Microclimate

Within each broad climatic zone there are environmental factors that vary that we know place limits on plant performance & growth. Radiation, temperature, humidity, wind, gasses, soil factors, etc. can all impose these limitations; these comprise a plant's microclimate. Ecophysiologists often apply the principle of limiting factors (or, "the law of the minimum") to identify the factor that is in shortest supply or lowest amount and by so doing identify the factor that most limits a plant at a particular site. We measure many of these factors.

I. *Radiation – in general*

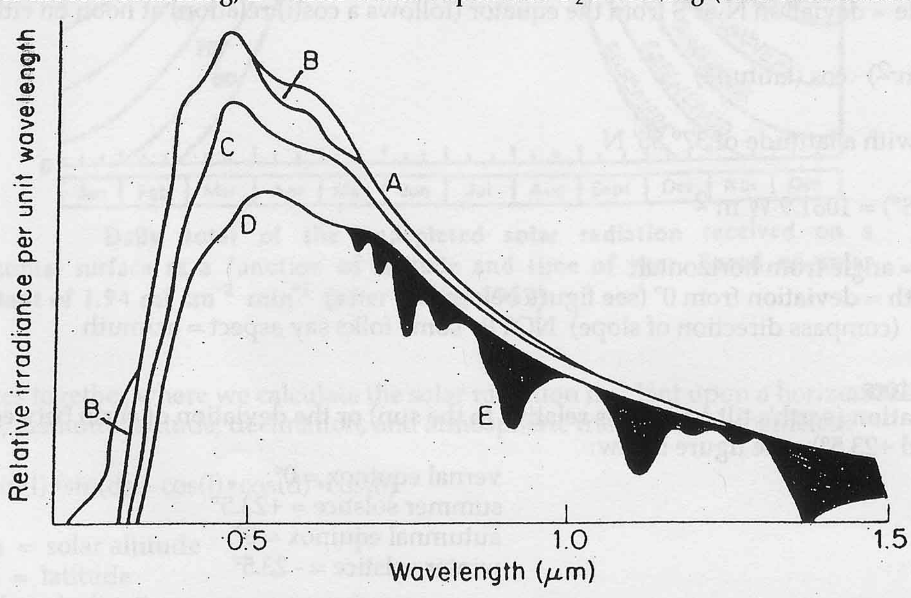
Two bands of electromagnetic radiation are useful in studies of plants and their microenvironments: solar radiation and terrestrial radiation.

Solar Radiation (SR)			Terrestrial Radiation (TR)	
100-400 nm	ultraviolet	germicidal	4,000-10,000 nm	infrared **heat**
400-700 nm	**visible**	photosynthesis		
700-3,000 nm	near infrared	**heat**		

1. Solar radiation **outside Earth's atmosphere** contains energy in wavebands from 100-400 nm. Radiation @ 400-700 nm is used by plants and is referred to as photosynthetic photon flux density (PPFD) or more commonly as photosynthetically active radiation (PAR) and is expressed in units of μmol m^{-2} s^{-1}; at solar noon **inside the atmosphere at sea-level** the Earth "sees" approximately 2000 μmol m^{-2} s^{-1} and at 4000m above sea-level approximately 2800 μmol m^{-2} s^{-1}

2. W m^{-2} is the energy unit useed in heat balance studies; at solar noon **inside the atmosphere** Earth "sees" a maximum of 497 W m^{-2}

3. Solar radiation is depleted while passing through atmosphere by H_2O, CO_2, O_3 and other trace gases (e.g. CH_4, SO_2, SO_4, etc.): **FIGURE:** A = extraterrestrial radiation; B = after ozone absorption; C = after molecular scattering; D = after aerosol scattering; E = after water vapor and O_2 scattering (after Henderson 1977).



4. The extent of the solar radiation attenuation is determined by the length of the atmosphere traversed (= **air mass**) and the clarity of the sky (= **transmission coefficient**) where the **air mass** is defined as the thickness of the atmospheric layer. At noon, the air mass (M) is equal to 1.0; at sunset the air mass is approximately 3.0. The **atmospheric transmission coefficient (G)** is a measure of the amount of solar radiation scattered and reflected by atmospheric particles and gases where,

clear sky, high mountain tops has G = 0.90
clear sky, sea level has G = 0.75
smoggy, sea level has G = 0.40

5. Once radiation has entered the atmosphere, there is solar **radiation scattering**; two types exisit (1) uniform (or Rayleigh) and non-uniform (or Mie) scattering off of atmospheric gasses and dust respectively;

• light scattering is inversely proportional to some power (between 1.4 and 4) of wavelength so that shorter wavelengths (blue; 400nm) scatter more incoming light than longer wavelengths (red; 700nm). Scattering is also influenced by path length.

• the sun and sky change appear to change color because of light scattering and wavelength depletion associated with changes in air mass:

+ **sun high, path short, air dry** = blue light is scattered (depleted), sun appears yellow/white & the sky blue

+ **sun low, path** long , air wet = blue/yellow light is scattered (depleted), sun appears orange/red & the sky red/ yellow to blue

II. *Radiation - on surfaces and the Cosine Law of Illumination*:

The Cosine Law of Illumination states; $I_S = I_O \cos(ß)$

I_S = flux density on surface
I_O = flux density perpendicular to direct beam
ß = angle between direct beam and perpendicular to surface

example: a plant with its leaves at I_O = 400 W m^{-2} and ß = 25° gets an $I_S = 400 \cdot \cos(25)$ = 362.5 W m^{-2}

How do we apply this law on the Earth's surfaces, mountain slopes, tree canopies, leaves, etc.?

→ The amount of solar radiation received on Earth depends on factors determining the angle of incidence of solar radiation at its surface:

a. Geographical factors -
latitude = deviation N or S from the equator (follows a cos(i) relation) at noon on either equinox

I_S = (1373 W m^{-2}) · cos (latitude)

example: **BERKELEY** with a latitude of 37° 55′ N

I = 1373 · cos(38°) = 1081.9 W m^{-2}

slope = angle from horizontal
azimuth = deviation from 0° (see figure below)
aspect (compass direction of slope) NOTE: some folks say aspect = azimuth

b. Seasonal factors -
declination (earth's tilt on its axis relative to the sun) or the deviation of earth between each equinox (e,g. -23.5° and +23.5°) - see figure below:

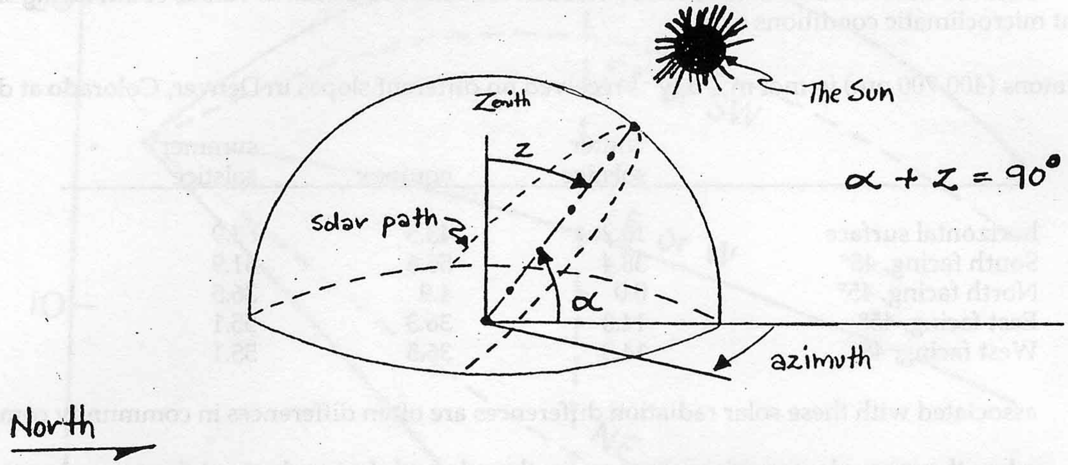
vernal equinox = 0°
summer solstice = +23.5°
autumnal equinox = 0°
winter solstice = - 23.5°

day-length (total solar period; hours) and **time** where at noon, any time of the year, and at any location the declination of the sun due to seasonal (time) effects is:

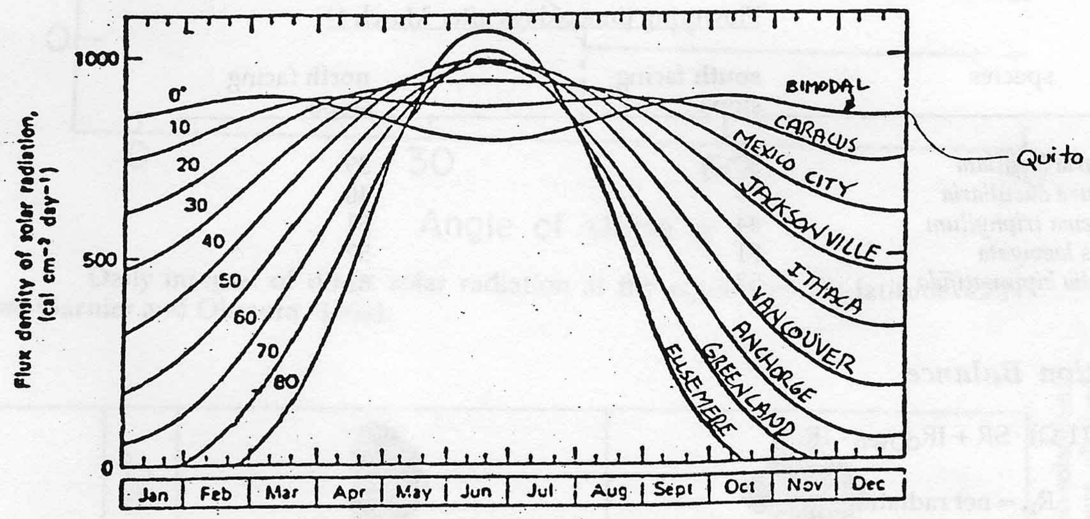
solar altitude = 90 - latitude + declination
zenith = latitude - declination

c. Solar factors -
solar altitude (or elevation; α) = angle of sun above the horizon
zenith angle (*z*) = angle of sun from the perpendicular (see figure below)

NOTE: **zenith angle + altitude = 90°** (where the zenith is a perpendicular line drawn from the sun to some point on earth as when the sun in the sky at noon is directly overhead) - figure.



→ Daily totals for solar radiation will vary with both season and latitude (figure below); this variation has strong implications for productivity and photoperiod.



Daily total of the undepleted solar radiation received on a horizontal surface as a function of latitude and time of year. Based on solar constant of 1.94 cal cm^{-2} min^{-1} (after Gates, 1962).

→ All of this comes together where we calculate the solar radiation incident upon a horizontal surface. This then depends on slope, azimuth, latitude, declination, and atmospheric transmission coefficient

$$\sin(a) = \sin(l)\bullet\sin(d) + \cos(l)\bullet\cos(d)\bullet\cos(h)$$

a = solar altitude
l = latitude
d = declination
h = hour angle

$$I_O = S\bullet\sin(a)\bullet G^{(1/\sin(a))}$$

I_O = light intensity at the earth's surface
S = solar constant outside atmosphere
G = atmospheric transmission coefficient

→ North-South slope comparisons

1. Because different amounts of solar radiation are received on north versus south facing slopes, vastly different microclimatic conditions exist

Total daily photons (400-700 nm) in mol m^{-2} day^{-1} received on different slopes in Denver, Colorado at different seasons

	winter solstice	equinox	summer solstice
horizontal surface	16.2	43.5	68.9
South facing, 45°	38.4	56.6	61.9
North facing, 45°	0.0	4.9	36.5
East facing, 45°	14.3	36.3	55.1
West facing, 45°	14.3	36.3	55.1

2. associated with these solar radiation differences are often differences in community composition

3. when the same plant species occurs on north and south facing slopes at the same elevation, the plant on the north facing slope is often retarded or delayed in growth activity even though the north facing slope is more mesic.

species	Flowering times (days after March 1) south facing slope	north facing slope
Dentaria laciniata	33	39
Dicentra cucullaria	34	40
Arisaema triphyllum	44	51
Arabis laevigata	51	57
Phacelia bipinnatifida	52	63

III. *Radiation Balance*

1. $R_n = (1-\Omega) \cdot SR + IR_{down} - IR_{up}$

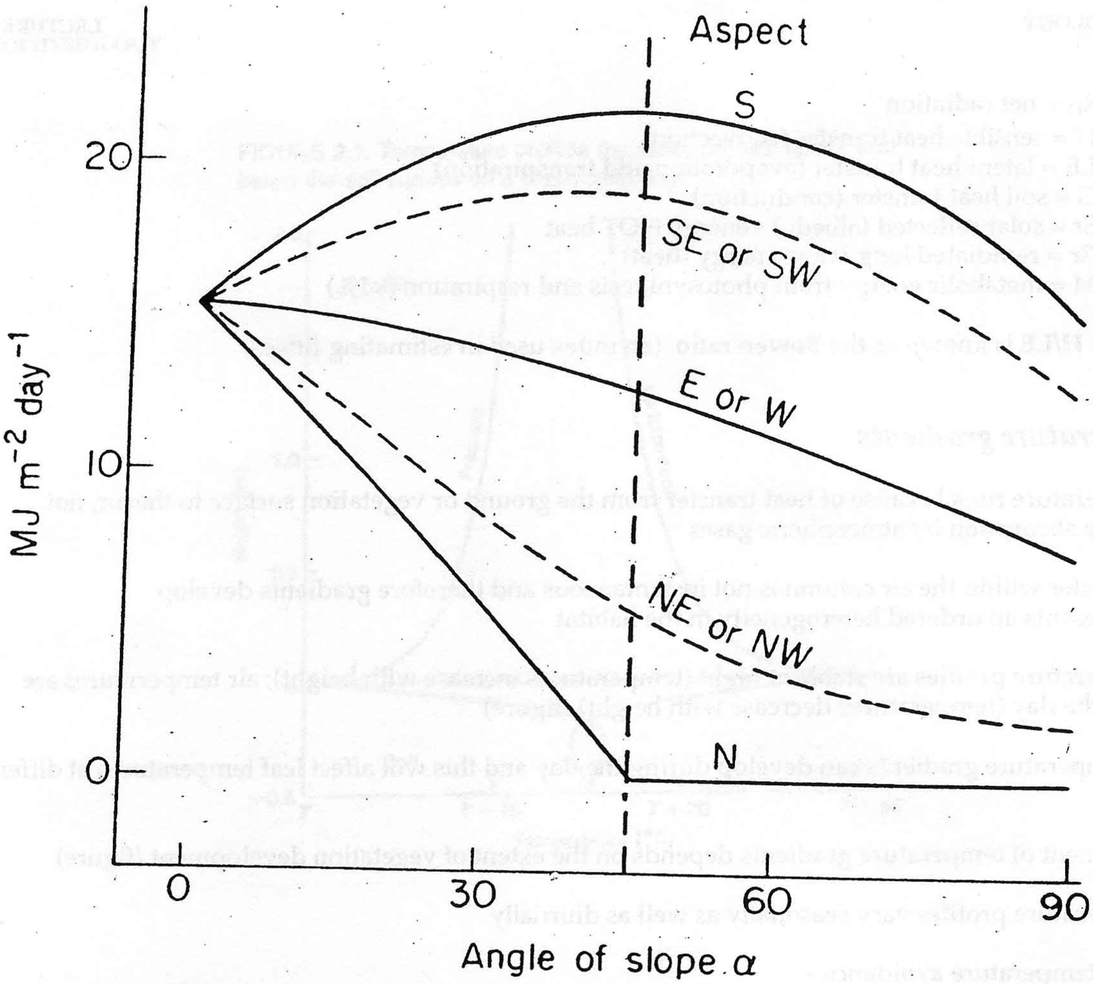
R_n = net radiation
Ω = surface reflectance
SR = solar radiation
IR = infrared radiation

2. net radiation balance changes throughout the day; driven by solar radiation (figure)
   a. infrared radiation levels are essentially constant
   b. net radiation is always less than solar radiation
   c. surface reflectance (albedo) varies greatly

	reflectance (%)
ocean	5
dry sand	18
bare ground	10-20
pasture	25
forest	18
snow	81

3. How is the net radiation dissipated? It is converted to heat and lost through heat transfer processes
   a. for plant canopies; $R_n = H + LE + Sr + Rr + M$
   b. for soil or land surfaces; $R_n = H + LE + G + Sr + Rr$

lecture topic 3



Daily integral of direct solar radiation at the equinoxes for latitude 45°N (from Garnier and Ohmura, 1968).

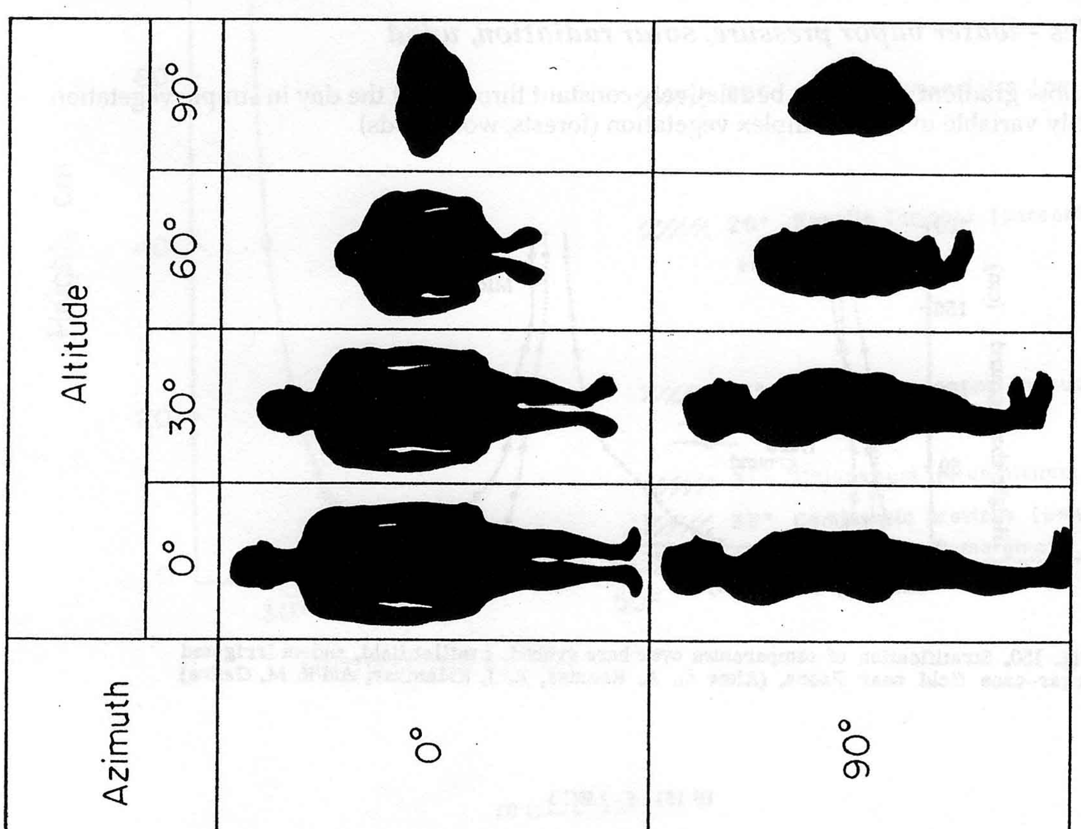


Fig. 5.8 The area of an erect male figure projected in the direction of the solar beam for different values of solar azimuth and altitude. The silhouettes were obtained photographically by Underwood and Ward (1966).

where: R_n = net radiation
H = sensible heat transfer (convection)
LE = latent heat transfer (evaporation and transpiration)
G = soil heat transfer (conduction)
Sr = solar reflected (albedo) - energy NOT heat
Rr = reradiated long-wave energy (heat)
M = metabolic energy from photosynthesis and respiration (<1%)

the ratio: H/LE is known as the **Bowen ratio** (an index used in estimating fluxes)

IV. *Air temperature gradients*

1. air temperature rises because of heat transfer from the ground or vegetation surface to the air, not because of energy absorption by atmospheric gases

a. heat transfer within the air column is not instantaneous and therefore gradients develop
b. this represents an ordered heterogeneity in the habitat

2. air temperature profiles are stable at night (temperatures increase with height); air temperatures are unstable during the day (temperatures decrease with height) (figure)

3. large temperature gradients can develop during the day and this will affect leaf temperatures at different heights (figure)

4. development of temperature gradients depends on the extent of vegetation development (figure)

5. air temperature profiles vary seasonally as well as diurnally

6. extreme temperature avoidance -
frost avoidance - height of cotyledon node in*Centrosperma virginianum*
high temperatures - moving stems in Death Valley sand
dune annuals (*Polygonum aviculare* and *Coldenia plicata*)
moving scape - *Cymopterus longipes* (the elevator plant)

V. *Other profiles - water vapor pressure, solar radiation, wind*

- relatively low gradient which can be relatively constant throughout the day in simple vegetation (grasslands) to highly variable in more complex vegetation (forests, woodlands)

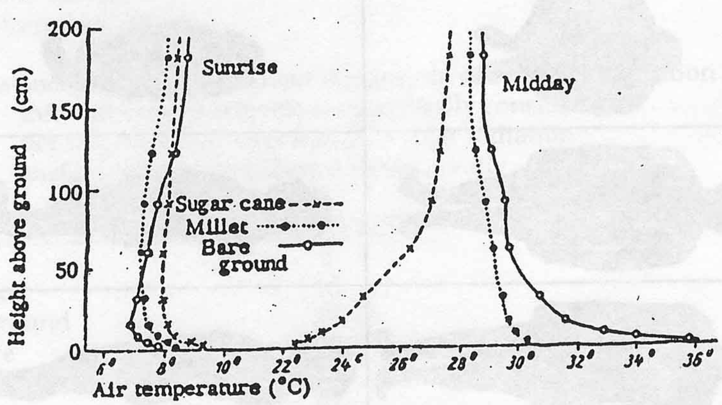
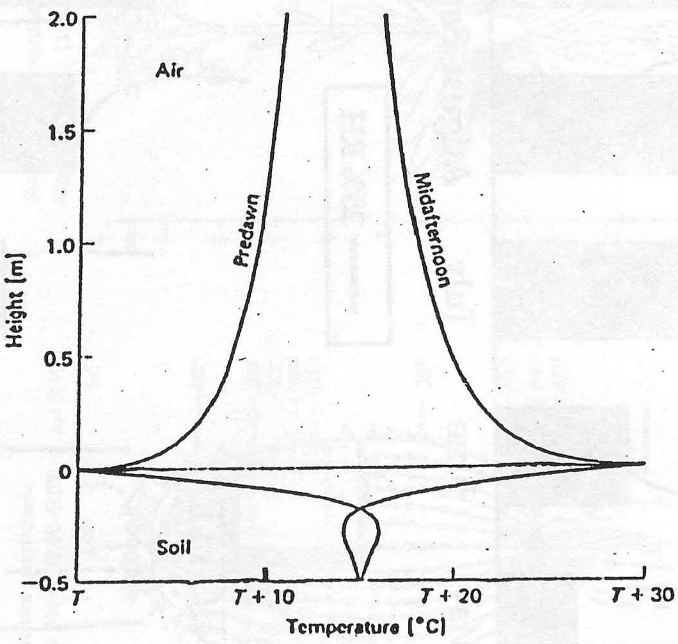
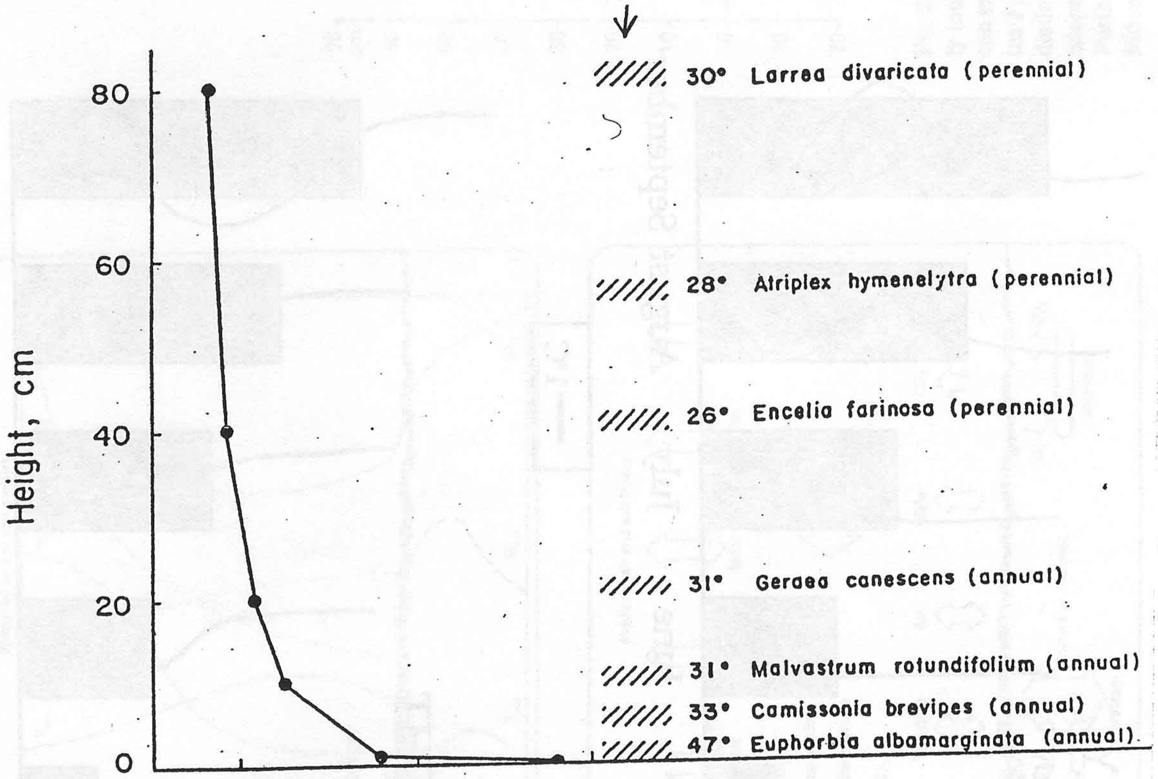


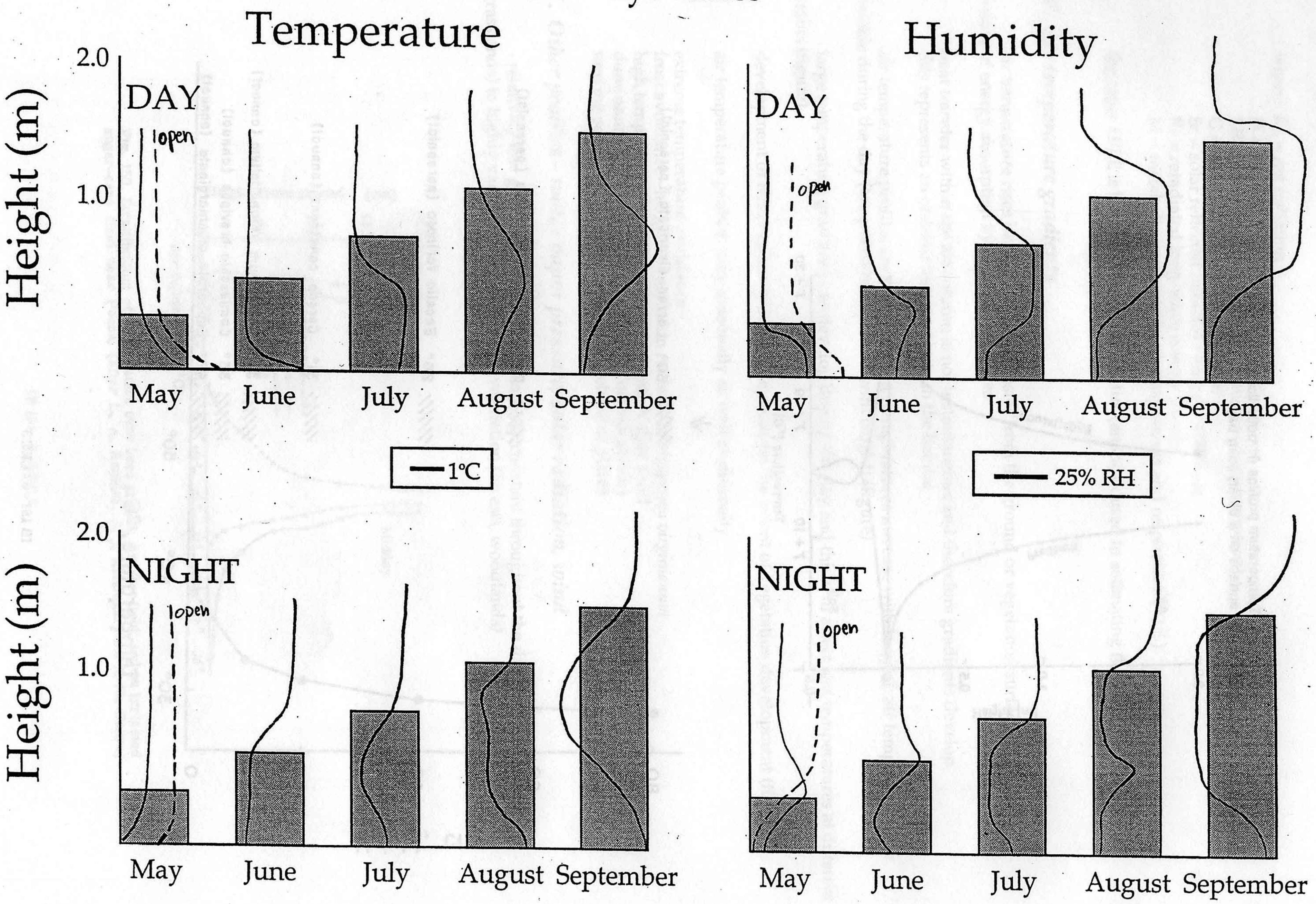
Fig. 150. Stratification of temperature over bare ground, a millet field, and an irrigated sugar-cane field near Poona. (After L. A. Ramdas, R. J. Kalamkar, and K. M. Gadre)

FIGURE 2.1. Temperature profiles (hypothetical) just above and below the soil surface on a clear, calm day.



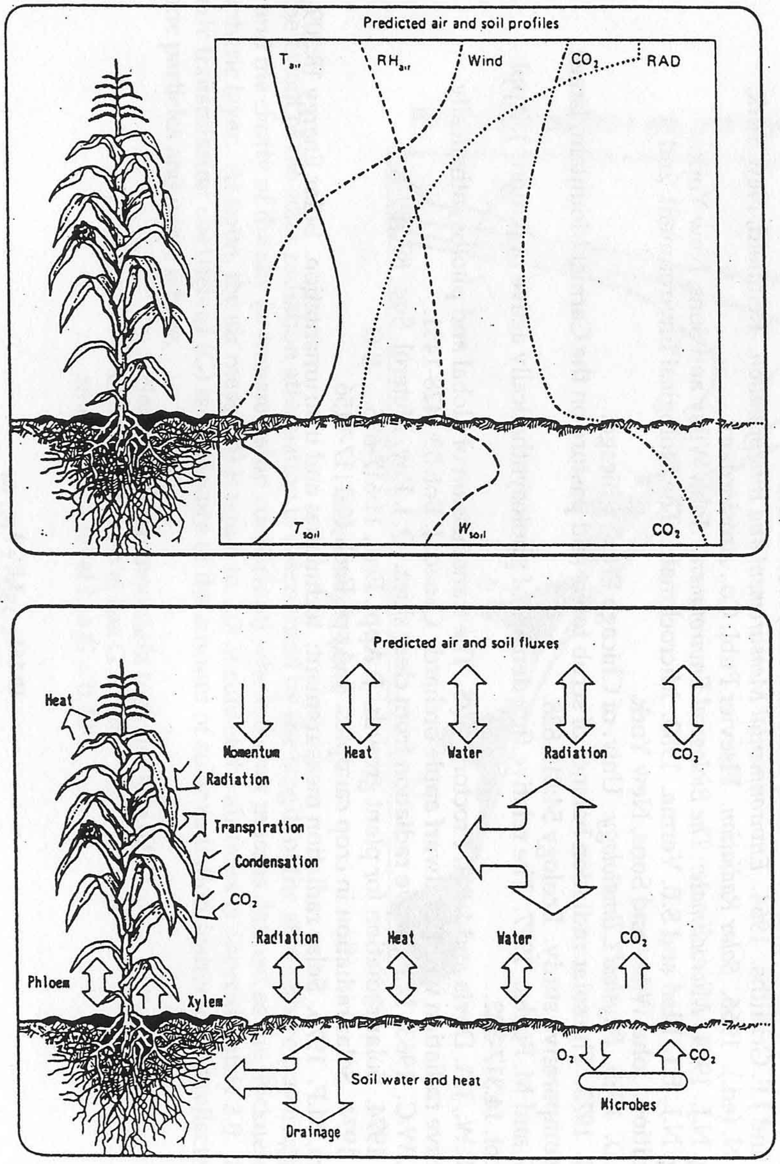


Rye Grass



Temperature
Humidity
Height (m)
2.0
1.0
DAY
NIGHT
open
May
June
July
August
September
1°C
25% RH

Fig. 9.2. The vertical exchange of energy, mass and momentum.



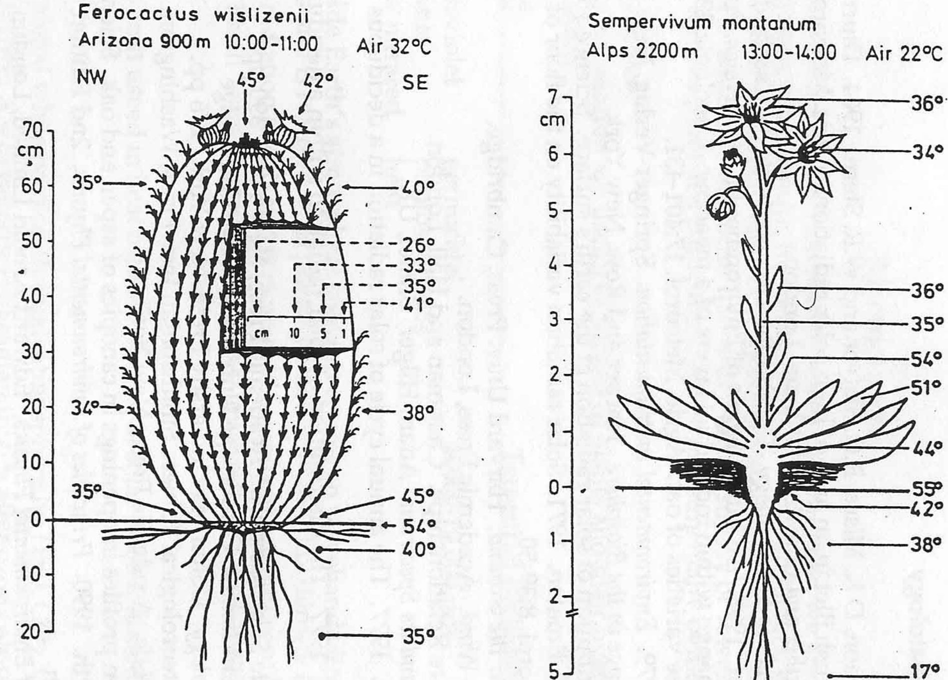


Fig. 2.10. The degrees to which succulent plants are warmed above air temperature under steeply incident radiation. The temperature in the center of the rosette of *Sempervivum montanum* can exceed that of the air by 32° C (unpublished measurements by W. Larcher). The barrel cactus *Ferocactus wislizenii* becomes warmest near the apex; when the sun is high the incident radiation tends to be tangential to the sides of the plant, which thus exceed the surrounding temperature by no more than 10° C (Monzigo and Comanor, 1975; K. Burian, pers. comm.). Further measurements of cactus temperatures are given by Lewis and Nobel (1977) and by Mooney et al. (1977)

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