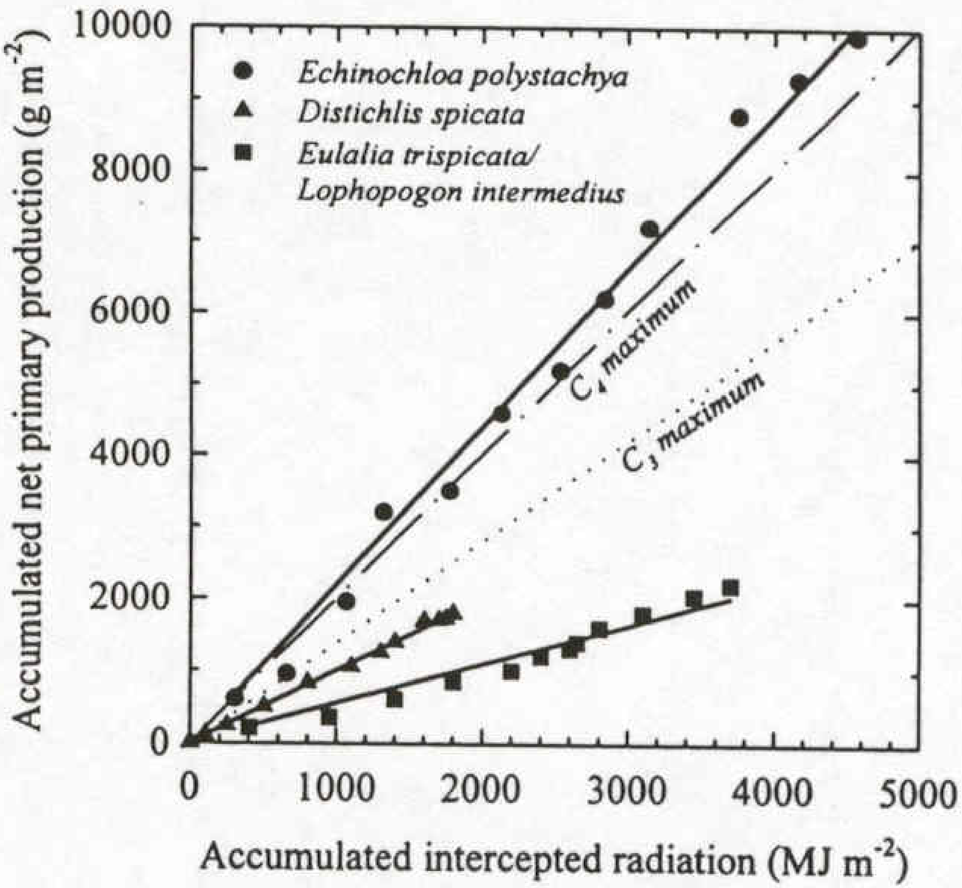
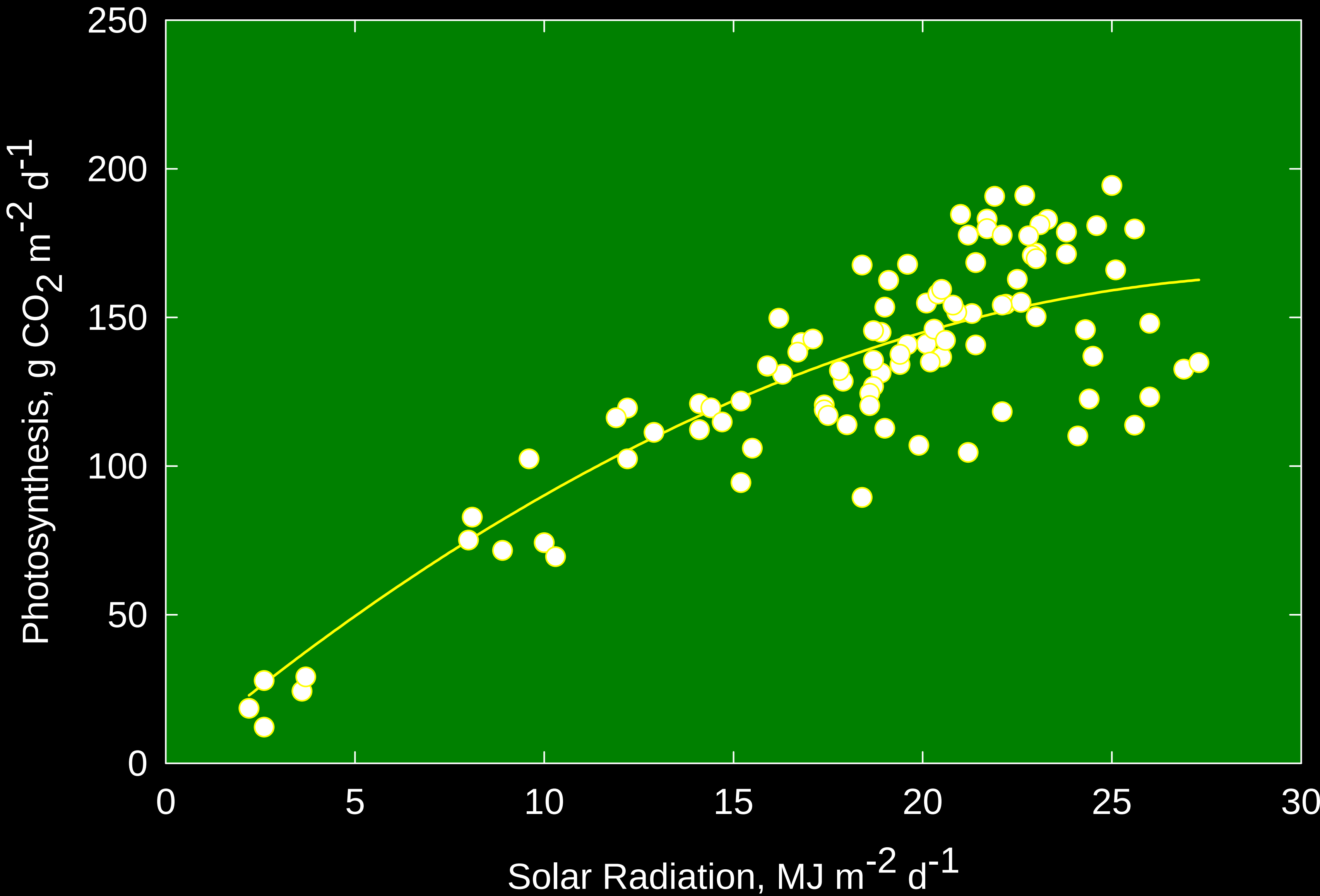


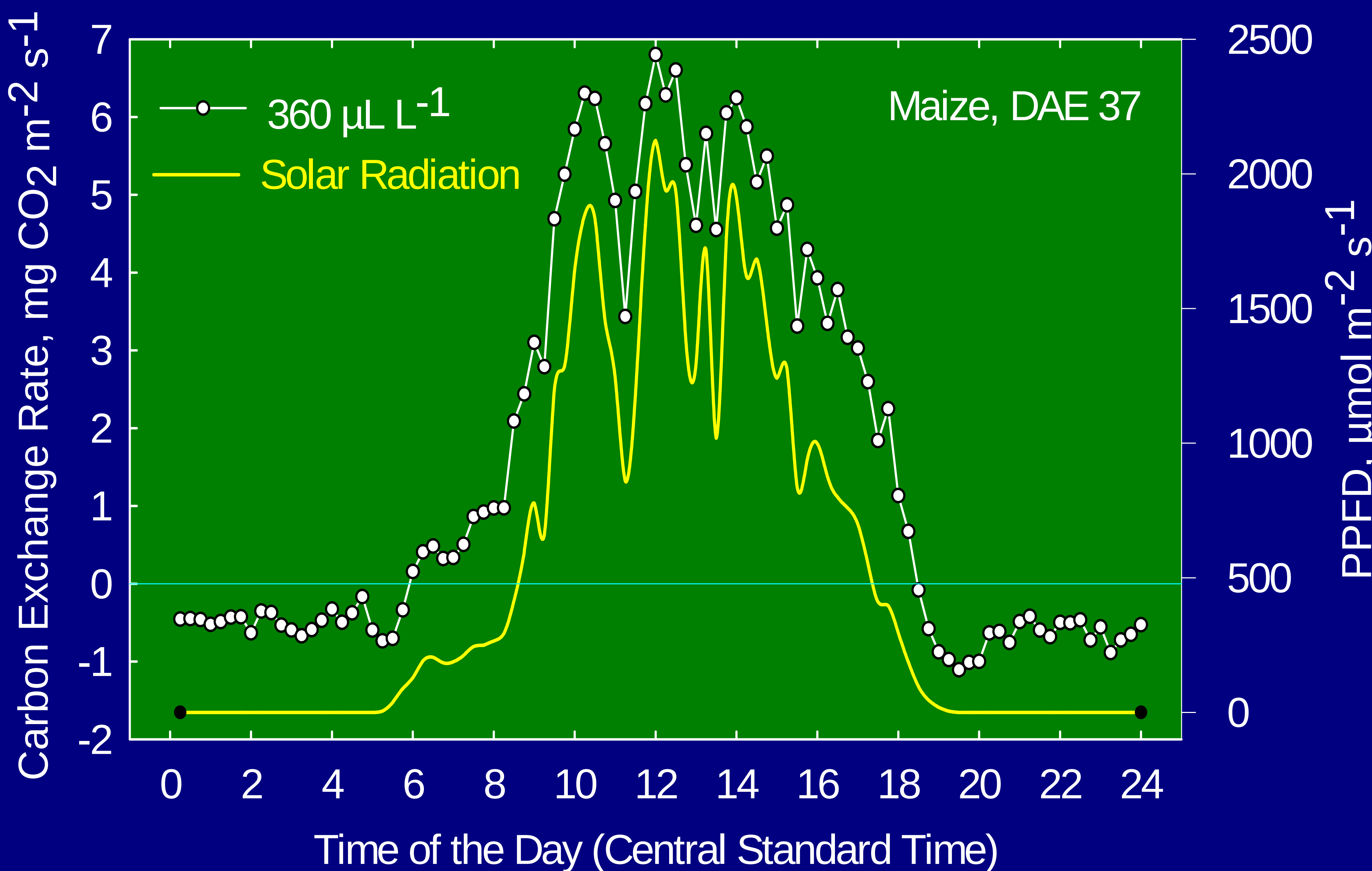
Figure 1 Accumulated monthly mean values of net primary production plotted against the accumulated quantity of total solar radiation (all wavelengths) intercepted by the same communities. Solid lines are the best-fitting straight lines to the illustrated data points. Data are for: (●) monotypic stands of *Echinochloa polystachya* on the Amazon floodplain near Manaus, Brazil (Piedade *et al.*, 1991); (▲) monotypic stands of *Distichlis spicata* on saline grassland close to Mexico City (Jones *et al.*, 1992); and (■) mixed C_4 grass stands codominated by *Eulalia trispicata* and *Lophopogon intermedius* in moist savanna near Hat Yai, Thailand (Kamnalrut and Evenson, 1992). The broken lines indicate the maxima suggested for the two photosynthetic types (after Monteith, 1978). Data redrawn from Piedade *et al.* (1991) and Jones *et al.* (1992).

Solar Radiation - Crop Growth

Cotton Photosynthetic response to solar radiation

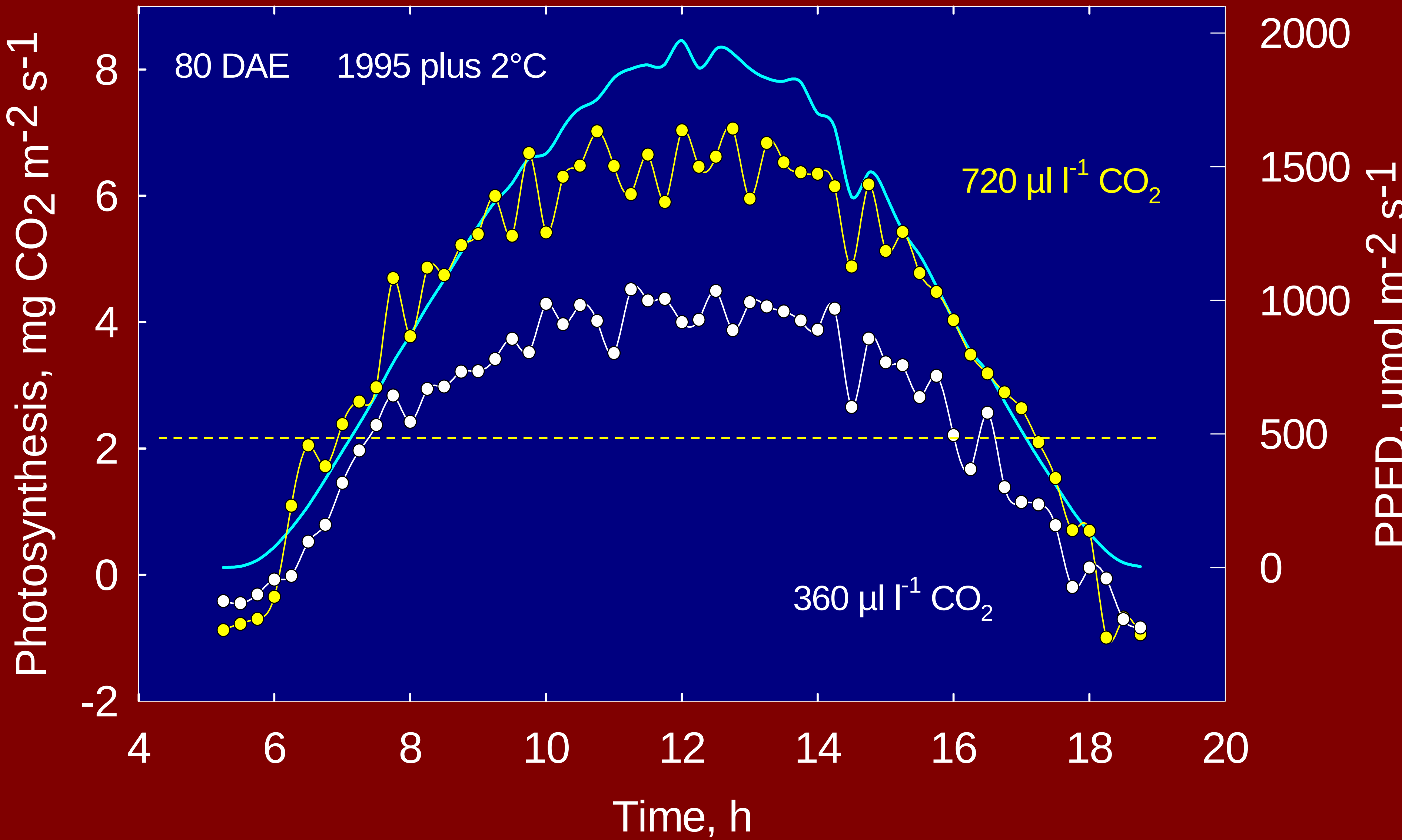


Net Photosynthesis and Available Light Intensity



SPAR - Data Acquisition

Canopy Photosynthesis and Solar Radiation



Radiation – Some Facts

Solar Radiation – Some Facts

- The Sun is the universal source of energy for the earth and the organisms living on it.
- At the outer limits of the Earth's atmosphere, the intensity of the radiation is 1360 W m^{-2} (Solar constant).
- More than half is lost, being cast back into space as a result of refraction and diffraction in the atmosphere, or scattered or absorbed by particles in the air.
- The radiation reaching Earth's surface is called global radiation, and ranges from 290 to 3000 nm.
- On average, 45% of the incoming solar radiation falls within the range of 389 to 710 nm, which is the range utilized by photosynthesis by plants. This range is often defined as photosynthetically active radiation, PAR, and is often denoted by the range between 400 to 700 nm.

Solar Radiation – Some Facts

- Radiation at shorter wavelengths (UV-A 315 to 380 nm and UV-B 280 to 315 nm) is known as ultraviolet radiation, and is absorbed in the upper atmosphere by ozone and oxygen.

- If we do not have the absorption of the ultraviolet radiation by ozone and oxygen, life on this planet as we know it could not survive because of the excessive levels of UV.

- UV radiation (<300 nm) are absorbed by nucleic acids and proteins.

- These high-energy wavelengths cause degradation of these molecules.

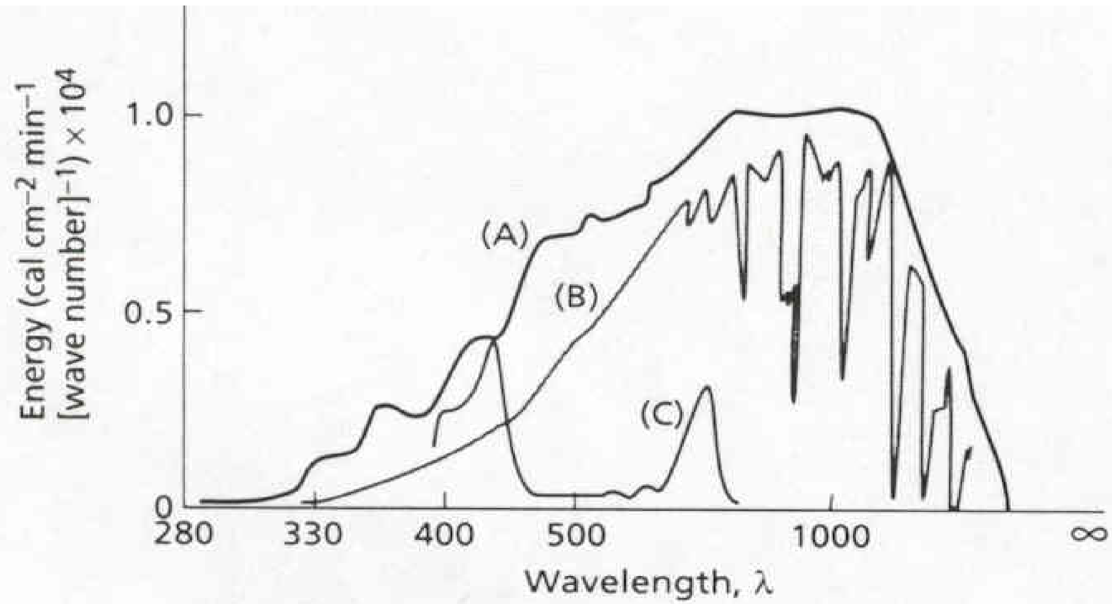
Solar Radiation – Some Facts

- The upper end of the spectrum is known as infrared radiation (IR 750 to 4000 nm).
- Plants do receive long wave radiation known as thermoradiation (IR 4000 to 10^5 nm) and themselves emit this type of radiation.
- Our eyes, for example, are sensitive to only a small range of frequencies – visible light region of the electromagnetic spectrum.

Solar Radiation – Some Facts

- Light is also a particle, which we call a photon. Each photon contains an amount of energy that is called quantum (plural quanta).

- The energy content of the light is not continuous but rather is delivered in these discrete packets, the quanta. Therefore, Sun light is like a rain of photons of different frequencies.



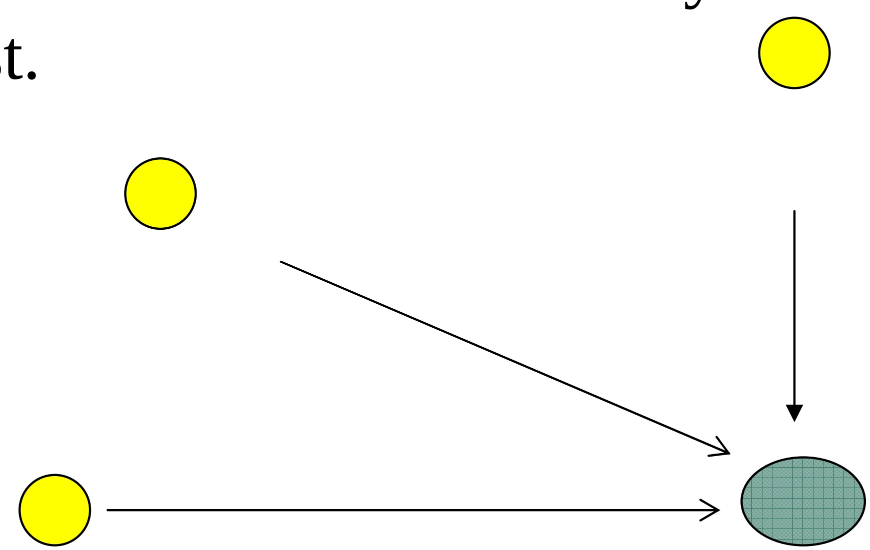
(A) Solar output
(B) Energy at earth's surface
(C) Absorption of chlorophyll *a*

Figure 7.3 The solar spectrum and its relation to the absorption spectrum of chlorophyll. Curve A is the energy output of the sun as a function of wavelength. Curve B is the energy that strikes the surface of Earth. The sharp valleys in the infrared region beyond 700 nm represent the absorption of solar energy by molecules in the atmosphere, chiefly water vapor. Curve C is the absorption spectrum of chlorophyll *a*, which absorbs strongly in the blue (about 430 nm) and the red (about 660 nm) portions of the spectrum. Since the green light in the middle of the visible region is absorbed only weakly, much of it is therefore reflected into our eyes and gives plants their characteristic green color. Note that curve C has absorbance rather than energy units. (Solar spectra from Calvin 1976.)

Solar Radiation – Some Facts

- As the Sun transverses the sky from 0 to 180°, the radiant energy passes through various densities of atmosphere which alters by absorption and scattering the spectral radiation received on the earth.

- This atmospheric absorption and scattering cause the solar irradiance reaching the earth to change; i.e., when the Sun is near the horizon, the light must pass through the longest air path compared to when the Sun is directly overhead when the air mass is least.



Radiation and Plant Life

Table 1.6. Effect of radiation on plant life. (Ross 1981)

Spectral region	Wavelength (nm)	Percent of solar radiant energy	Photo-synthetic	Effects of radiation		
				Photo-morpho-genetic	Photo-destruc-tive	Thermal
Ultraviolet	290 – 380	0 – 4	Insignifi-cant	Slight	Signifi-cant	Insignifi-cant
Photosynthetically active range (PhAR)	380 – 710	21 – 46[a]	Signifi-cant	Signifi-cant	Slight	Significant
Infrared	750 – 4000	50 – 79[a]	Insignifi-cant	Signifi-cant	Insignifi-cant	Significant
Longwave radiation	4000 – 100000		Insignifi-cant	Insignifi-cant	Insignifi-cant	Significant

[a] Depending on position of sun and degree of cloud cover.

Solar Radiation and Day-length

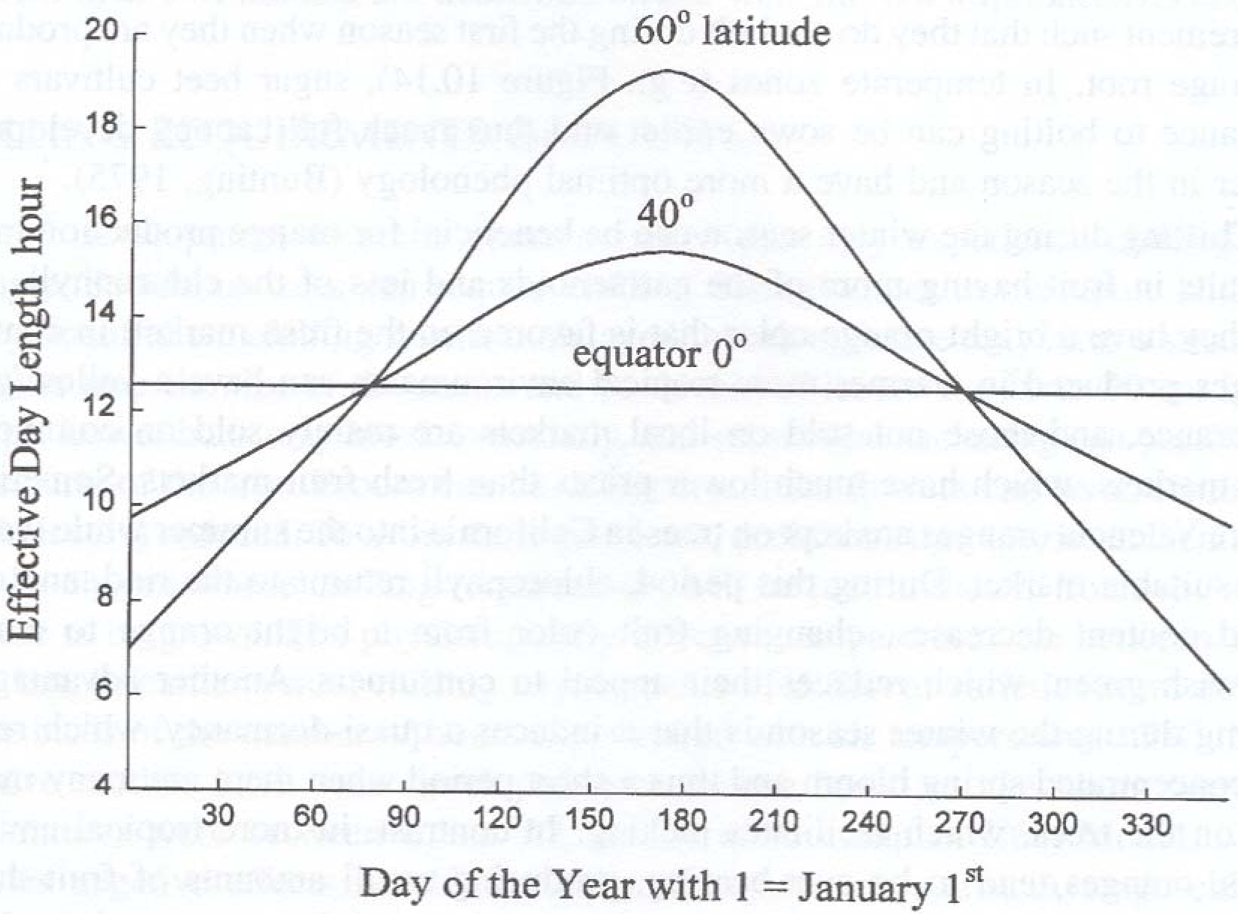


FIGURE 6.2 Day length in hours between sunrise and sunset plus 26 minutes of twilight for the equator and two locations with different latitudes in the northern hemisphere at different days of the year.

Solar Radiation and Day-length

In the northern hemisphere,
Summer solstice: 22 June
Winter solstice: 22 December

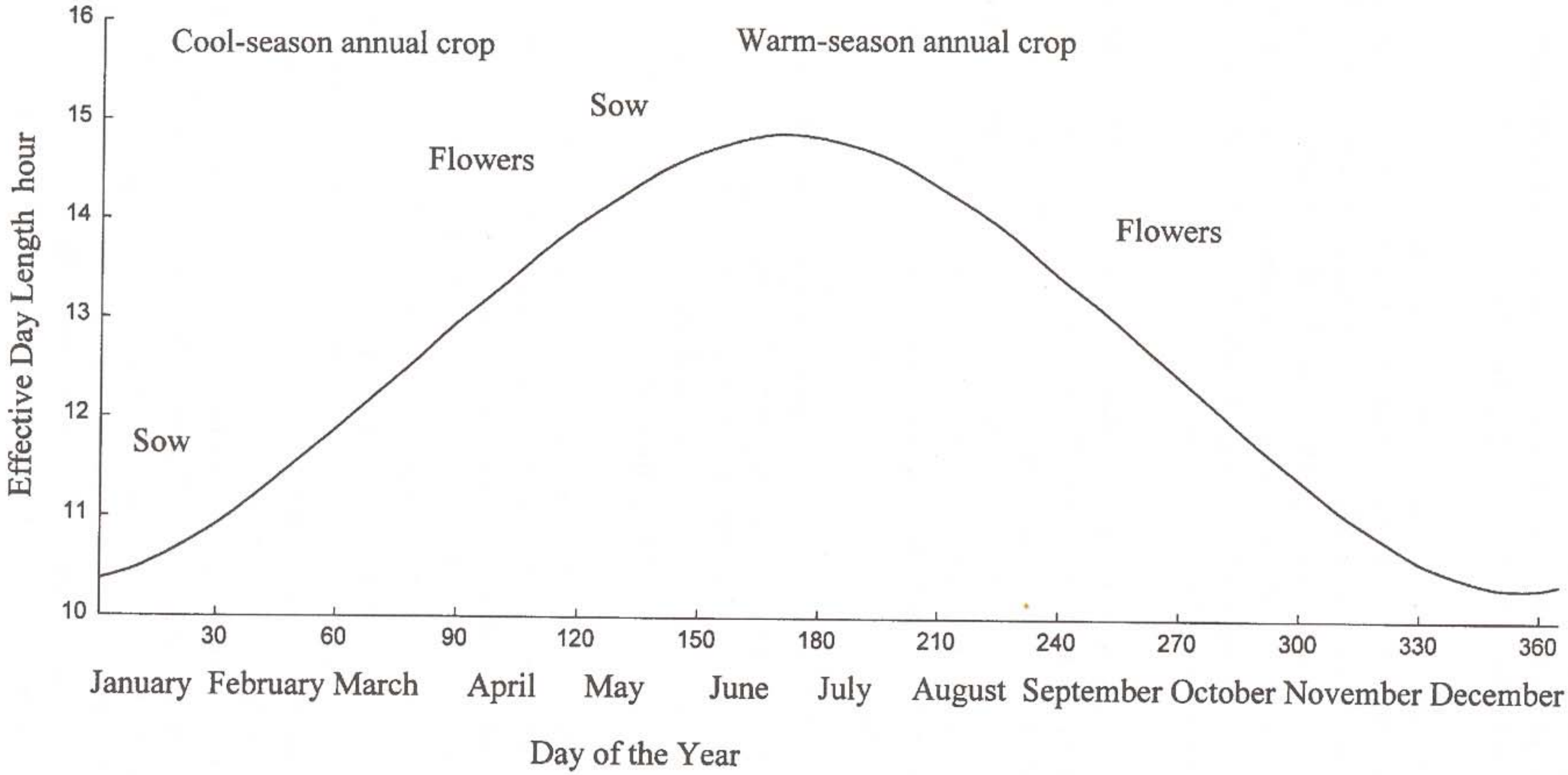
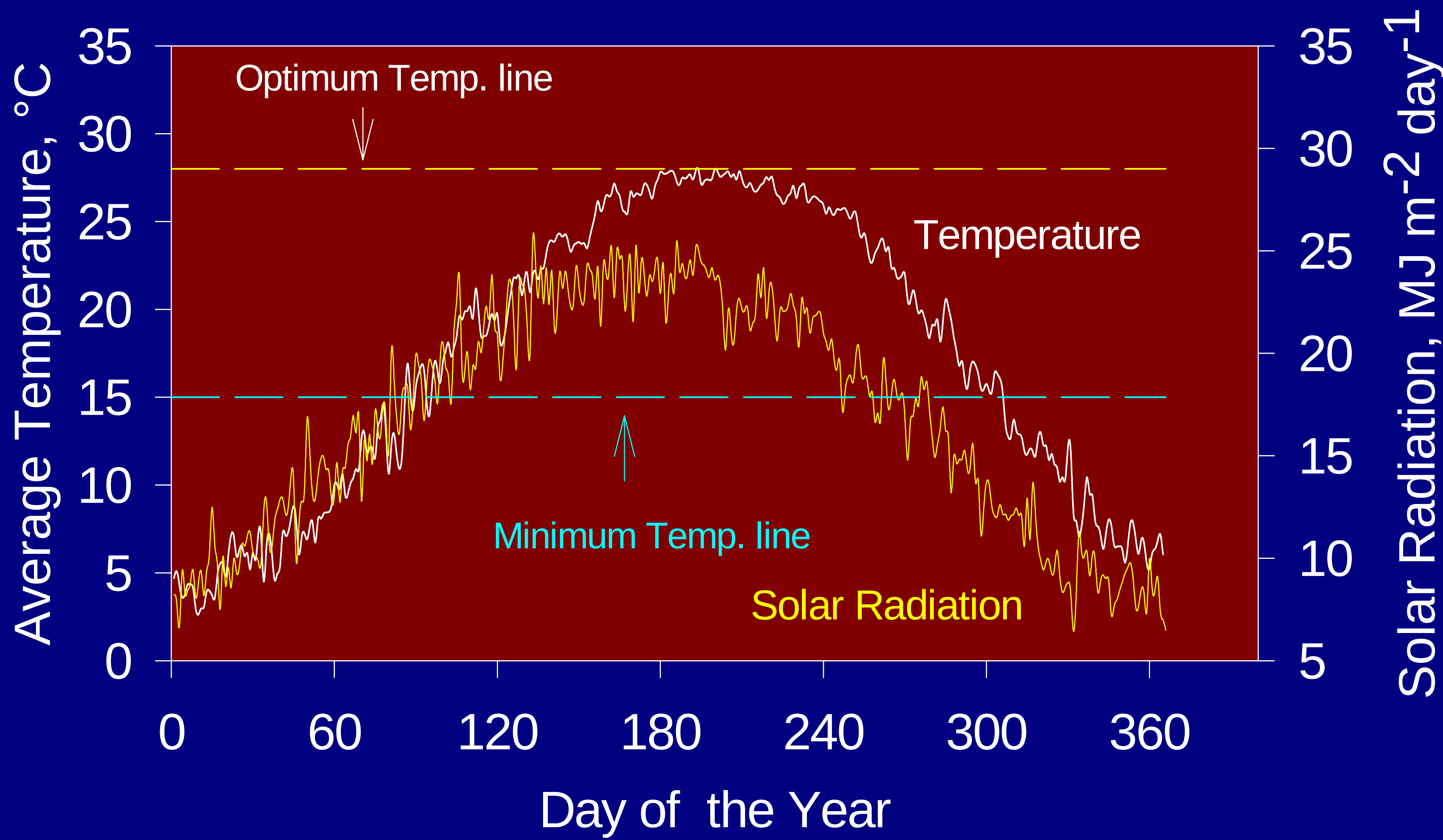


FIGURE 6.3 Effective day length throughout the year at Riverside, California, U.S.A. (location 33°58'N, 117°21'W). Dates of sowing and first flowering are indicated for a cool-season annual crop and a warm-season annual crop.

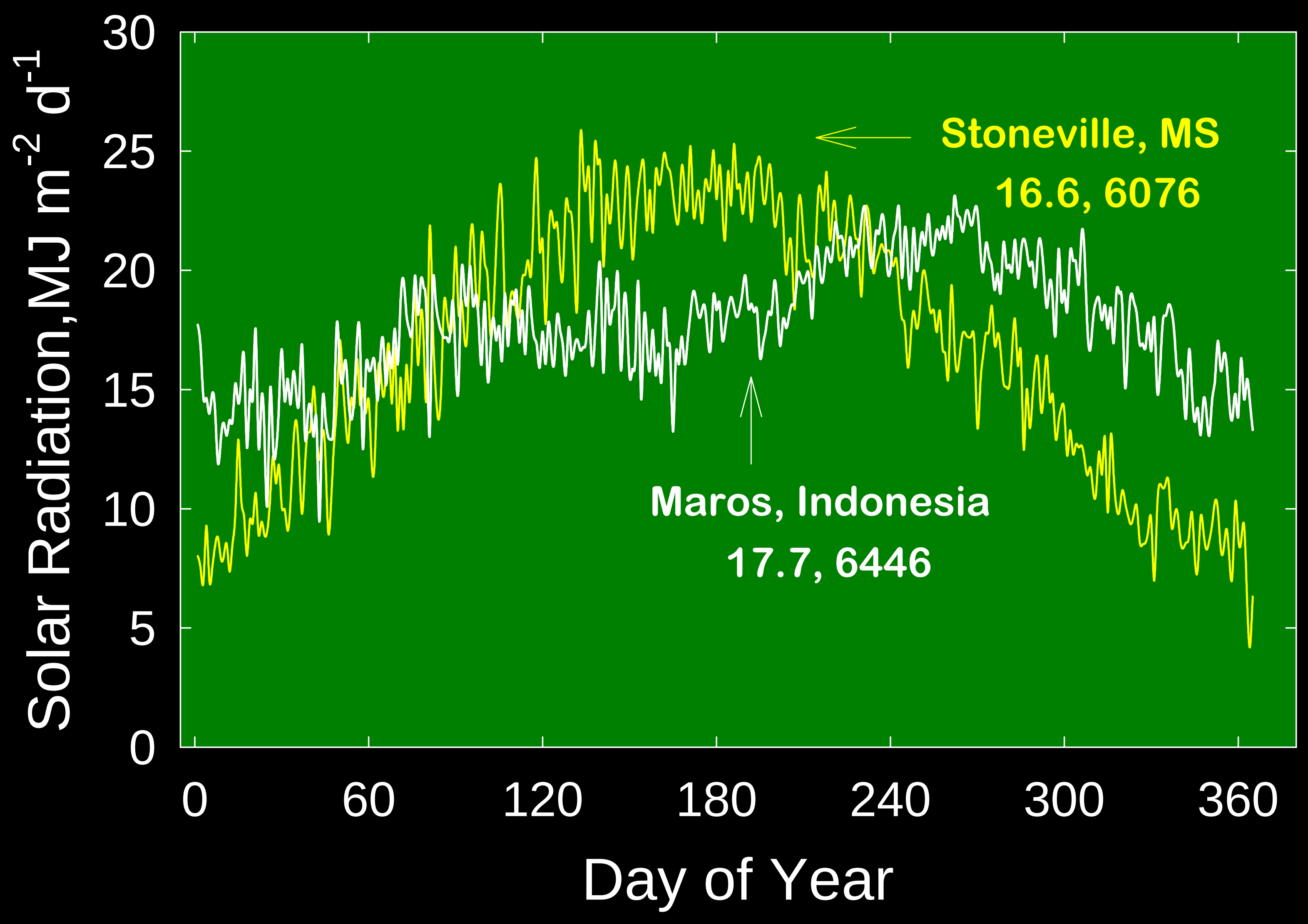
Radiation Trends

Mississippi Long-term Climatic Data

Temperature and Solar Radiation

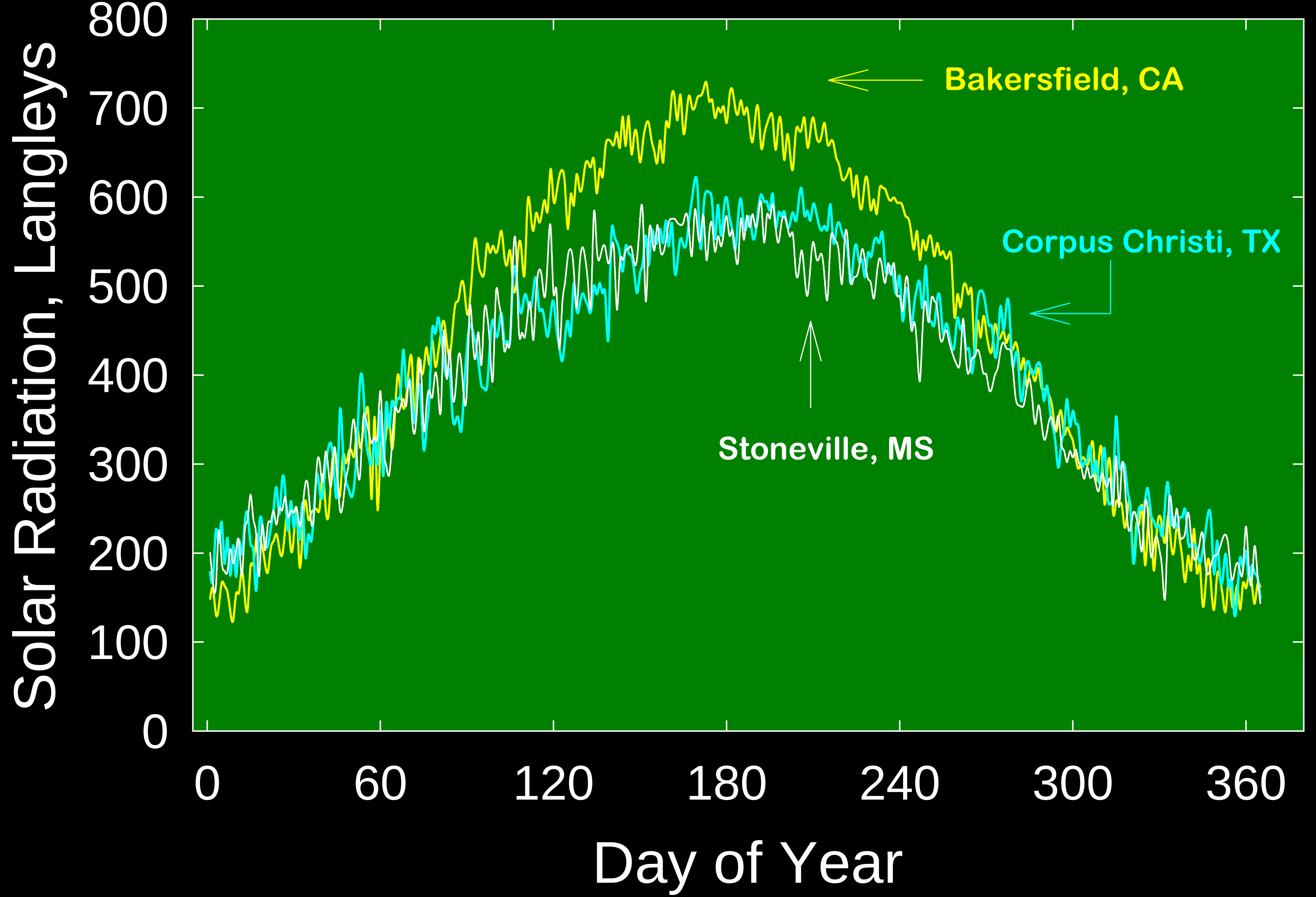


Radiation Conditions - Seasonal Trends
Stoneville, MS and Maros, Indonesia



Radiation Conditions - Seasonal Trends

Bakersfield, CA, Corpus Christi, TX and Stoneville, MS

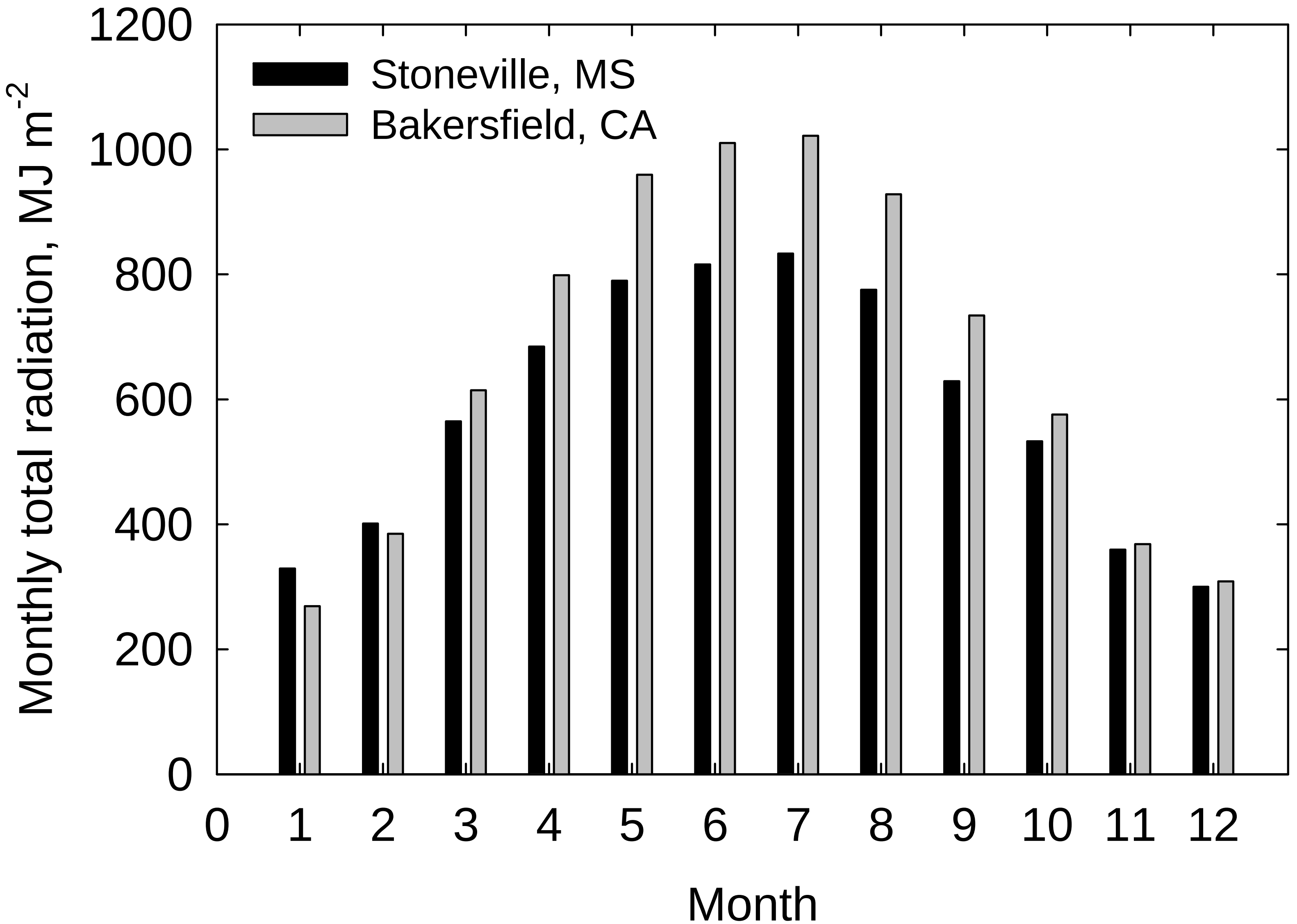


1 langley = 0.04186 MJ m^{-2} d^{-1}

Radiation – Long-term Typical Values
Several places across the US

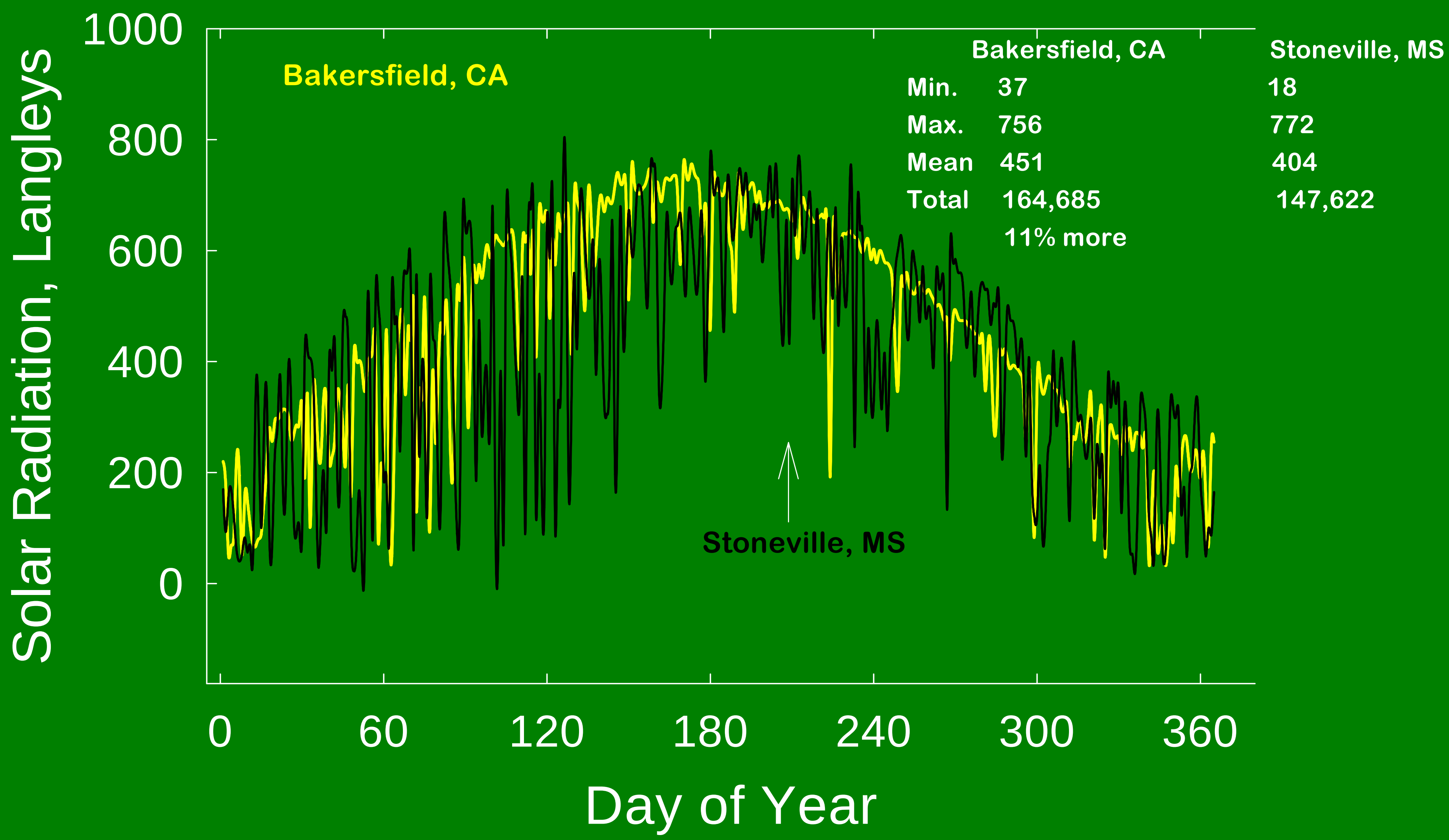
Location	MJ m^{-2} $year^{-1}$	
Bakersfield, CA	7923	100%
Stoneville, MS	7378	-7%
Corpus Christi, TX	7146	-10%
Florence, SC	6817	-14%
Huntsville, AL	6718	-15%

Radiation – Long-term Typical Values
Stoneville, MS and Bakersfield, CA



Radiation Conditions - Seasonal Trends

Bakersfield, CA and Stoneville, MS - 1991



Radiation Distribution in the Plant Cover

Radiation and Canopy Interception

The incident light at the top of the canopy is absorbed by successive layers of leaves in the canopy. This light enters the bottom of the canopy by:

1. Direct radiation as sun fluxes through the gaps in the canopy
2. Scattered light from the leaves and soil.
3. Transmittance through the leaves.

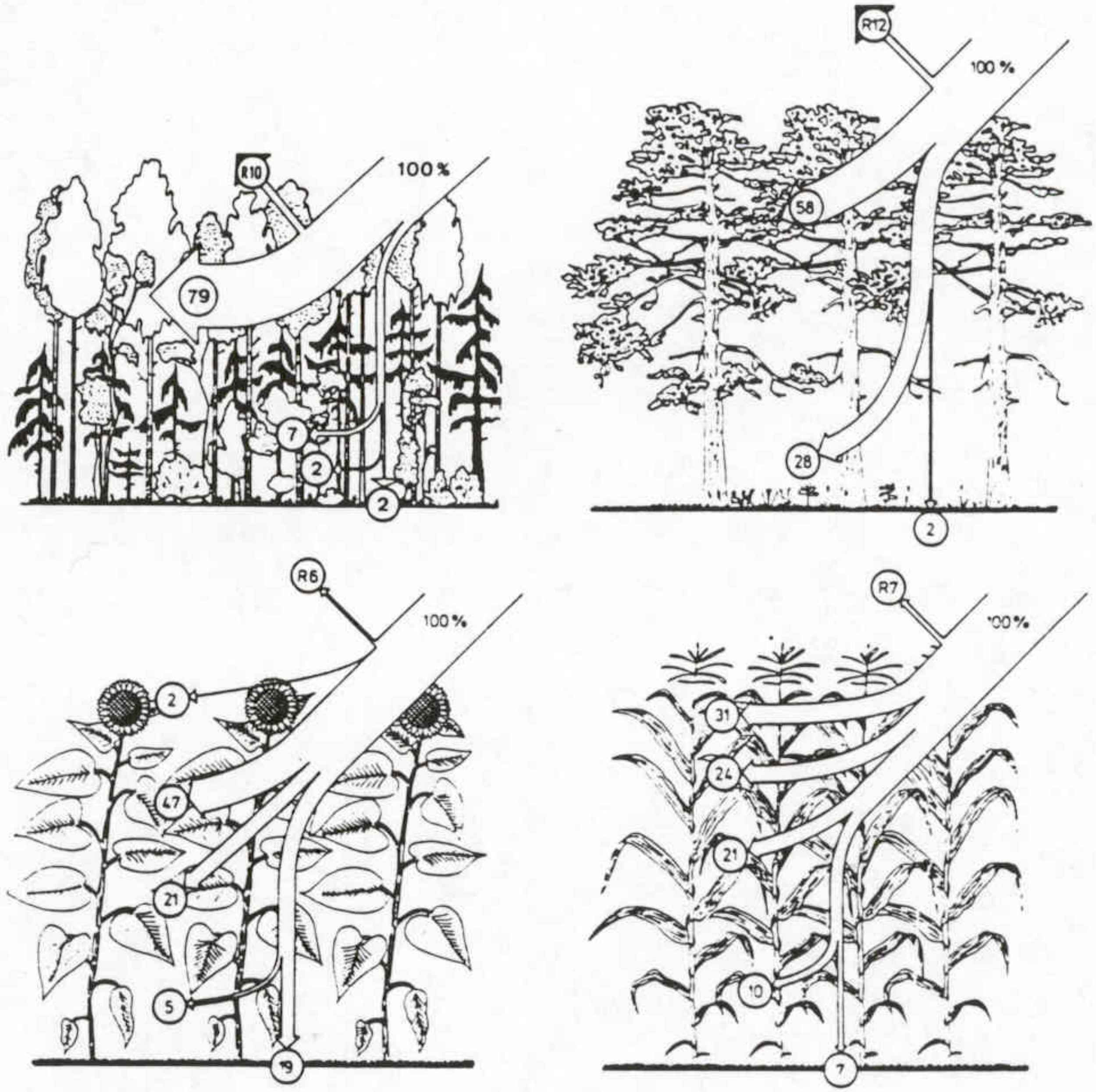


Fig. 1.25. Attenuation of radiation in various stands of plants. *Top left* A boreal birch-spruce mixed forest (Kairiukshtis 1967); *top right* a thin pine forest (Cernusca 1977); *below left* a sunflower field (Hiroi and Monsi 1966); *below right* a maize field (Allen et al. 1964). *R* canopy reflectance. Most of the radiation penetrating dense, flat-leaved stands is absorbed and scattered in the upper third, whereas in stands with narrow, erect leaves the radiation is more evenly distributed

Radiation Interception

The interception of the light by the canopy is expressed by Beer's law as follows:

$$\mathbf{I = I_0\, e^{-kLAI}}$$

Where I is the intensity of the light at the point in the canopy, I_0 = light intensity at the top of the canopy, LAI is the leaf area index above that point and k represents the extinction coefficient determined empirically.

Leaf area index is the most commonly used canopy structure parameter, and is defined as:

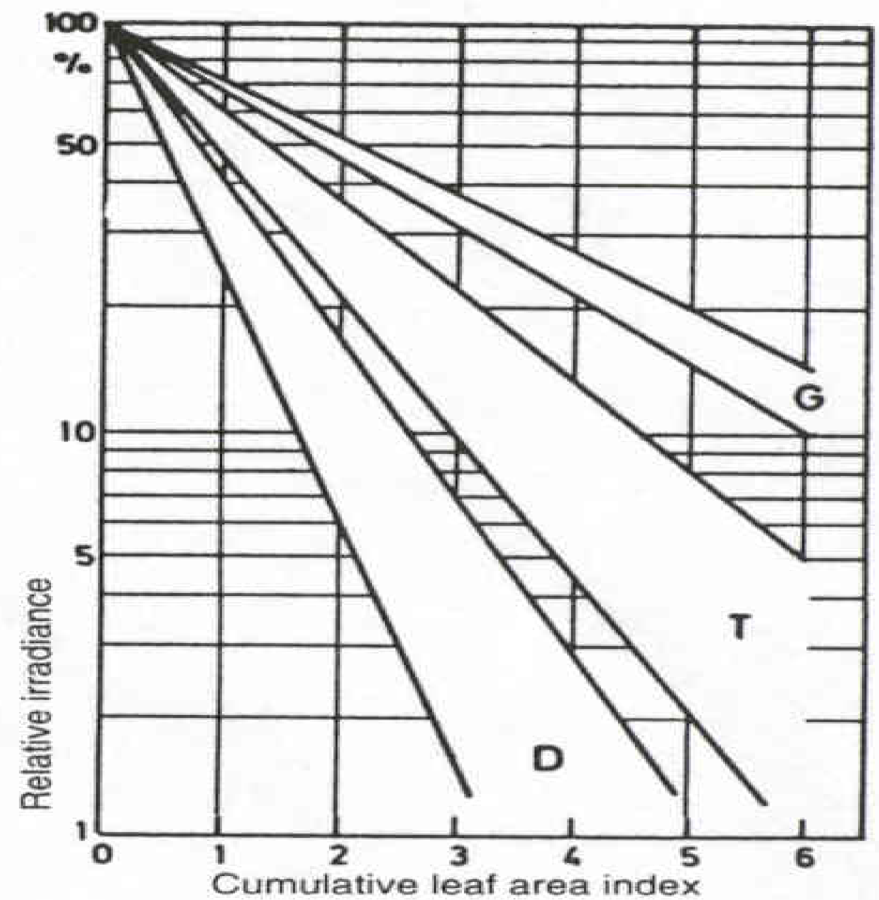
Leaf Area Index (LAI) = Total leaf area / ground area

The decrease in light intensity or the attenuation of radiation (attenuation coefficient) in a stand depends on:

1. Density of the foliage.
2. The arrangement of the leaves within the canopy.
3. The inclination (angle) of the leaves.

Therefore, for grain crops and grasses, the attenuation coefficient is between 0.3 to 0.5, in the dicots, for example, it is about 0.7 and in a dense forest, it is mostly absorbed by the top canopy and very little is pass through the lower layers.

Fig. 1.27. The exponential decrease of light intensity in different stands of plants as a function of leaf area index. The cumulative LAI is derived by summation of the index values for the individual horizontal layers of leaves in the stand. In broadleaved dicotyledonous communities (*D*) the attenuation of light is considerable even with a low LAI, whereas in grass communities (*G*) attenuation occurs more gradually; stands of trees (*T*) represent an intermediate position. (After Monsi and Saeki 1953; Kira et al. 1969). For different aquatic stands see Pokorný and Ondok (1991)



Radiation Interception and Leaf Type

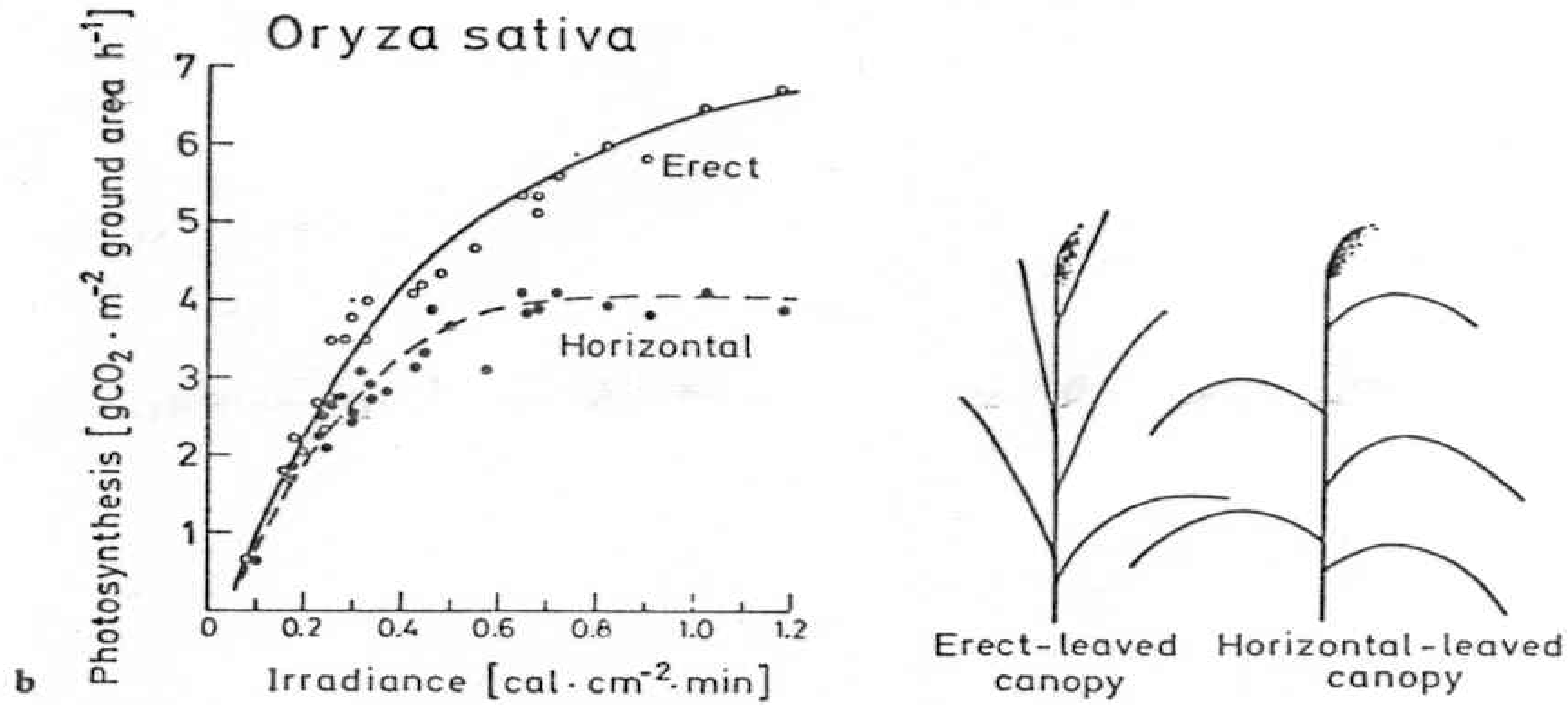


Fig. 3.29a and b. Net photosynthesis of grain plants in a stand. **a** Comparison of the photosynthesis of oat leaves receiving radiation incident perpendicular to the surface with those at the natural angle to the sunlight, under increasing irradiation. Within a stand, because of the angle at which light strikes the leaf surface and because of the shading of the leaves by one another, light-saturation is not reached even under strong irradiation. After Boysen-Jensen (1932). Data on single leaf and canopy photosynthesis in a ryegrass sward are given by Woledge and Leafe (1976). **b** Comparison of the rates of photosynthesis (per m^2 covered by the stand) of rice plants with erect and with horizontal leaves. After Tanaka as cited by Monsi et al. (1973); for photosynthesis of plant stands with different foliage angles see Kuroiwa (1978)

Radiation Distribution in the Soil and Water

- Radiation or light scarcely penetrates soil at all; 1% in sandy and clay soils reaches a depth of 2-5 mm below the soil surface.
- In water, radiation is more strongly attenuated than in the atmosphere.

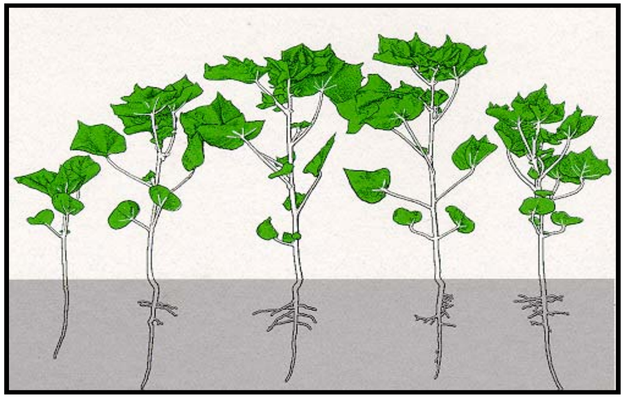
\- Long-wave radiation is absorbed in the upper few mm, infra-red in the upper few cm and UV penetrates up to a 1 m.

- For an example, in open ocean – 1% of the light penetrates down to 150 m and it is about 20 – 50 m near the shorelines.

- In clear lakes, light penetrates in sufficient quantities to support vascular plants up to 5 m.

Radiation, Remote Sensing and Plant Physiology

Remote Sensing and Plant Physiology



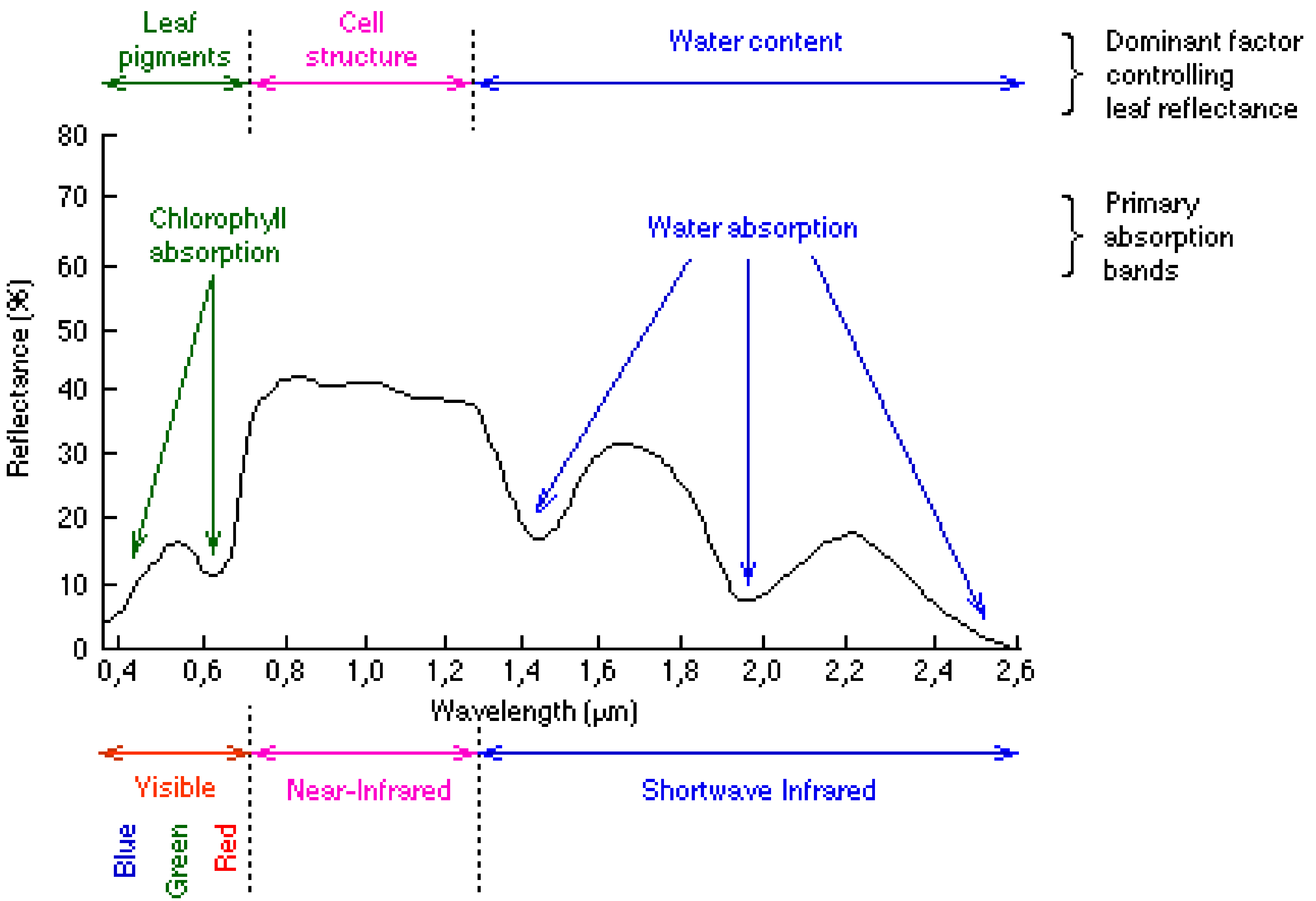
Reflectance - Leaf Level

- Leaf surface properties (wax and cuticle)
- Internal structure (anatomy)
- Biochemistry (concentration and distribution)
- Leaf physiology

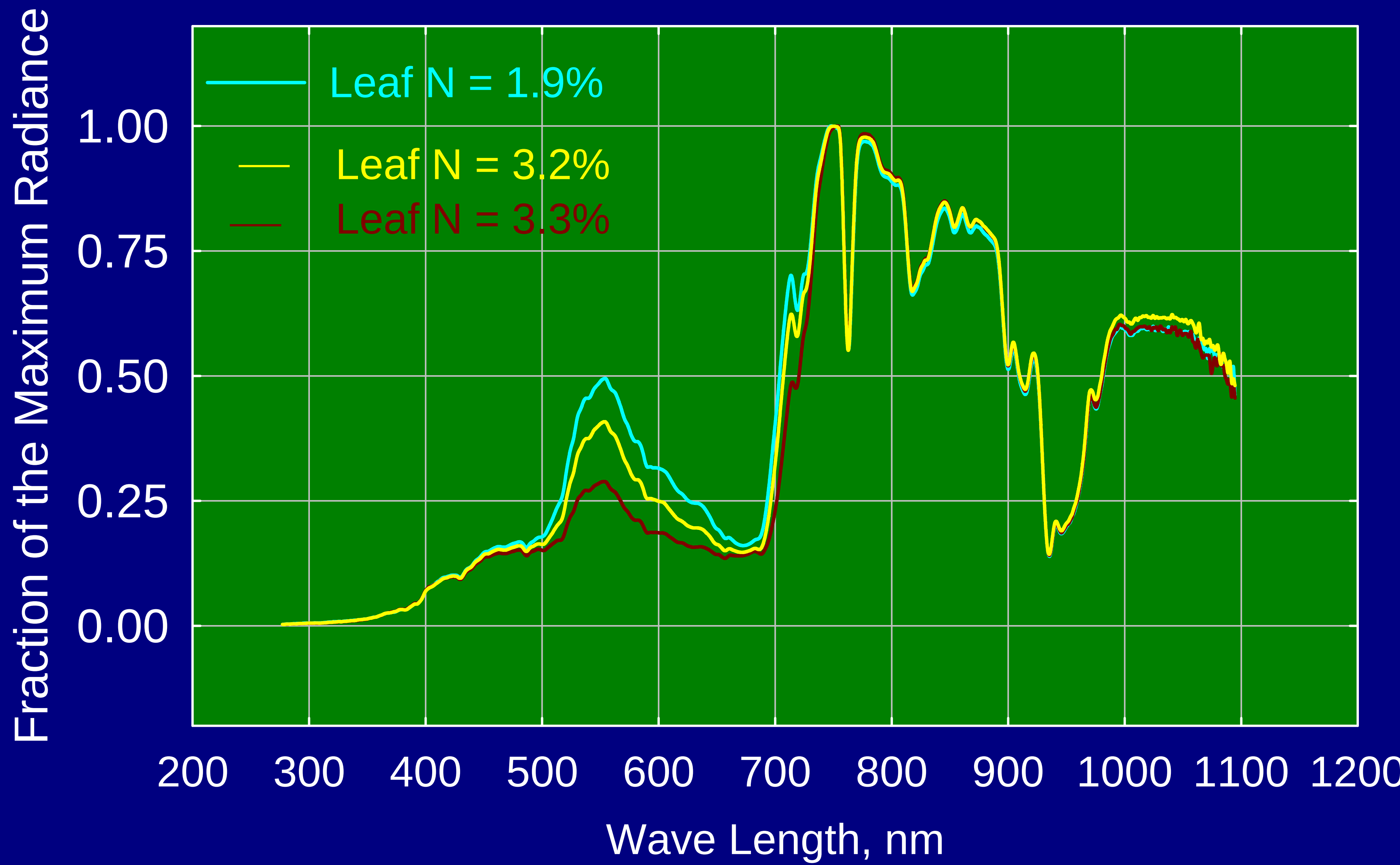
Reflectance - Canopy Level

- Soil characteristics
- Vegetation characteristics

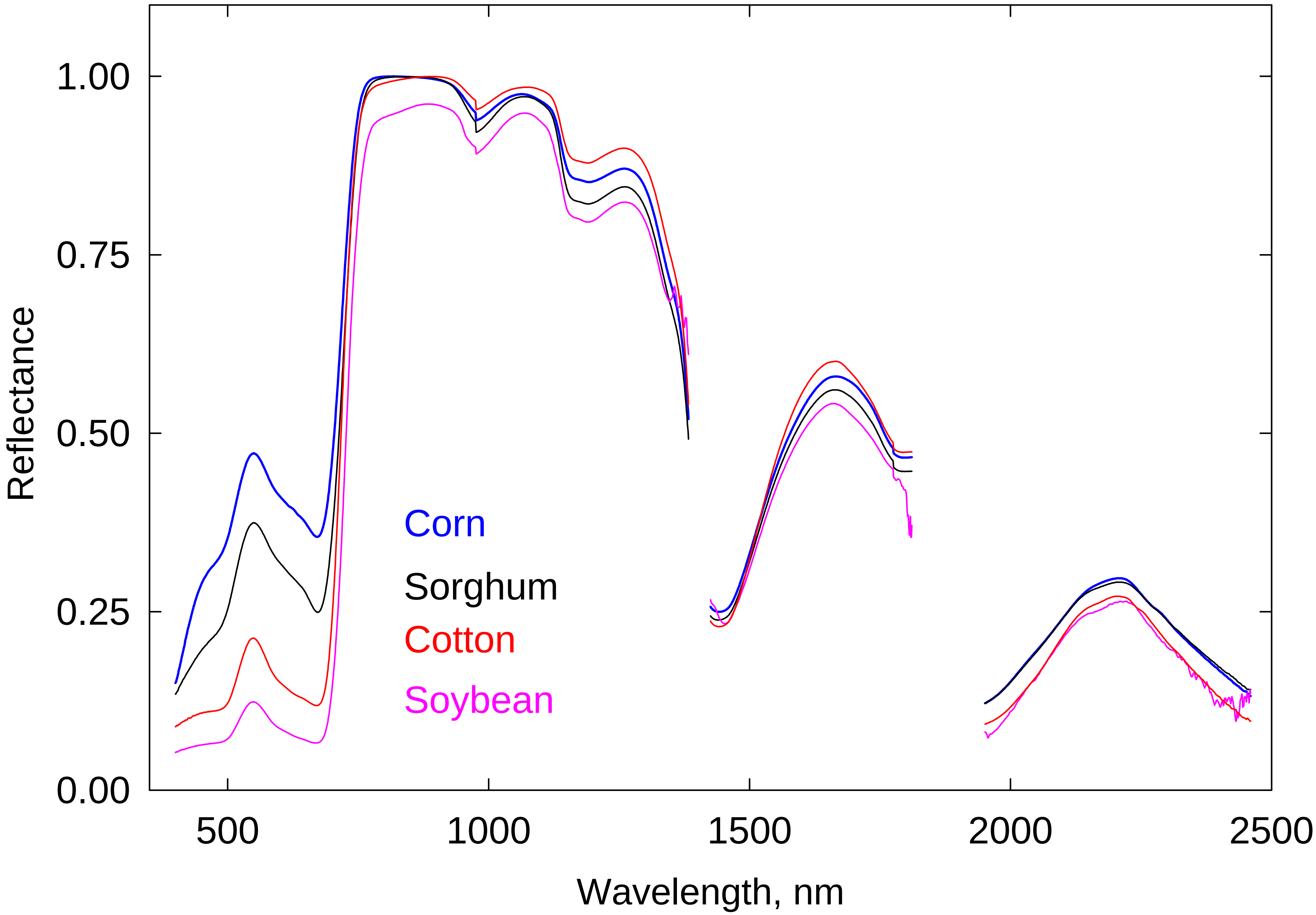
Typical spectral response characteristics of green vegetation (after Hoffer, 1978)



Leaf Nitrogen and Spectra



Typical Spectra - Species Differences
Well-watered and well-fertilized



Environmental Plant Physiology

Reading and Reference Material

1. Larcher, W. 1995. Physiological Plant Ecology. 1.2 Radiation and Climate, pages 31-56 (You have to read).

2. Pressaraki, M. (eds). 1994. Handbook of Plant Physiology, Chapter 11 by Serano, L., J. A. Pardos, F. I. Punalre and F. Domingo. Absorption of radiation, photosynthesis, and biomass production in plants. Pages243-256.

3. Hall, A.E. Chapter 4, pages 33-58, Crop physiological responses to light.

4. ASAE EP344.3 Jan2005. Lighting Systems for Agricultural Facilities (A must read paper if you are working with greenhouses and controlled environments and radiation environments, and also for unit explanations and conversions).