

UNIVERSIDAD DE LA SERENA
VICERRECTORÍA ACADÉMICA
DIRECCIÓN DE DOCENCIA

MANUAL DEL CURSO
RELACIÓN SUELO-AGUA-PLANTA (SAP)
PARA INGENIERÍA AGRONÓMICA

Parte II

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Unidad II: EL AGUA EN LA PLANTA

Capítulo 7: ESTOMAS E INTERCAMBIO DE GASES

* Características y funcionamiento de los estomas

- Ocurrencia y frecuencia
60 a 80 estomas / mm² (maíz), 1000 estomas / mm² (roble); 1% de la superficie foliar
- Funcionamiento de los estomas
 - células guardianas
 - conducta estomática
 - mecanismo de apertura y cierre estomatal
- Factores que afectan la apertura estomática
 - el rol de la luz
 - dióxido de carbono
 - humedad
 - temperatura
 - viento
 - nutrición mineral
 - estomas y contaminación atmosférica
 - estomas y hongos
 - factores internos que afectan a los estomas
- Comportamiento anómalo de los estomas
 - oscilaciones cíclicas
 - heterogeneidad en la respuesta de los estomas
- Optimización
- Capacidad difusiva de los estomas
- Medidas de apertura estomática y conductancia
 - observaciones visuales
 - infiltración
 - porómetros

LEER

Kramer P.J. y J.S. Boyer (1995) Water Relations of Plants and Soils. Academic Press, San Diego. Capítulo 8.

Salisbury, F.B. y C.W. Ross (1994) Fisiología Vegetal. Grupo Editorial Iberoamérica, S.A., México. Capítulo 4.

Table 8.1 Representative Dimensions and Frequencies of Guard Cells

Plant type	Representative species	Comments	Stomatal frequency (pores · mm ⁻²)		Guard cell dimensions (μm)				Dimensions of stomatal pore (lower surface, μm)		Pore area as proportion of total leaf area if open to 6 μm (%)
			Upper	Lower	Upper surface		Lower surface		Length of pore	Depth of whole pore	
					Length	Width	Length	Width			
Moss	<i>Polytrichum commune</i>	Stomata present on sporophyte only	16	16	46	15	46	15	15	12	—
Fern	<i>Osmunda regalis</i>	Many chloroplasts in guard cells	0	67	—	—	56	19	30	15	0.5
Gymnosperm tree	<i>Pinus sylvestris</i>	Sunken stomata, needle-like leaf	120	120	28	7	28	7	20	6	1.2
Dicot tree	<i>Tilia europea</i>	Hypostomatous leaf	0	370	—	—	25	9	10	8	0.9
Dicot herb	<i>Helianthus annuus</i>	Typical mesophyte Succulent leaves	120	175	35	13	32	14	17	—	1.1
Dicot herb (xero-phyte)	<i>Sedum spectabilis</i>		35	56	32	10	33	10	20	18	0.4
Monocot herb	<i>Allium cepa</i>	Cylindrical leaves, elliptical guard cells	175	175	42	19	42	19	24	18	2.0
Monocot C ₃ grass	<i>Avena sativa</i>	Graminaceous guard cells	50	45	52	15	56	13	20	10	0.5
Monocot C ₄ grass	<i>Zea mays</i>	Graminaceous guard cells	98	108	38	10	43	12	20	10	0.7

Note. The mean values quoted are derived from Meidner and Mansfield (1968) with additional data estimated by the authors. "Upper" and "lower" surfaces refer to leaves except in *Polytrichum*; note that there is no differentiation of surfaces in *Allium*, *Pinus*, and *Polytrichum*. Dashes indicate that category is not applicable. It should be appreciated that the values of parameter shown depend on cultivars, growth conditions, insertion level of leaf, and other factors. From Weyers and Meidner (1990).

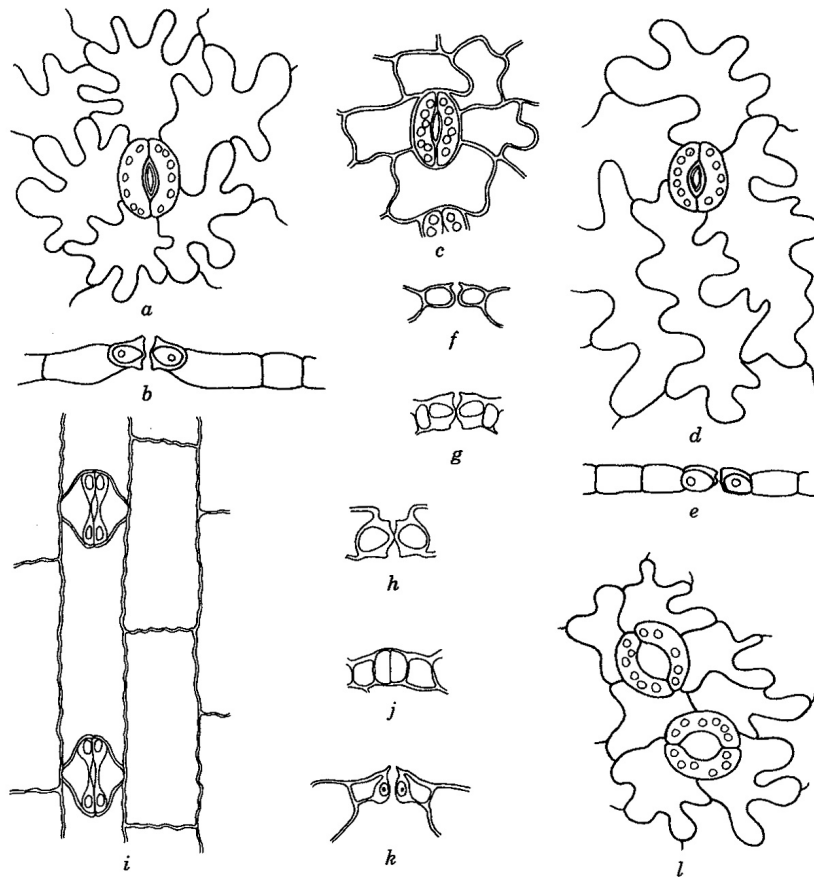


Figure 8.1 Various types of stomata: (a,b) *Solanum tuberosum* in face view and in cross section (c) apple; (d,e) *Lactuca sativa*; (f) *Medeola virginica*; (g) *Aplectrum hyemale*; (h) *Polygonatum biflorum*; (i,j,k) *Zea mays*. Part (i) is a face view; (j) is a cross section near the ends of guard cells; (k) is a cross section through the center of a stoma; and (l) is a face view of *Cucumis sativus*. From Kramer (1983), after Eames and MacDaniels (1947), by permission of McGraw-Hill.

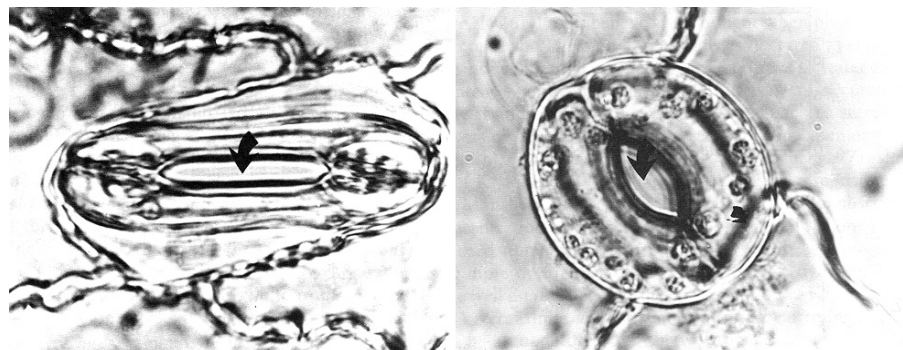


Figure 8.2 (Top) An open stoma of maize, typical of stomata of grasses. (Bottom) An open stoma of bean, typical of most dicots. From Kramer (1983). Courtesy of J. E. Pallas, U.S. Department of Agriculture.

FIGURE 4.13. Electron micrograph showing a pair of guard cells from the dicot *Nicotiana tabacum*, the tobacco plant. The section was made perpendicular to the main surface of the leaf. The pore, facing the atmosphere, is on the top; the bottom faces the substomatal cavity inside the leaf. L, Ledges flanking the stomatal forechamber, F; V, vacuole; N, nucleus; P, plastid; OW, IW, VW, and DW, outer, inner, ventral, and dorsal walls. Note the uneven thickening pattern of the walls, which determines the asymmetric deformation of the guard cells when their volume increases during stomatal opening. Bar = 2 μ m (From Sack, 1987.)

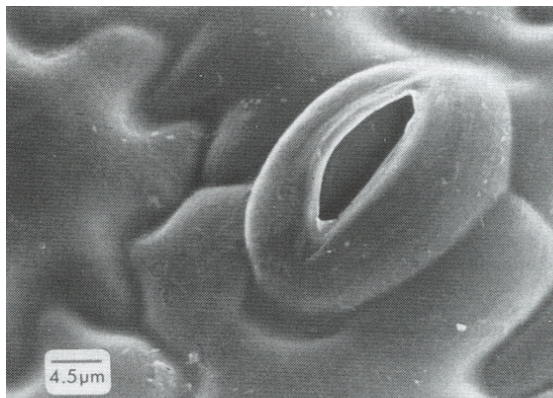
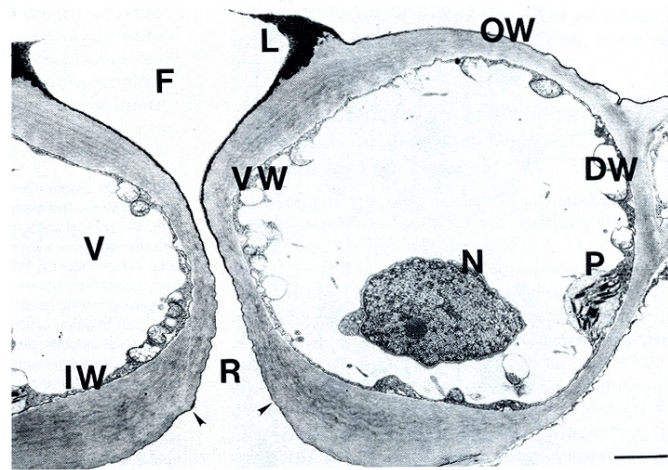
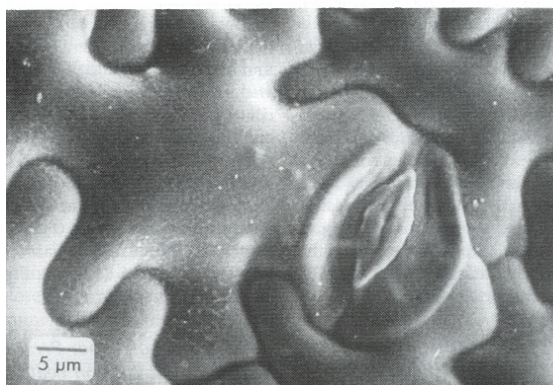


FIGURE 27. (A) Stomatal aperture and cell volume as a function of the guard cell hydrostatic pressure. The pressure in the cells of *Tradescantia virginiana* was controlled with a pressure probe apparatus after the guard cells had been filled with silicon oil (Franks et al. 1995). Copyright Blackwell Science Ltd. (B) Electron micrographs of an open and a closed stoma of the abaxial surface of a leaf of *Vicia faba* (broad bean). Leaves were plunge-frozen in liquid nitrogen and their surfaces were observed still frozen in a cryoscanning electron microscope (courtesy M.E. McCully, Biology Department, Carleton University, Ottawa, Canada).



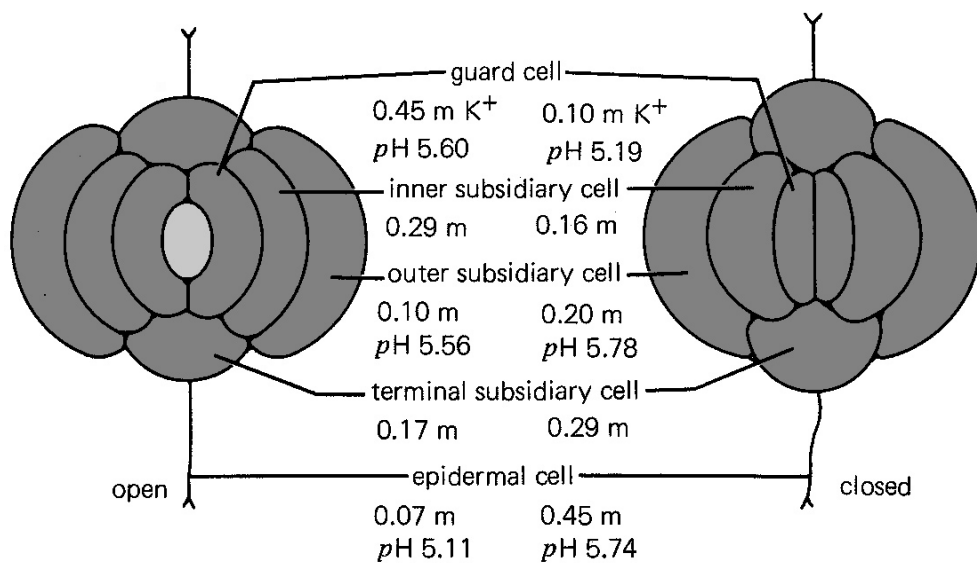
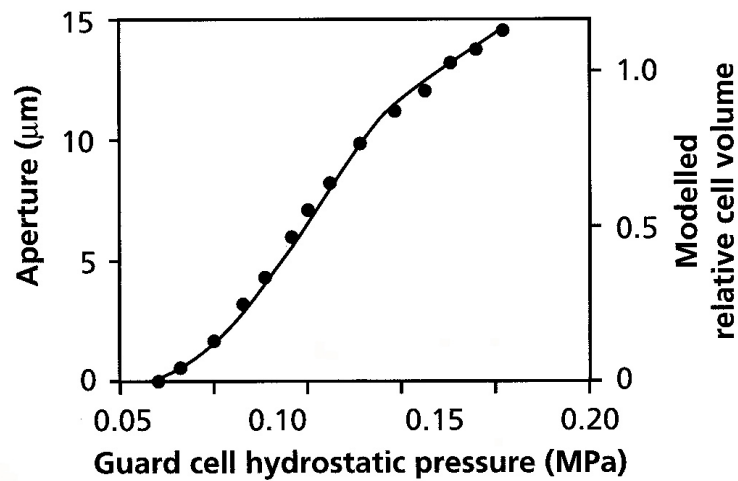
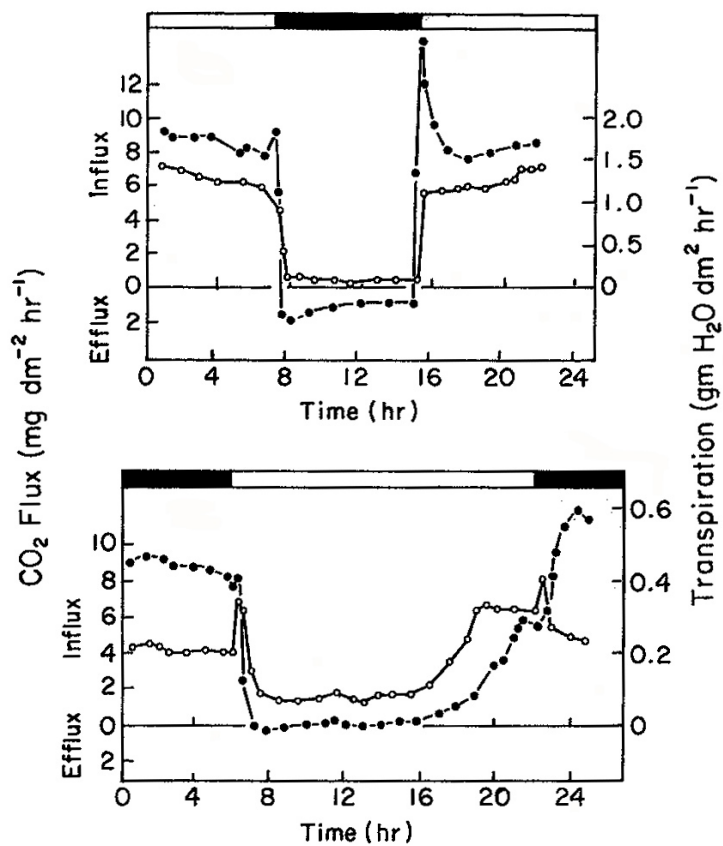
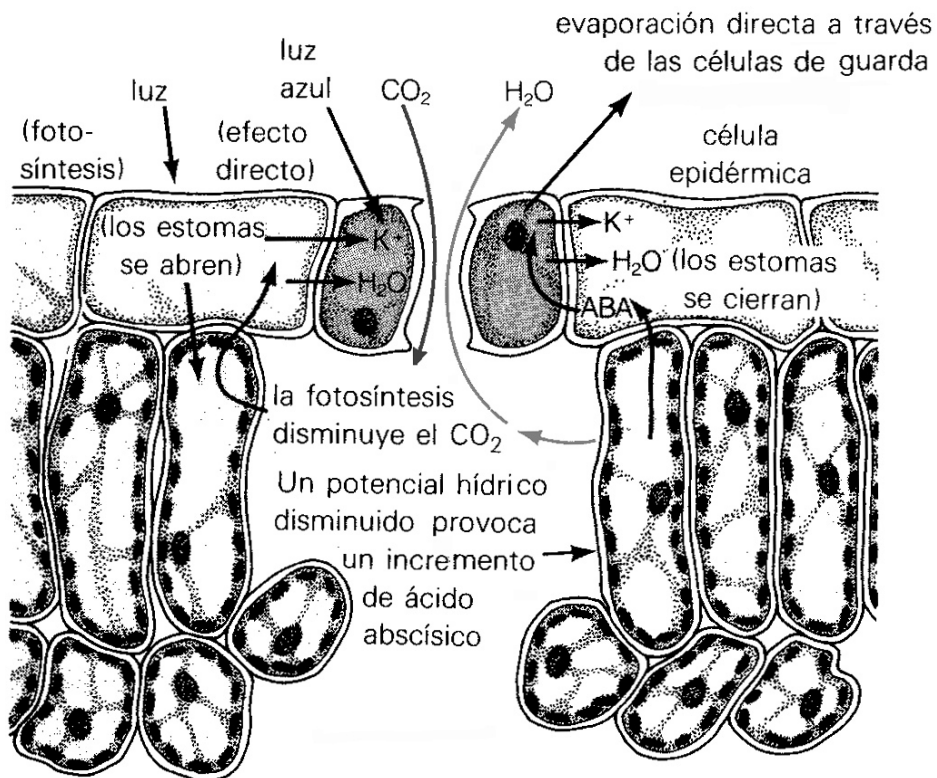
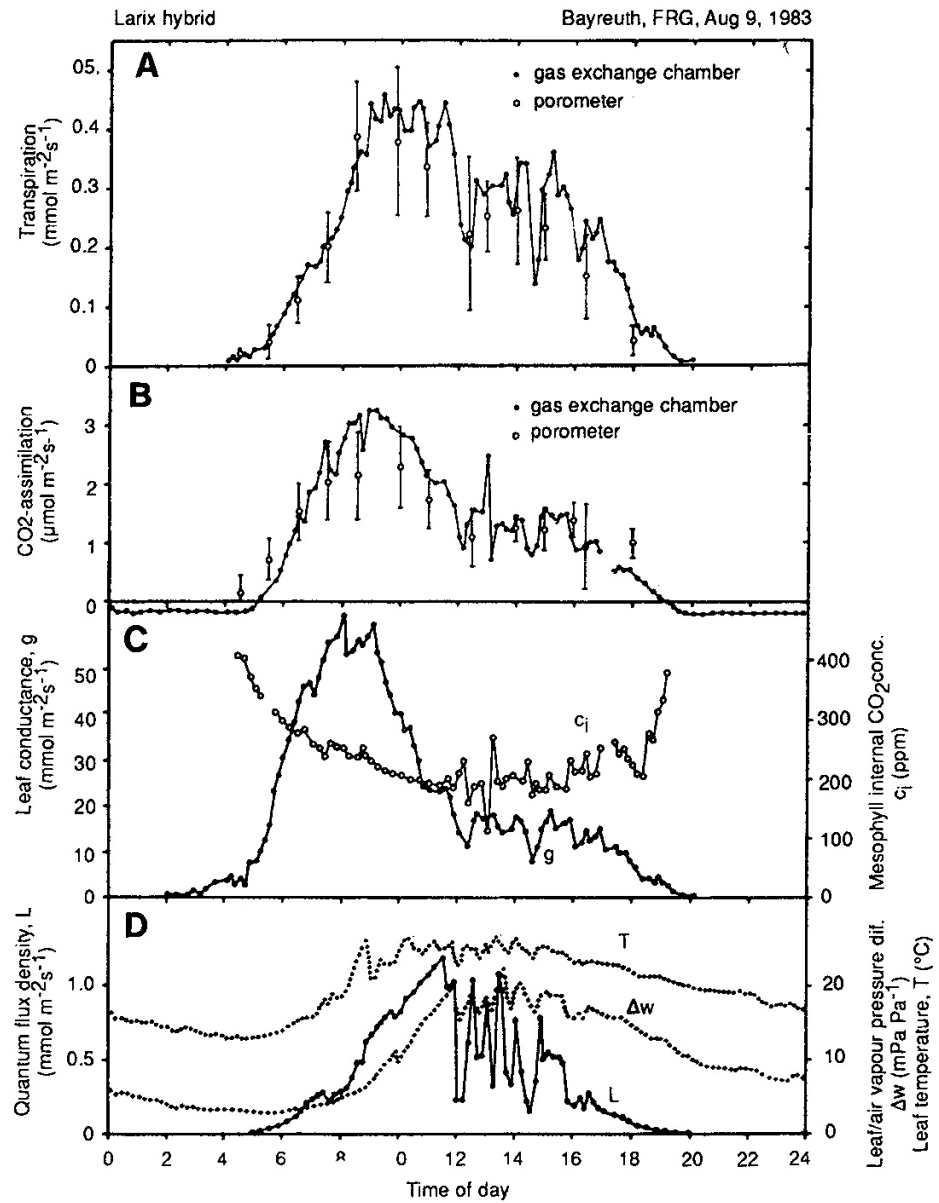


Figure 3-9 Quantitative changes in K⁺ concentrations and pH values of the vacuoles in several cells making up the stomatal complex of *Commelina communis*. Values are given for the open (left) and closed conditions of the stomatal pore. (Data of Penny and Bowling, 1974 and 1975.)





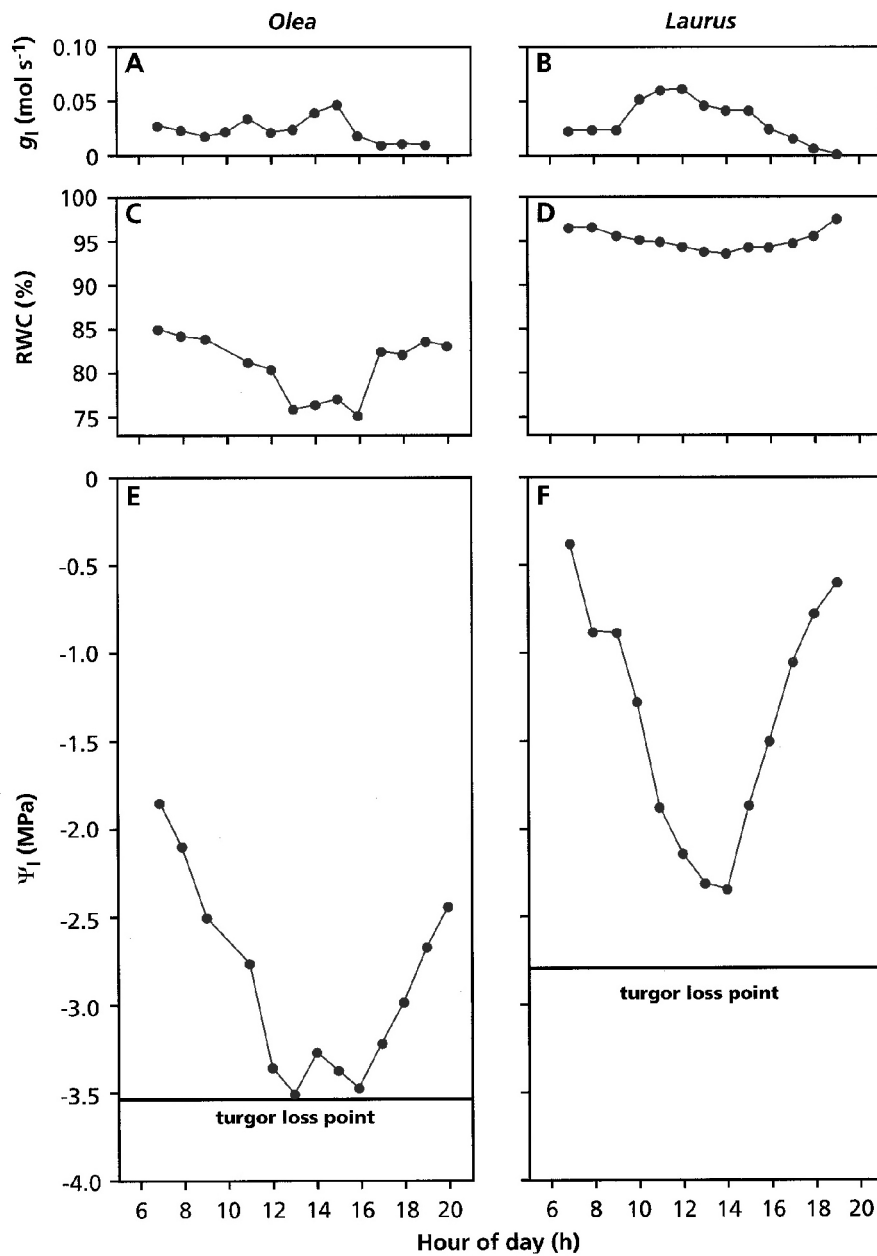


FIGURE 28. Time course of the leaf conductance to water vapor, the relative water content (RWC) of the leaves and the leaf water potential for two Mediterranean tree species; the relatively drought-tolerant *Olea oleaster* and the less tolerant *Laurus nobilis*. RWC is defined as the amount of water per unit plant mass relative to the amount when the tissue is fully hydrated. Measurements were made in September (dry season) (Lo Gullo & Salleo 1988) Copyright Trustees of The New Phytologist.

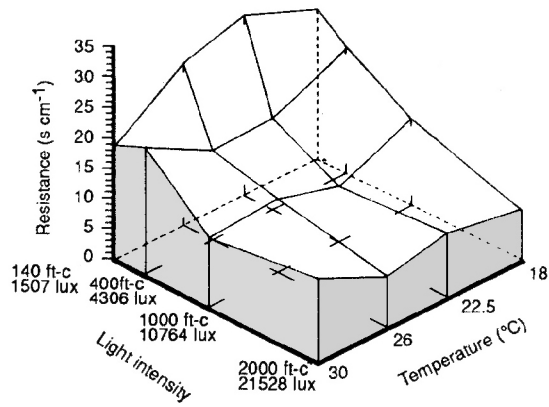


Figure 8.5 Interacting effects of light and temperature on stomatal resistance of sugar maple (*Acer saccharum*). From Pereira and Kozlowski (1977), by permission of the authors and the *Canadian Journal of Forest Research*.

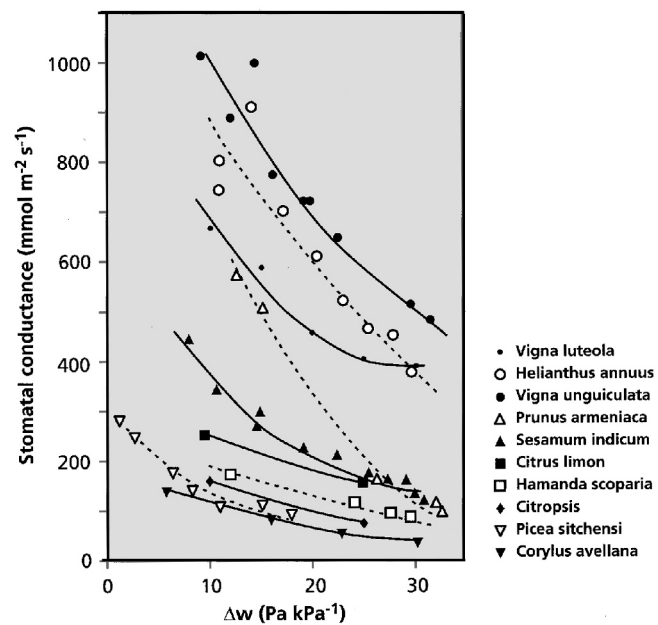


FIGURE 29. Stomatal conductance for water vapor as a function of the difference in water vapor between leaf and air (Schulze & Hall 1982).

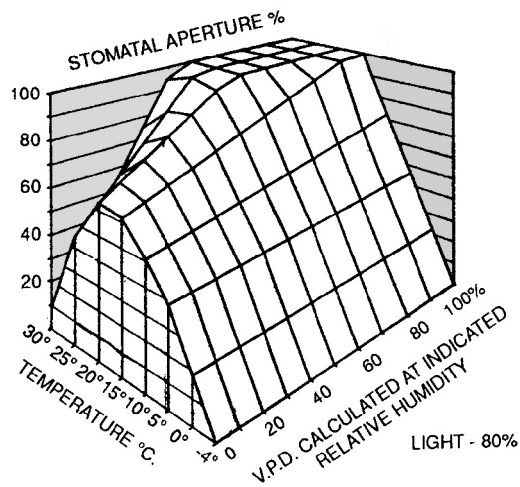


Figure 8.6 Effect of temperature and vapor pressure deficit on stomatal aperture of camellia at 60% of full sun. From Wilson (1948).

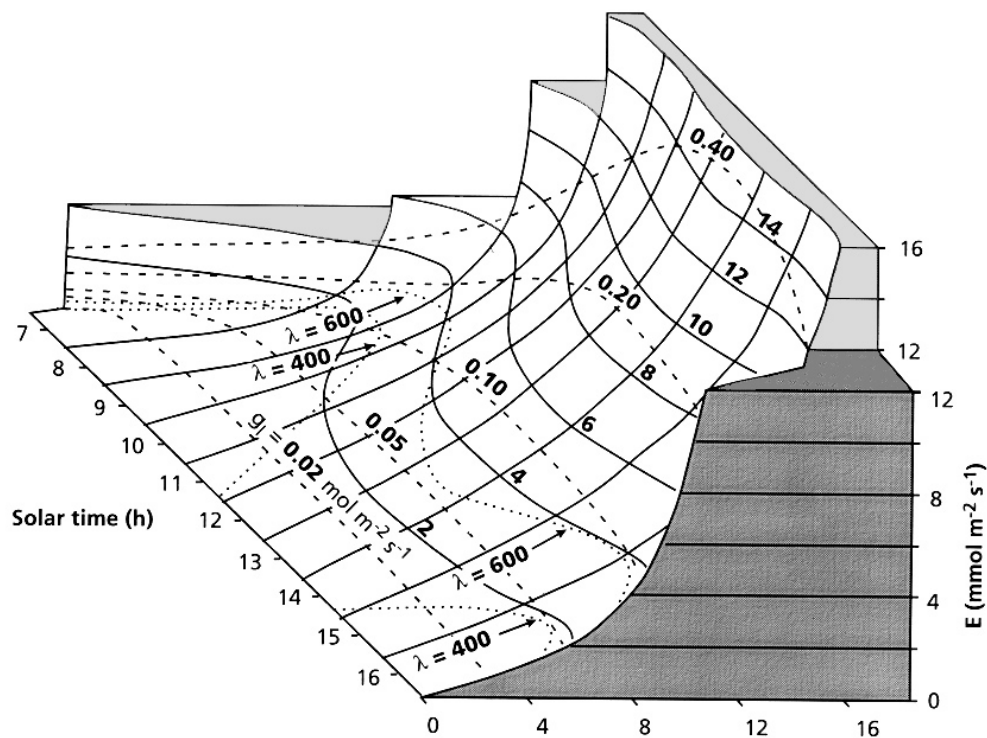


FIGURE 33. Calculated rates of evaporation (E), as a function of the rate of CO_2 assimilation (A) and time of the day, assuming certain characteristics of leaf metabolism and environment. The magnitudes for E are given on the contours of the surface. The broken lines are trajectories on the surface giving the diurnal variation in E and A for particular constant magnitudes of leaf conductance (g ; 0.02, 0.05, 0.10, 0.20 or $0.40 \text{ mol m}^{-2} \text{ s}^{-1}$). The dotted lines are trajectories for which λ is constant (400 or 600) (Cowan 1977). By permission of the Australian Academy of Science.

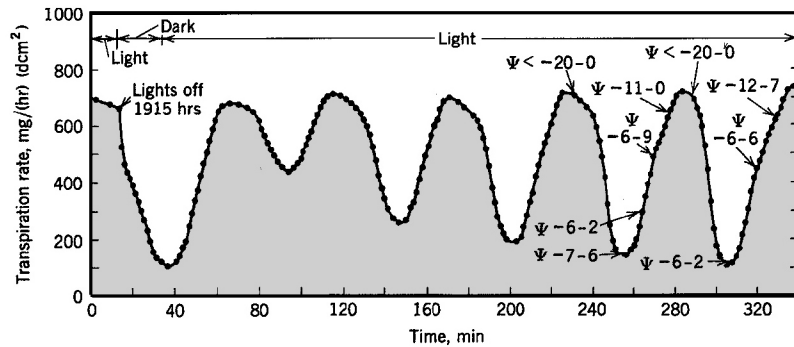


Figure 8.7 Cyclic variation in transpiration and water potential of cotton leaves, caused by stomatal cycling initiated by a 20-min dark period at 3:15 PM. The cycling was attributed to oscillations in water potential caused by high root resistance in rapidly transpiring plants. From Kramer (1983), after Barrs and Klepper (1968).

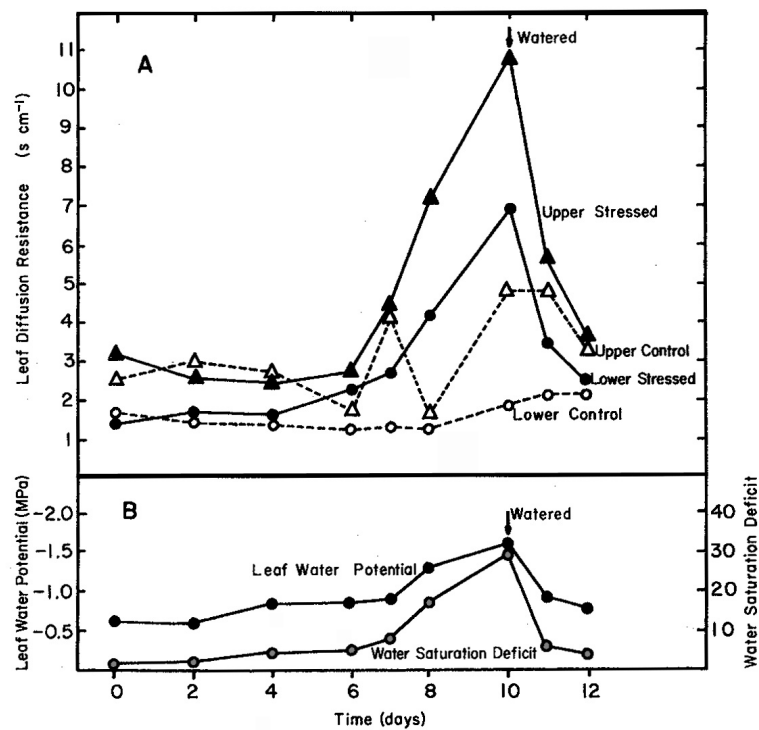


Figure 8.8 (A) Diffusion resistances of upper (adaxial) and lower (abaxial) surfaces of the seventh and eighth leaves of water-deficient and control maize, measured in the morning with a diffusion porometer. The plants were grown in a controlled environment chamber. (B) Leaf water potential and saturation deficit of water-deficient maize plants. From Kramer (1983), after Sanchez-Diaz and Kramer (1971).

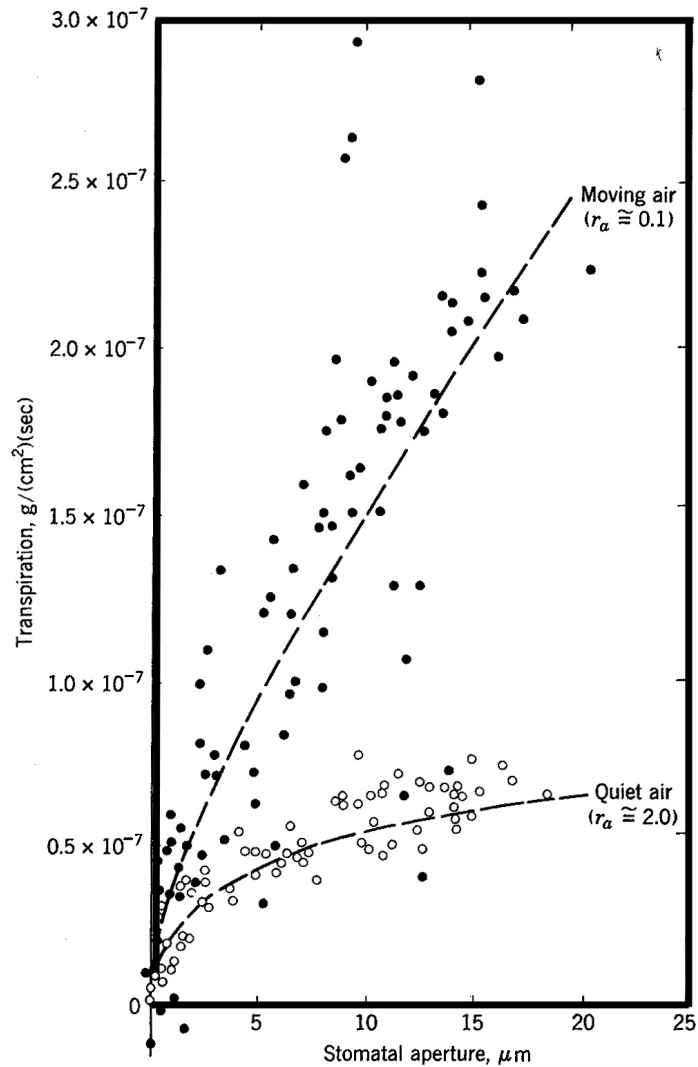


Figure 8.9 The effect of increasing stomatal aperture on transpiration rate of Zebrina leaves in quiet and moving air. The effect of increasing aperture is very large in moving air, but small in quiet air where the boundary layer resistance is relatively large compared to stomatal resistance.

Unidad II: EL AGUA EN LA PLANTA

Capítulo 8: TRANSPORTE DE IONES Y METABOLISMO DEL NITRÓGENO

- * Diagnósis de desórdenes nutricionales por síntomas visibles.
- * Relación entre tasa de crecimiento y contenido de nutrientes minerales.
- contenidos de nutrientes minerales en el rango adecuado para especies anuales y perennes.
- * Movimiento de Nutrientes hacia la superficie de la raíz
 - intercepción
 - flujo de masa
 - difusión
- * Absorción de iones y transporte
 - condiciones óptimas
 - efectos de la deshidratación
- * El rol de la densidad radicular
- * Disponibilidad de nutrientes y distribución del agua en el suelo
- * El rol de la estructura del suelo
- * Proporción intensidad/cantidad de nutrientes disponibles.

- * Metabolismo del nitrógeno
 - fijación biológica de nitrógeno
$$\text{N}_2 + 8[\text{H}] \rightarrow 2\text{NH}_3 + \text{H}_2$$
 - metabolismo del nitrato
$$\text{NO}_3^- + 2[\text{H}] \rightarrow \text{NO}_2^- + \text{H}_2\text{O}$$
$$\text{NO}_2^- + [\text{H}] \rightarrow \text{NH}_3$$
 - síntesis de proteínas

- * Deshidratación y señales raíz/tallo
- * Deshidratación y actividad enzimática
 - efectos directos sobre las enzimas
 - hipótesis regulatoria del control enzimático

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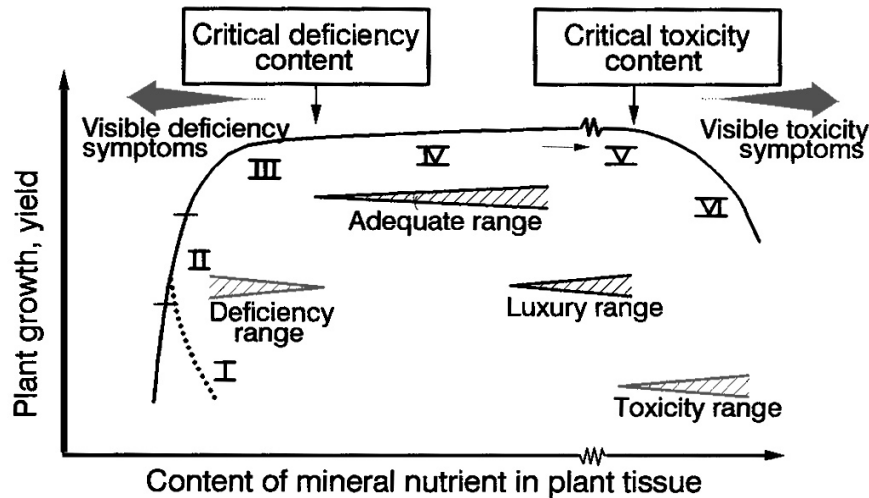
Kramer P.J. y J.S. Boyer (1995) Water Relations of Plants and Soils. Academic Press, San Diego. Capítulo 9.

Marschner H. (1995) Mineral Nutrition of Higher Plants. Academic Press, London. Capítulos 12 y 13.

Salisbury, F.B. y C.W. Ross (1994) Fisiología Vegetal. Grupo Editorial Iberoamérica, S.A., México. Capítulos 6, 7 y 14.

Table 12.1
Some principles of visual diagnosis of nutritional disorders

Plant part	Prevailing symptom		Disorder
<i>Deficiency</i>			
Old and mature leaf blades	Chlorosis	Uniform	N (S)
		Interveinal or blotched	Mg (Mn)
	Necrosis	Tip and marginal scorch	K
		Interveinal	Mg (Mn)
Young leaf blades and apex	Chlorosis	Uniform	Fe (S)
		Interveinal or blotched	Zn (Mn)
	Necrosis (chlorosis)		Ca, B, Cu
	Deformations		Mo (Zn, B)
<i>Toxicity</i>			
Old and mature leaf blades	Necrosis	Spots	Mn (B)
		Tip and marginal scorch	B, salt (spray injury)
	Chlorosis, necrosis		Nonspecific toxicity



Range	I deficient	II low	III adequate	IV high	V toxic
Element *					
P (%)	<0.16	0.16-0.25	0.26-0.50	0.51-0.80	>0.80
K (%)	<1.26	1.26-1.70	1.71-2.50	2.51-2.75	>2.75
Mn (mg kg ⁻¹)	< 15	15 - 20	21 -100	101 - 250	> 250

Table 12.2
Critical Deficiency Content (CDC) of Copper (at Maximum Yield) in Subterranean Clover and Plant Organs and Plant Age^a

Plant part	Age of plant (days after sowing)				
	26	40	55	98	F ^b
Whole plant tops	3.9	3.0	2.5	1.6	1.0
Youngest open leaf blade	3.2	~3	~3	~3	~3

^aCDC expressed as mg g⁻¹ dry weight. Based on Reuter *et al.* (1981).

^bEarly flowering.

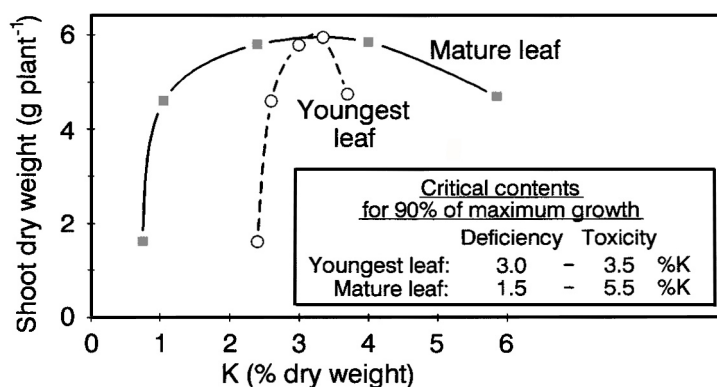


Fig. 12.4 Relationship between shoot dry weight and potassium content of mature and youngest leaves of tomato plants grown in nutrient solutions with various potassium concentrations. Inset: calculated critical contents.

Table 12.3

Critical Deficiency and Adequate Concentrations of Nitrate Nitrogen (NO₃-N) in Press Sap of Leaf Sheath from Basal Stem at Different Developmental Stages of Maize, and Estimated Amounts of NO₃-N Stored in the Above-ground Biomass^a

Developmental stage	Concentration range (mg NO ₃ -N l ⁻¹)		Estimated amounts of stored NO ₃ -N (kg ha ⁻¹)	
	Critical defic.	Adequate	Critical defic.	Adequate
4-5 leaf stage	800	1400	3.6	6.3
Onset of shooting	375	700	6.2	11.6
Shooting	250	550	7.0	15.3
Heading	250	550	10.6	23.3

^aBased on Geyer and Marschner (1990) and Geyer (unpublished).

Table 12.4

Mineral Nutrient Content of Norway Spruce (*Picea abies* Karst)
Needles of Different Age^a

Mineral nutrient	Age of needles (years)			
	1	2	3	4
Nitrogen	1.79	1.76	1.46	1.22
Phosphorus	0.20	0.17	0.14	0.13
Potassium	0.63	0.56	0.47	0.44
Magnesium	0.04	0.04	0.03	0.03
Calcium	0.28	0.40	0.50	0.59

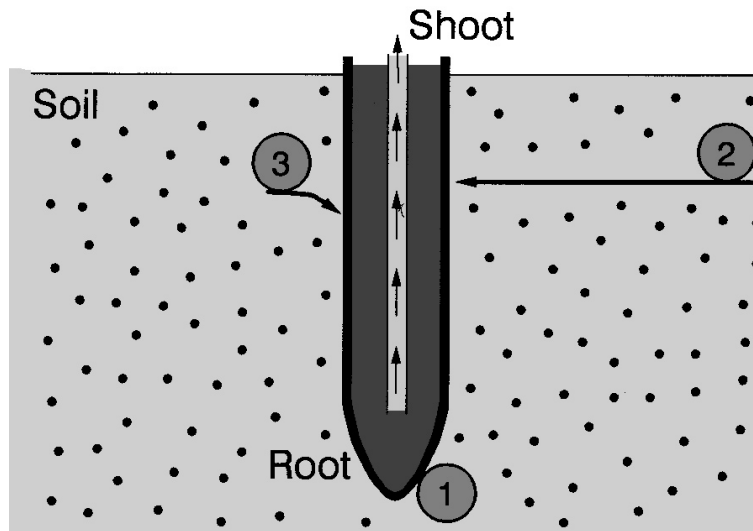
^aContents of mineral nutrients expressed as a percentage of the dry weight. Based on Bosch (1983).

Table 12.5
Mineral Nutrient Contents in the Adequate Range of Some Representative Annual and Perennial Species^a

Species (organ)	Contents (% dry wt)							Contents (mg kg ⁻¹ dry wt)				
	N	P	K	Ca	Mg	B	Mo	Mn	Zn	Cu		
Spring wheat (whole shoot, booting stage)	3.0-4.5	0.3-0.5	2.9-3.8	0.4-1.0	0.15-0.3	5-10	0.1-0.3	30-100	20-70	5-10		
Ryegrass (whole shoot)	3.0-4.2	0.35-0.5	2.5-3.5	0.6-1.2	0.2-0.5	6-12	0.15-0.5	40-100	20-50	6-12		
Sugar beet (mature leaf)	4.0-6.0	0.35-0.6	3.5-6.0 ^b	0.7-2.0	0.3-0.7	40-100	0.25-1.0	35-100	20-80	7-15		
Cotton (mature leaf)	3.6-4.7	0.3-0.5	1.7-3.5	0.6-1.5	0.35-0.8	20-80	0.6-2.0	35-100	25-80	8-20		
Tomato (mature leaf)	4.0-5.5	0.4-0.65	3.0-6.0	3.0-4.0	0.35-0.8	40-80	0.3-1.0	40-100	30-80	6-12		
Alfalfa (upper shoot)	3.5-5.0	0.3-0.6	2.5-3.8	1.0-2.5	0.3-0.8	35-80	0.5-2.0	30-100	25-70	6-15		
Apple (mature leaf)	2.2-2.8	0.18-0.30	1.1-1.5	1.3-2.2	0.20-0.35	30-50	0.1-0.3	35-100	20-50	5-12		
Orange (<i>Citrus</i> spp.) (mature leaf)	2.4-3.5	0.15-0.3	1.2-2.0	3.0-7.0	0.25-0.7	30-70	0.2-0.5	25-125	25-60	6-15		
Norway spruce (1-2 year-old-needles)	1.35-1.7	0.13-0.25	0.5-1.2	0.35-0.8	0.1-0.25	15-50	0.04-0.2	50-500	15-60	4-10		
Oak; Beech (mature leaves)	1.9-3.0	0.15-0.30	1.0-1.5	0.3-0.5	0.15-0.30	15-40	0.05-0.2	35-100	15-50	6-12		

^aBased on Bergmann (1988, 1992).

^bSodium content below 1.5%.



¿Como llegan los nutrientes hasta la raíz?

- (1) las raíces crecen hacia ellos
- (2) arrastrada por el agua (movimiento de masa)
- (3) difusión

Table 13.2

Nutrient Demand of a Maize Crop and Estimates on Nutrient Supply from the Soil by Root Interception, Mass Flow, and Diffusion^a

Nutrient	Demand (kg ha ⁻¹)	Estimates on amounts (kg ha ⁻¹) supplied by		
		Interception	Mass flow	Diffusion
Potassium	195	4	35	156
Nitrogen	190	2	150	38
Phosphorus	40	1	2	37
Magnesium	45	15	100	0

^aFrom Barber (1984).

Table 13.3

Annual Average Concentrations of Mineral Nutrients in the Soil Solution (Topsoil, 0–20 cm) of an Arable Soil (Luvisol, pH 7.7)^a

Concentration in μM								
K	Ca	Mg	NH ₄ -N	NO ₃ -N	SO ₄ -S	PO ₄ -P	Zn	Mn
510	1650	490	48	3100	590	1.5	0.48	0.002

^aRecalculated from Peters (1990).

Table 13.4
Time Course of Nutrient Concentrations in the Soil Solution of the
Topsoil (0–20 cm) of a High-Yielding Winter Rape (*Brassica napus*)
Crop^a

Nutrients	Concentration (μM) at		
	22 February	28 March ^b	15 May
NO ₃ -N	620	11 300	1843
NH ₄ -N	29	1100	<1
PO ₄ -P	14	14	10
K	91	202	133
Ca	1106	5258	1558
Mg	34	84	52

^aBarracough (1989). Reprinted by permission of Kluwer Academic Publishers.

^bSplit application of 265 kg N ha⁻¹ as calcium ammonium nitrate on 25 February and 25 March.

Table 13.6
Plant Uptake and Estimates on Supply to the Roots by Mass Flow of
Potassium, Magnesium, and Calcium in Spring Wheat and Sugar Beet
Grown in a Silty Loam Soil (Luvisol Derived from Loess)^a

	Amount (kg ha ⁻¹)					
	Spring wheat			Sugar beet		
	K	Mg	Ca	K	Mg	Ca
Plant uptake	215	13	35	326	44	104
Mass flow	5	17	272	3	10	236
(% of total uptake)	(2)	(131)	(777)	(1)	(23)	(227)

^aFrom Strebel and Duynisveld (1989).

Table 13.7
Estimates of Diffusion Coefficients ($\text{m}^2 \text{s}^{-1}$) of Ions in Water (D_1) and in Soils (D_e), and of Movement per Day at Average Values of D_e^a

Ion	Diffusion coefficient		Average D_e in soils	Movement in soils (mm per day)
	Water (D_1)	soil (D_e)		
NO_3^-	1.9×10^{-9}	10^{-10} – 10^{-11}	5×10^{-11}	3.0
K^+	2.0×10^{-9}	10^{-11} – 10^{-12}	5×10^{-12}	0.9
H_2PO_4^-	0.9×10^{-9}	10^{-12} – 10^{-15}	1×10^{-13}	0.13

^aFrom Jungk (1991). Reprinted by courtesy of Marcel Dekker Inc.

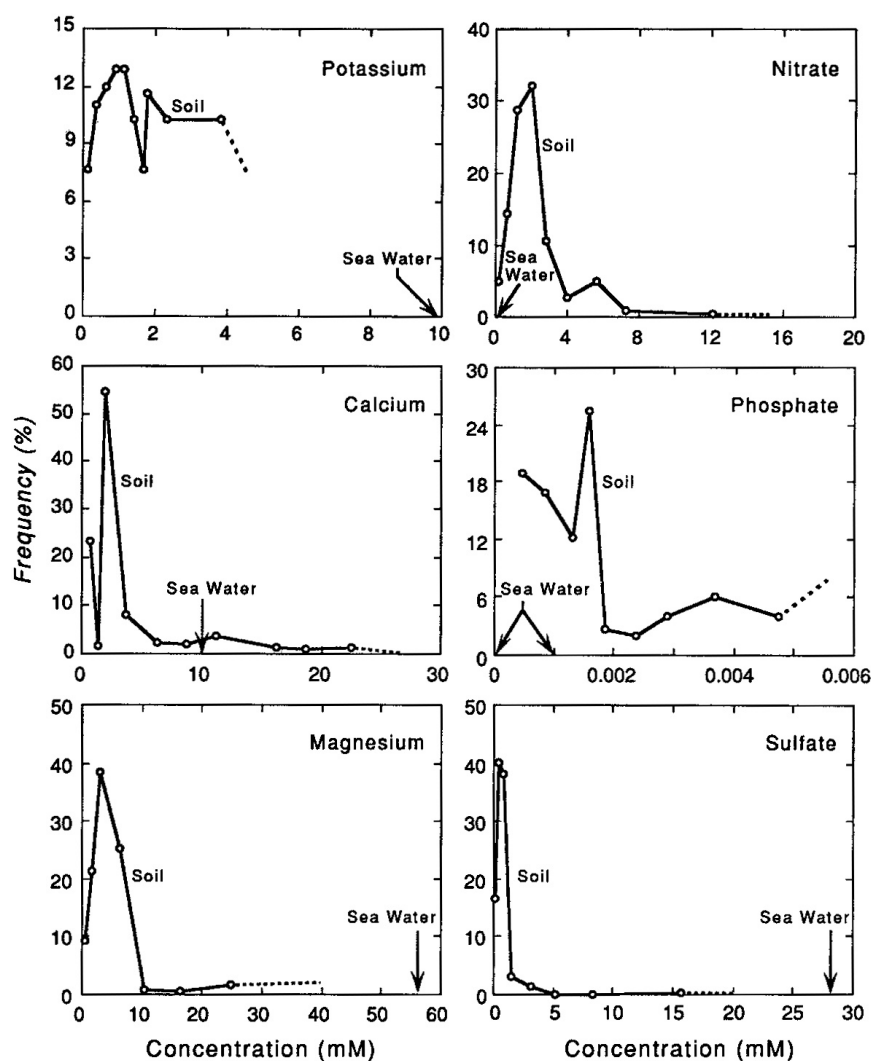


Figure 9.1 Concentration of mineral nutrients in soil solution and seawater. The frequency with which various concentrations occur is shown for each range of concentrations. The number of soils sampled was 149 to 979 depending on the element. The dashed lines indicate that a few soils had concentrations above those shown. Seawater concentrations are stable except for phosphate and nitrate, which vary in the range shown. After Epstein (1972).

Table 9.1 Area of Total World Land Surface Subject to Environmental Limitations of Various Types^a

Environmental limitation	Area of world soil subject to limitation (%)
Drought	27.9
Shallow soil	24.2
Mineral excess or deficiency	22.5
Flooding	12.2
Miscellaneous	3.1
None	10.1
Total	100.0
Temperature	14.8

Note. Area affected by unfavorable temperatures overlaps with other classifications and is shown separately.

^aFrom Dudal (1976).

Table 9.2 Elemental Composition of a Maize Plant as a Percentage of Dry Matter

O	44.43	P	0.20
C	43.57	Mg	0.18
H	6.24	S	0.17
N	1.46	Cl	0.14
Si	1.17	Al	0.11
K	0.92	Fe	0.08
Ca	0.23	Mn	0.04

^aFrom Miller (1938).

Table 9.3 Supply of Elements to Maize Roots by Bulk Flow Caused by Transpiration

Element	Percent of plant dry matter	Concentration of soil solution needed if transpiration is 500X dry matter (mM)	Concentration of soil solution in 145 Maize soils (mM)
Ca	0.22	0.11	0.83
Mg	0.18	0.15	1.15
K	2.0	1.02	0.10
P	0.20	0.13	0.002

^aAfter S. A. Barber *et al.* (1962a).

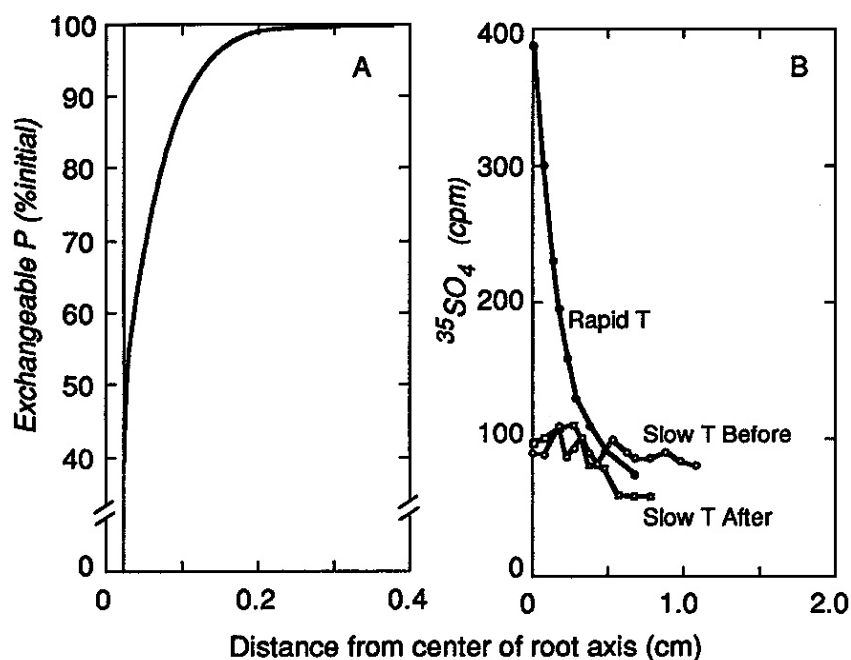


Figure 9.2 (A) Depletion zone for phosphate and (B) accumulation zone for sulfate extending radially from the root. For (B), transpiration (T) was varied, and the accumulation zone was measured before, during, and 16 hr after exposing the plant to rapid T for 18 hr.

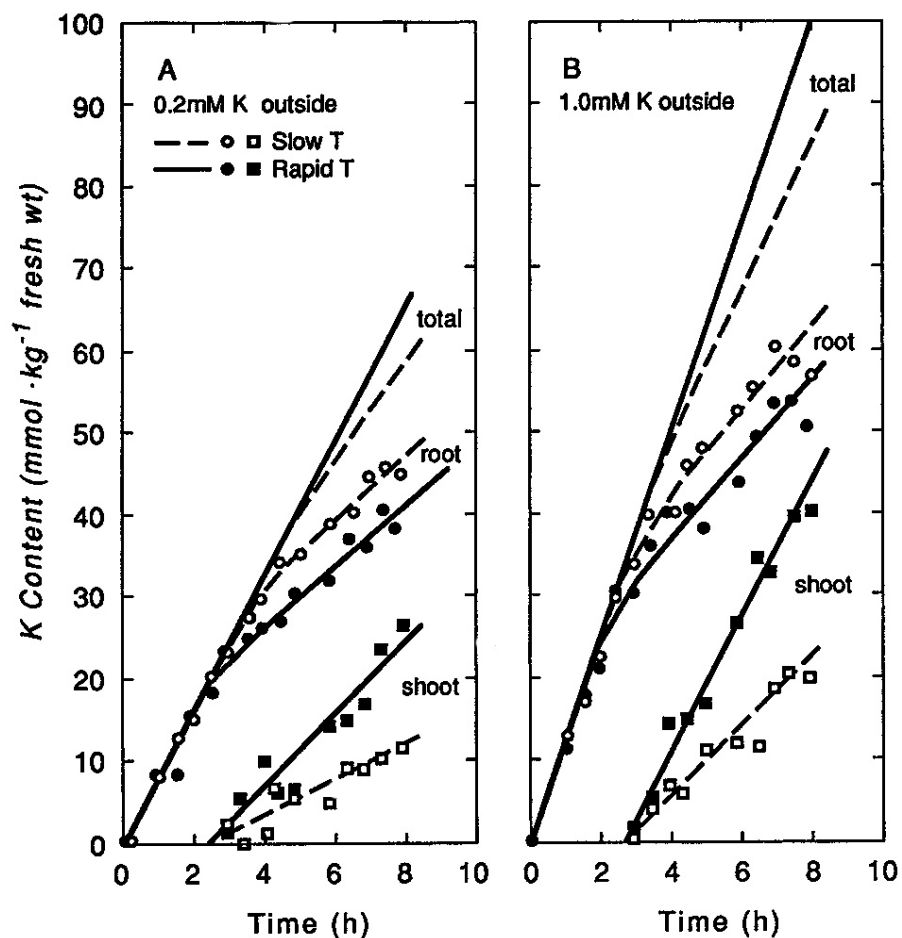


Figure 9.3 Potassium content of roots and shoots of barley plants at various times after exposing the plants to high or low rates of transpiration (T). (A) Roots in nutrient solution with 0.2 mM K. (B) Roots in nutrient solution with 10 mM K. Note that for the total plant, rapid transpiration suppressed uptake more when the external K concentration was high than when it was low.

Table 9.4 Effect of Soil Moisture on Percentage of Elements in Dry Matter of Apple Plants^a

Element	Shoot		Root	
	Dry	Wet	Dry	Wet
N	0.97	0.53	1.40	1.21
P	0.09	0.10	0.10	0.21
K	0.46	0.47	0.64	0.86
Ca	0.41	0.39	0.50	0.57
Mg	0.06	0.06	0.08	0.11

^aFrom Mason (1958).

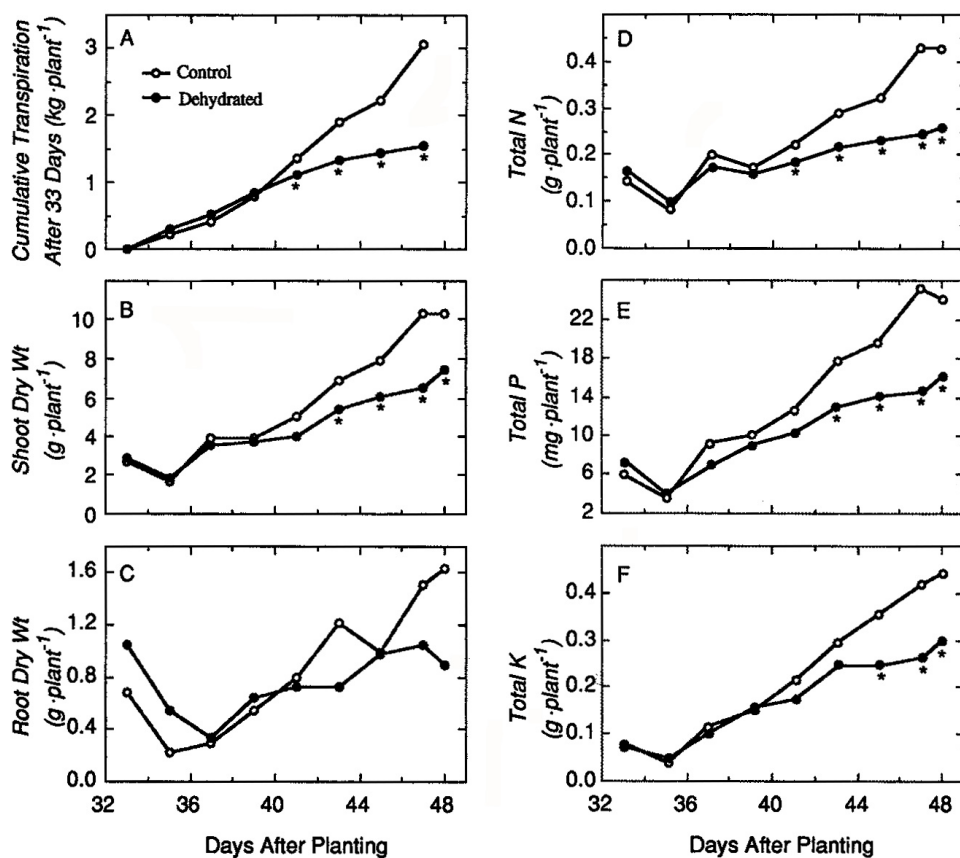


Figure 9.4 (A) Transpiration, (B) shoot dry mass, (C) root dry mass, (D) total N, (E) total P, and (F) total K contents of rice plants from which water was withheld after Day 30. The asterisk shows significant differences at the 5% confidence level.

Table 9.5 Supply of Elements to Rice Roots Calculated from Bulk Flow Caused by Transpiration^a

Treatment	Gain (% of DM gain) ^b			Transpiration ratio ($\text{g H}_2\text{O}$ g DM gain^{-1}) ^b	Concentration needed if transpiration provided nutrients (mM) ^d			Concentration typical in soil solution (mM) ^e		
	N	P ^c	K		N	P ^c	K	N	P	K
Control	2.8	0.18	3.3	256	7.8	0.23	3.3			
H ₂ O deficient	1.9	0.14	2.9	190	7.1	0.24	3.9	0.1–4	0.0005–0.002	0.1–4

Note. The effect of a water deficit is also shown.

^aFrom O'Toole and Baldia (1982).

^bFrom Fig. 9.4

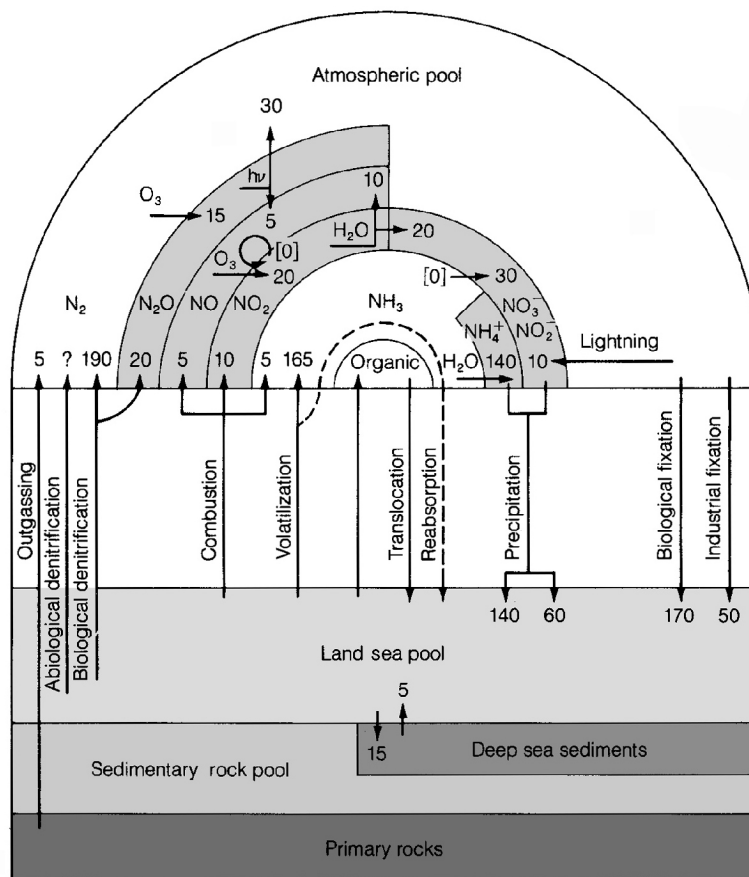
^cData for phosphate are reported here at 10X the concentration in the original paper because of a misplaced decimal point in the original (J.C. O'Toole, personal communication).

^dCalculated as:

$$\frac{(\text{Gain in Element})(10^4)}{(\text{Transpiration Ratio})(\text{Atomic Wt})} = \frac{(\% \text{ of DM gain} \cdot 10^{-2})(10^3 \text{ g H}_2\text{O} \cdot \text{kg}^{-1})(10^3 \text{ mmol} \cdot \text{g}^{-1} \cdot \text{atom}^{-1})}{(\text{g H}_2\text{O} \cdot \text{g DM gain}^{-1})(\text{g element} \cdot \text{g}^{-1} \cdot \text{atom}^{-1})}$$

= Concentration Needed (mM)

^eFrom Fig. 9.1.



Cantidades estimadas de transferencia de nitrógeno entre compartimentos globales, expresado en 10^6 Tonelada a^{-1} . $h\nu$ = reacciones fotoquímicas.

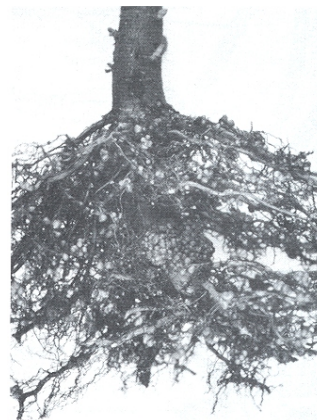
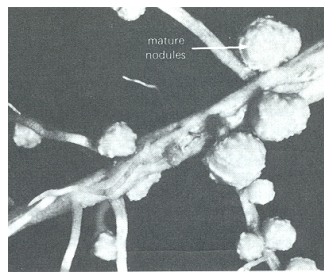
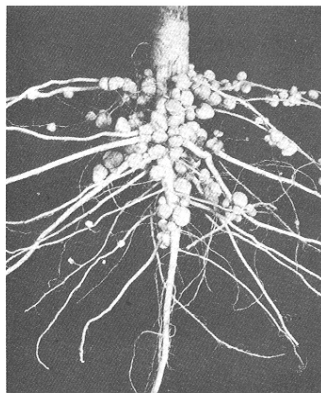
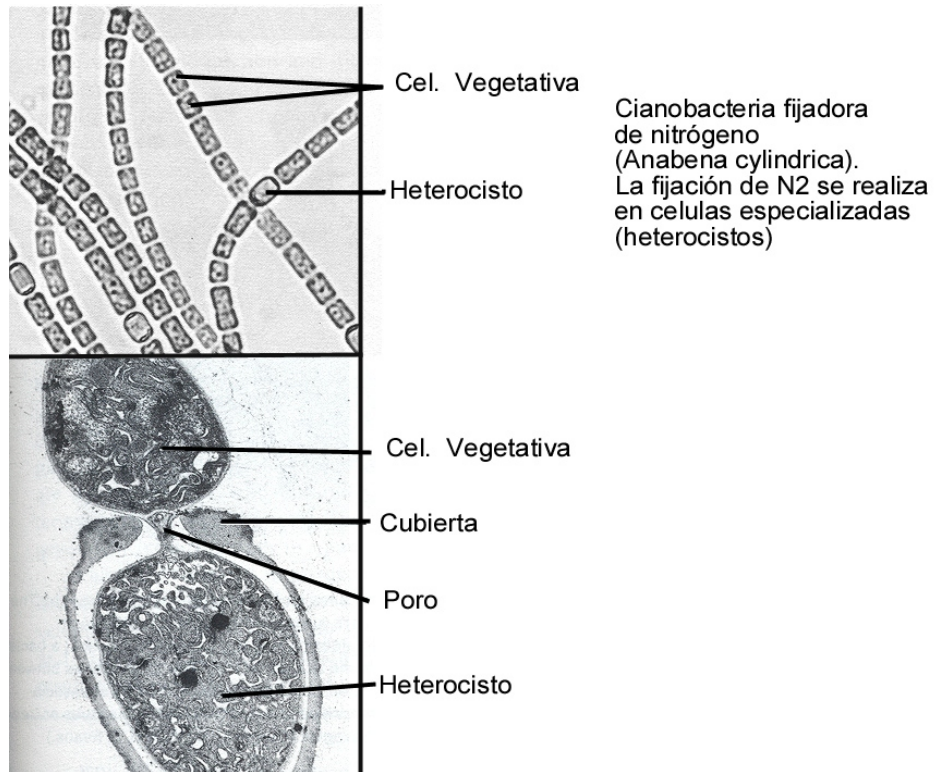
TABLE 12.1. Some examples of organisms that can carry out nitrogen fixation

Symbiotic nitrogen fixation

1. Leguminous plants, *Parasponia*: *Rhizobium*, *Bradyrhizobium*
2. Alder (tree), *Ceanothus* (shrub), *Casuarina* (tree): *Frankia* (actinomycete)
3. Tropical grasses: *Azospirillum* (actinomycete)
4. *Azolla* water fern: *Anabaena*

Nonsymbiotic nitrogen fixation

1. Cyanobacteria (blue-green algae): *Nostoc*, *Anabaena*, *Calothrix*, etc.
2. Other bacteria
 - a. Aerobic: *Azotobacter*, *Beijerinckia*, *Derrxia*, etc.
 - b. Facultative: *Bacillus*, *Klebsiella*, etc.
 - c. Anaerobic:
 - i. Nonphotosynthetic: *Clostridium*, *Methanococcus* (archaebacterium), etc.
 - ii. Photosynthetic: *Rhodospirillum*, *Chromatium*, etc.



Nódulos en raíces de poroto de soya (hierba, A - B (*Rhizobium*)) y en aliso (arbol, C (*Clarkia*))

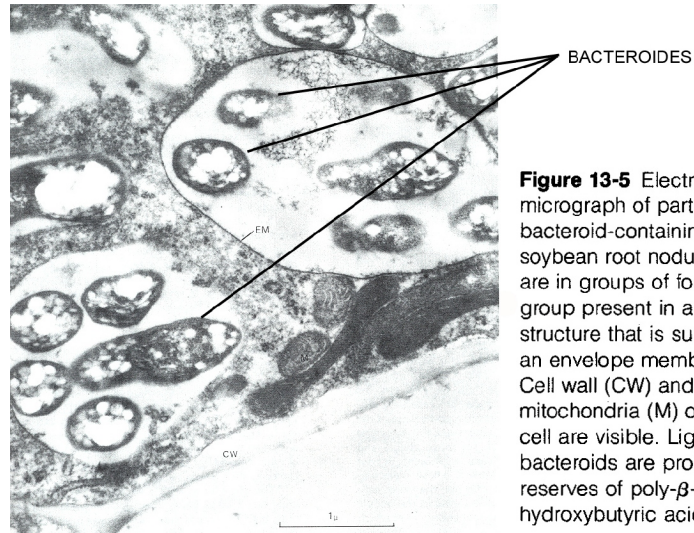


Figure 13-5 Electron micrograph of part of a bacteroid-containing cell from a soybean root nodule. Bacteroids are in groups of four to six, each group present in a sac-like structure that is surrounded by an envelope membrane (EM). Cell wall (CW) and a few mitochondria (M) of the nodule cell are visible. Light areas in bacteroids are probably food reserves of poly-β-hydroxybutyric acid.

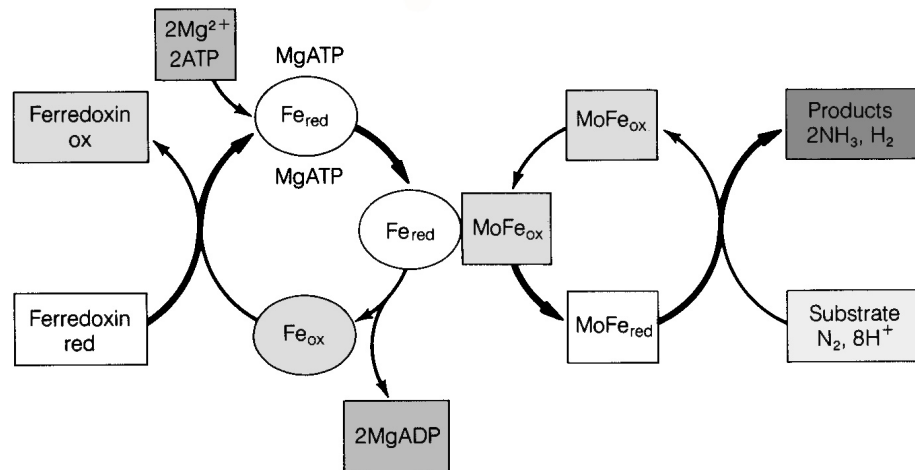


FIGURE 12.7. The reaction catalyzed by nitrogenase. Ferredoxin reduces the Fe protein, while binding of ATP takes place. The Fe protein reduces the MoFe protein, and the MoFe protein reduces the nitrogen. The flow of electrons is shown by the darker arrows.

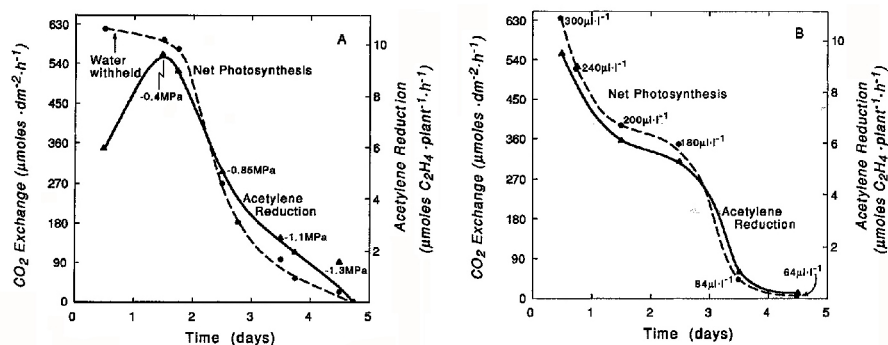


Figure 9.5 Net photosynthesis in shoots and nitrogen fixation (acetylene reduction) in roots of soybean plants at various times after (A) withholding water from the soil or (B) decreasing CO₂ around the shoot without withholding water. The nodule water potentials are shown in (A). The CO₂ concentrations around the shoot are shown in (B). In (B), the low CO₂ was selected to mimic the effects of low water potentials on photosynthesis as in (A). Note that because (B) involves only decreased CO₂ around the shoot, acetylene reduction was inhibited by the lack of products of photosynthesis. Therefore, in (A) the effect on photosynthesis indicates that acetylene reduction must have been similarly inhibited by a lack of photosynthetic products. In (A) and (B), photosynthesis and acetylene reducing activity were measured simultaneously in the same plants *in situ*.

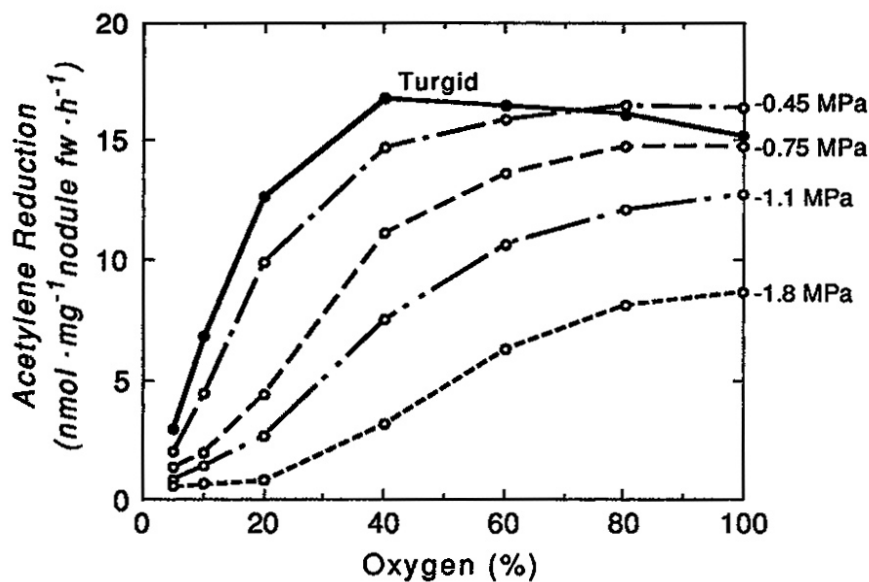
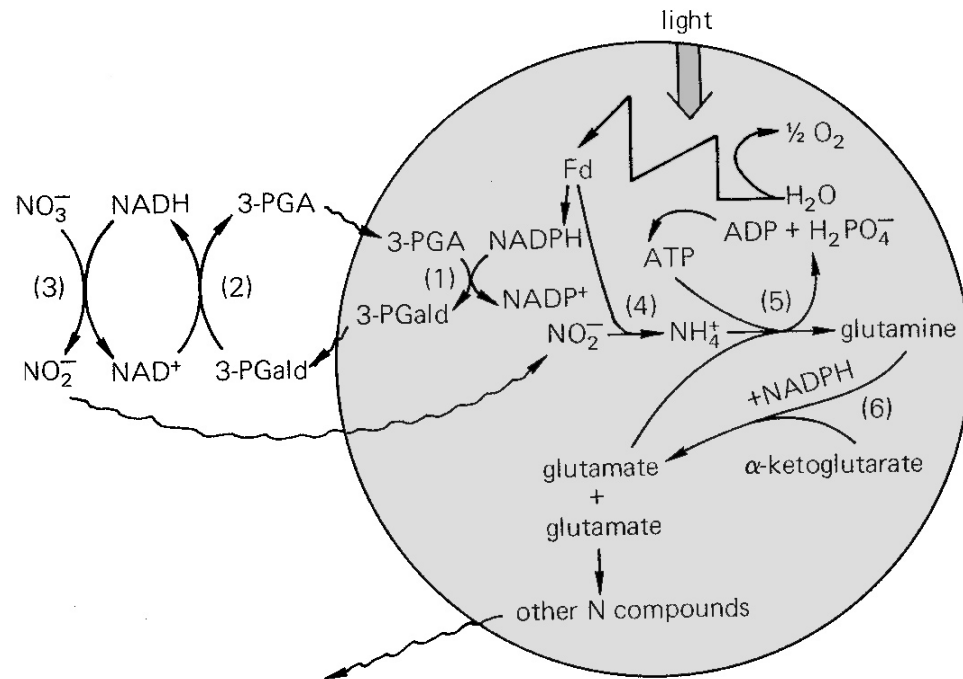


Figure 9.6 Nitrogen fixation (acetylene reduction) at various oxygen partial pressures in detached soybean nodules dehydrated to varying degrees. Dehydration is indicated by nodule water potentials beside each curve. After Pankhurst and Sprent (1975).



Metabolismo del nitrógeno: incorporación del nitrato a amino-ácidos en la hoja.

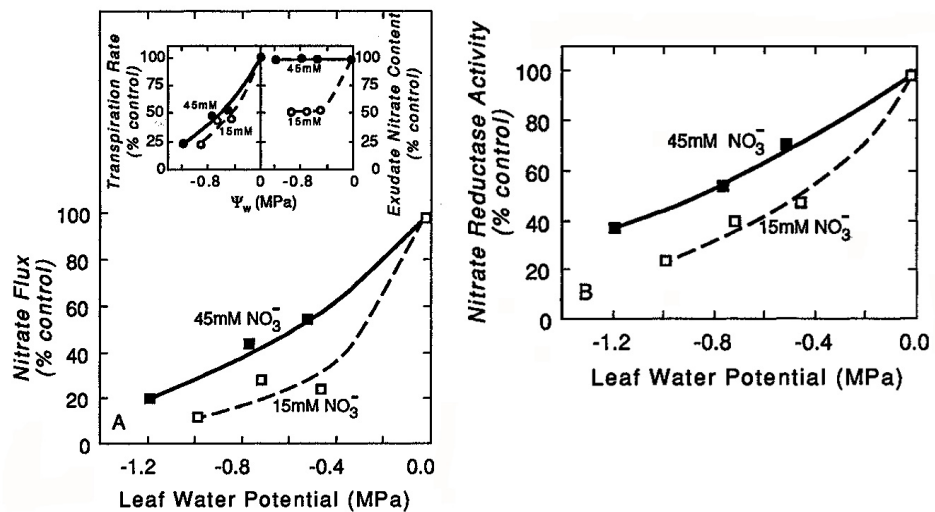


Figure 9.7 (A) Nitrate flux to the shoot and (B) leaf nitrate reductase activity in the shoot at various leaf water potentials in intact maize seedlings. (Insets) Transpiration and nitrate concentration in the xylem solution of the intact seedlings. The nitrate flux in (A) was calculated as transpiration rate $\times$ nitrate concentration shown in the insets. Immediately before dehydration, half the plants were provided with supplemental nitrate (45 mM) around the roots.

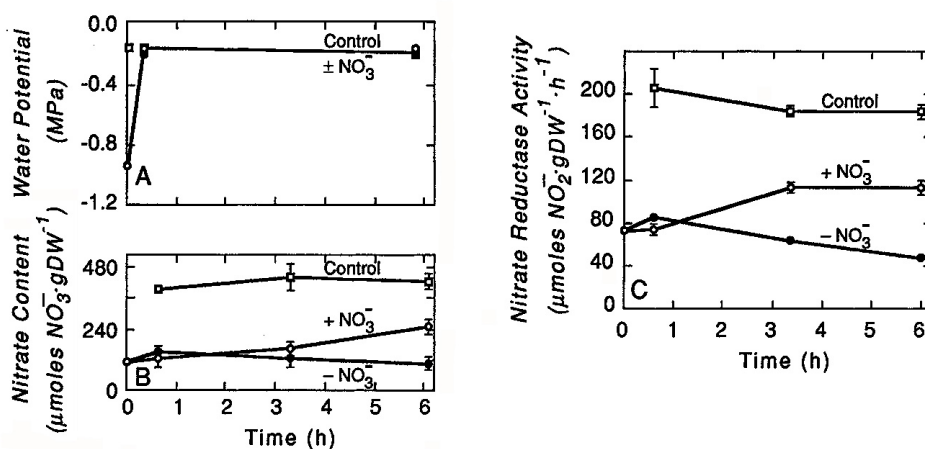


Figure 9.8 (A) Leaf water potential, (B) leaf nitrate content, and (C) leaf nitrate reductase activity in maize shoots recovering from dehydration after cutting under solution with or without nitrate. There was a substantial nitrate flux to the shoot in the +NO₃⁻ treatment but little if any in the -NO₃⁻ treatment. Note that the recovery of leaf nitrate reductase activity depended on a NO₃⁻ flux during rehydration. The recovery could be blocked by inhibitors of enzyme synthesis, indicating that recovery required new enzyme molecules to be synthesized. After Shaner and Boyer (1976b).

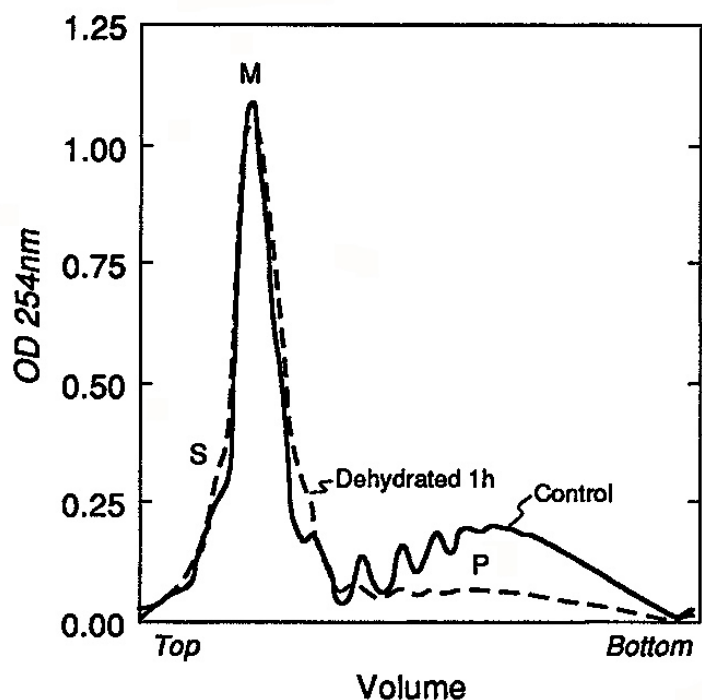


Figure 9.9 Polyribosomes (P), monoribosomes (M), and ribosome subunits (S) isolated from young maize leaves dehydrated for 1 hr to a water potential of -1.27 MPa. The ribosomes were separated from each other on a density gradient so that the largest ones (P) are on the right and the smallest ones (S) are on the left. The ribosomes are detected by their absorbance of ultraviolet radiation (OD 254 nm). Note the loss in P after the dehydration. After Morilla *et al.* (1973).

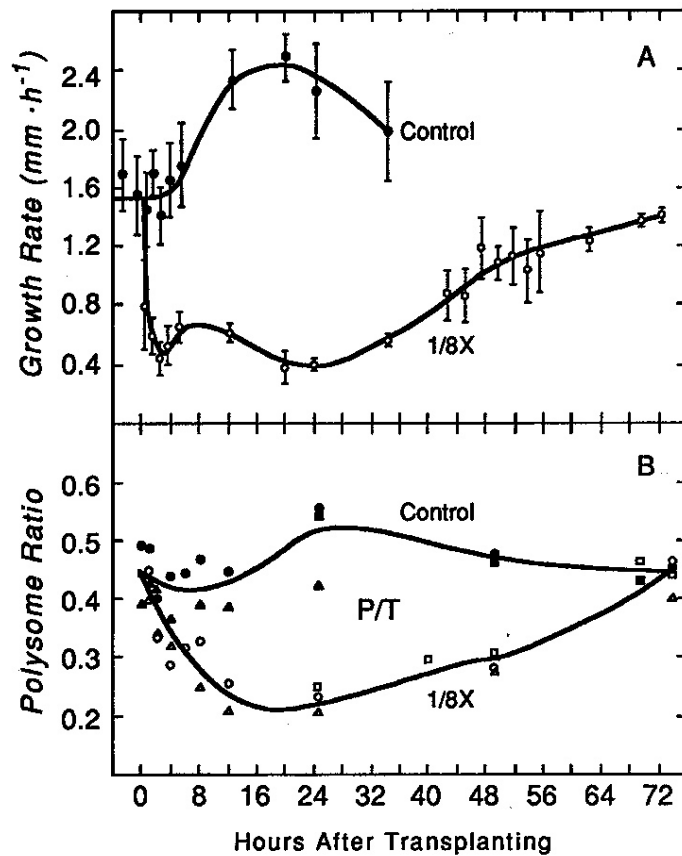


Figure 9.10 (A) Growth and (B) polyribosomal content in the elongating region of stems of intact soybean plants after transplanting to vermiculite of low water content. The dehydrated vermiculite had a water content one-eighth that of the control vermiculite. The response in control vermiculite is shown by dark points and in dehydrated vermiculite by open points. The polyribosome (P) content is shown relative to the total ribosomes (T) in the tissue. After Mason *et al.* (1988a).

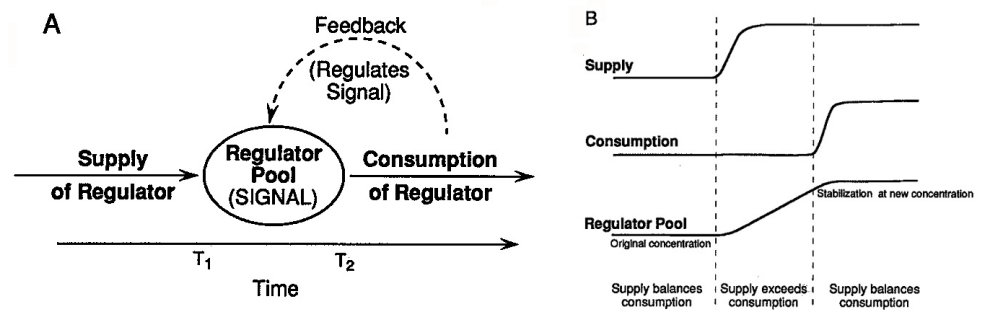


Figure 9.11 (A) Basic elements of a regulating system applicable to the control of enzyme activity in dehydrated plants. (B) Operation of the regulating system. There is a small pool of an enzyme regulator that acts as a signal. The pool is fed by a supply of the regulatory molecule (supply) and is depleted by reactions associated with the enzyme (consumption). Before time T₁, the supply is balanced by consumption. At T₁, the supply increases and the concentration of the regulator pool increases. This causes an increase in the enzyme activity at T₂, which feeds back to stabilize the regulator concentration at the new level. Because the pool size is small, it rapidly reflects changes in supply and thus responds to the flux of the regulator.

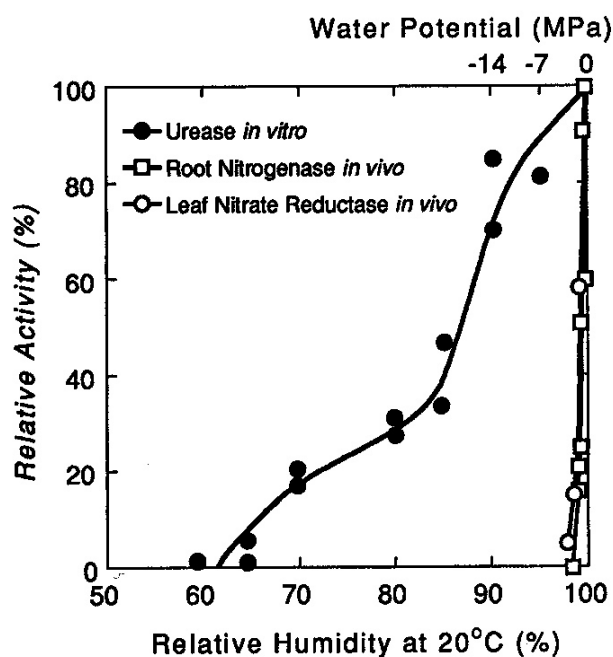


Figure 9.12 Activity of urease in equilibrium with various relative humidities, nitrate reductase exposed to various leaf water potentials, and nitrogenase exposed to various nodule water potentials. Water potentials equivalent to humidities are shown at the top of the graph (calculated according to Chapter 2). The urease catalyzes the reaction converting urea and water to NH_3 and CO_2 . The enzyme was isolated, frozen, dehydrated, mixed with dehydrated substrate, and exposed to the humidity shown (*in vitro* dehydration). The rate of reaction was determined as the enzyme mix equilibrated at each humidity. The nitrate reductase was dehydrated in the intact maize leaf (*in vivo* dehydration), then isolated, and assayed in aqueous medium. Nitrogenase was assayed *in vivo* in roots of intact soybean plants. Note the large difference in the enzyme response to *in vitro* and *in vivo* dehydration.

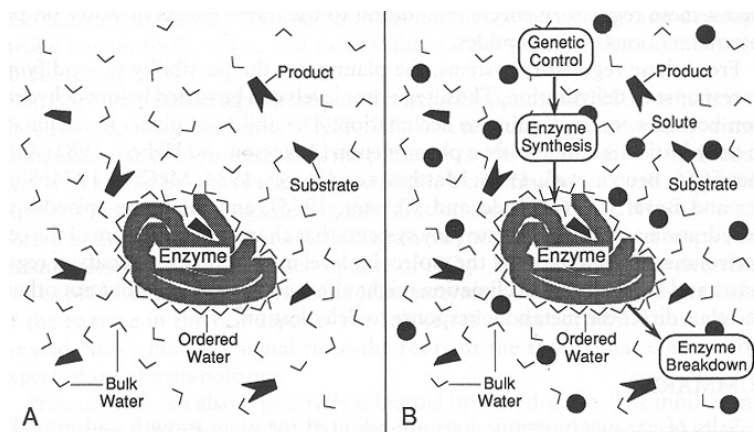


Figure 9.13 Schematic diagram of the difference between dehydration effects on isolated enzymes (A) and the same enzyme inside a cell (B). In (A), dehydration can act only on the water surrounding the enzyme and on the enzyme, substrate, or product as for urease in Fig. 9.12. In (B), dehydration has the additional possibility of altering genetic control, enzyme synthesis, enzyme breakdown, and the solute environment, as for nitrate reductase and nitrogenase in Fig. 9.12. These additional factors act as regulators of the enzyme response at dehydration levels that are less extreme than those needed for the changes in (A).

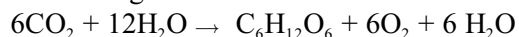
Unidad III: EL AGUA Y LA PRODUCTIVIDAD VEGETAL

Capítulo 9: FOTOSÍNTESIS Y RESPIRACIÓN - CRECIMIENTO

A) Fotosíntesis y Respiración

*** Introducción**

*** Fotosíntesis y disponibilidad de agua**



- Suelos inundados y suelos secos

*** Mecanismos de respuesta fotosintética**

- cambios en la respiración

- déficit de sustratos

- agua

- dióxido de carbono



- mecanismos de inhibición

- señales de la planta que inducen respuestas metabólicas

*** Aclimatación**

*** Recuperación**

*** Translocación**

B) Crecimiento

*** Introducción**

*** Crecimiento de células individuales**

$G = M (\Psi_p - Y)$, donde G es la tasa de crecimiento relativa (tasa de cambio en volumen por unidad de volumen celular, en $\text{m}^3 \text{s}^{-1}$), Ψ_p es la presión de turgor (MPa), Y es el potencial hídrico de campo para la mantención de turgor, y M es la extensividad de la pared celular ($\text{m}^3 \text{s}^{-1} \text{MPa}^{-1}$).

*** Crecimiento de tejidos complejos**

- Crecimiento inducido por potenciales hídricos

- Gradiente de potencial hídrico durante el crecimiento

- Ajuste osmótico y crecimiento

*** Transpiración y crecimiento**

*** Crecimiento a potenciales hídricos bajos**

- señal primaria

- cambios metabólicos

* Significados ecológicos y agronómicos

- Cambio en el uso del suelo
- Cambio en el ciclo del carbono y aumento del CO₂ atmosférico

* Causa y desarrollo de déficit hídricos

- Desarrollo de déficit a medio día
- Desarrollo de déficit al largo plazo (transpiración, disponibilidad de agua en el suelo)
- Balance hídrico en la planta

LEER

Kramer P.J. y J.S. Boyer (1995) Water Relations of Plants and Soils. Academic Press, San Diego. Capítulos 10 y 11.

Salisbury, F.B. y C.W. Ross (1994) Fisiología Vegetal. Grupo Editorial Iberoamérica, S.A., México. Capítulos 11, 12 y 13.

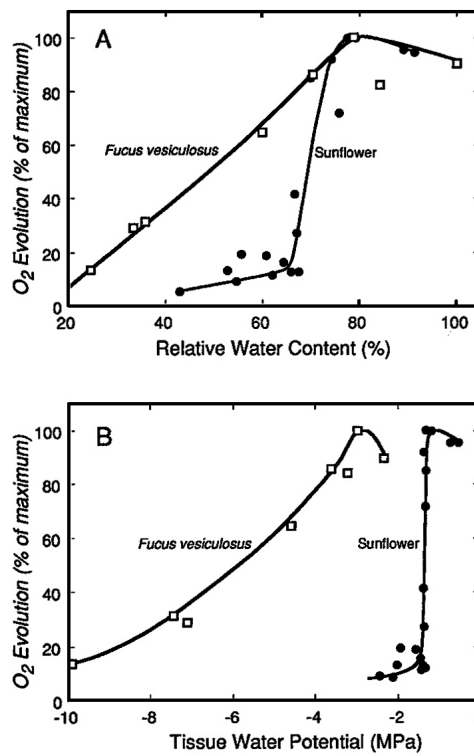
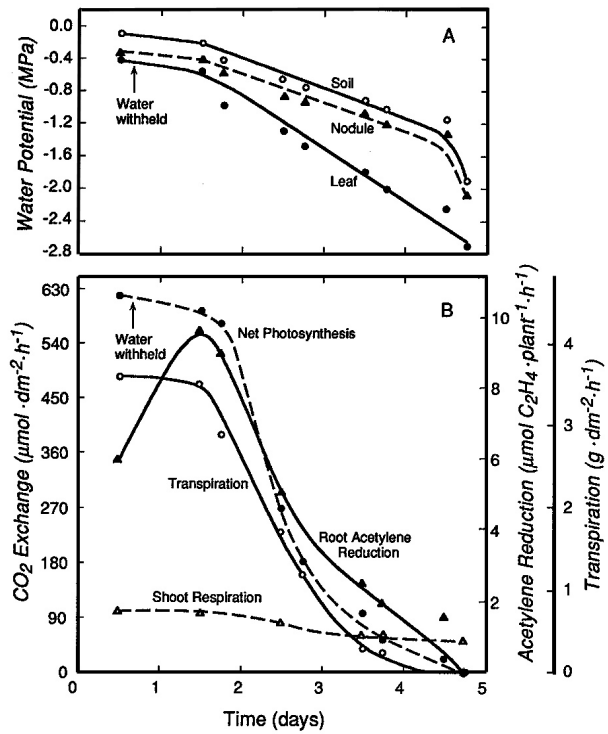
Table 10.1 Global Net Productivity by Photosynthesis in Terrestrial and Marine Plants^a

Community	Production (10 ⁹ tons dry mass · year ⁻¹)	Chlorophyll (10 ⁷ tons)	Standing biomass (10 ⁹ tons dry mass)	Area (% of surface)
Marine				70.78
Open Ocean	42	1.0	1.0	
Coastal ^b	13	0.8	2.9	
Terrestrial	118	23	1840	29.22

Note. The quantity of chlorophyll and standing plant biomass are also shown.

^aAfter Whittaker and Likens (1975).

^bContinental shelves, estuaries, seaweed beds, and reefs.



Fotosíntesis durante la deshidratación de *Fucus vesiculosus* (alga) y girasol

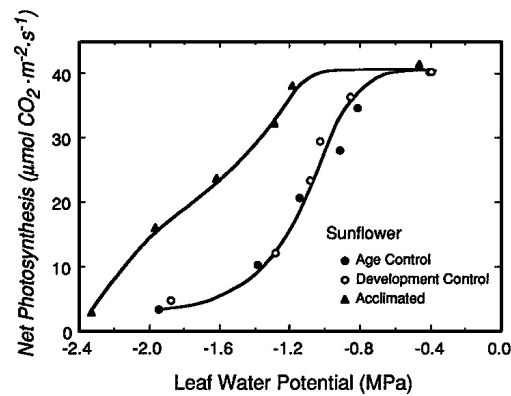


Figure 10.3 Photosynthesis at various leaf water potentials in sunflower acclimated for 2 weeks to partially dehydrated soil. The age control was given abundant water until the plants were the same age as the acclimated plants. The development control was given abundant water until the plants had developed to the same extent as the acclimated plants. After Matthews and Boyer (1984).

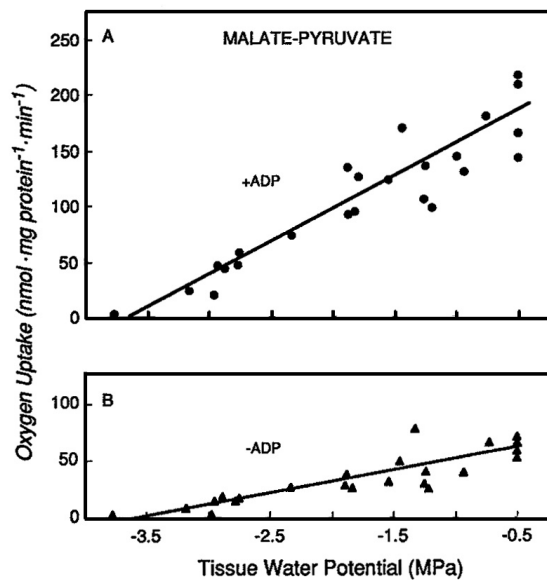


Figure 10.4 Mitochondrial respiration after isolation from maize mesocotyls having various tissue water potentials. Malate and pyruvate substrates were supplied at physiological concentrations. Rates were measured both with (A) and without (B) ADP in the medium. After Bell *et al.* (1971).

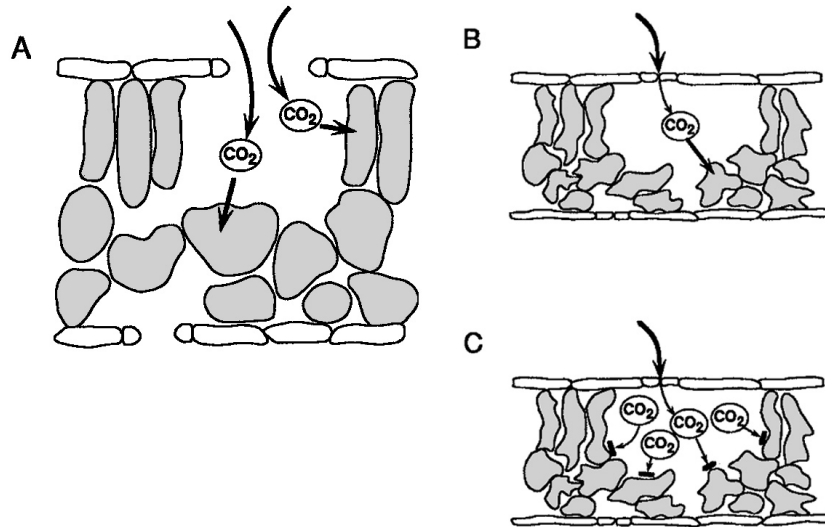


Figure 10.5 Hydrated leaf showing normal entry and use of CO₂ during active photosynthesis while stomata are open (A), dehydrated leaf showing depletion of CO₂ because of active photosynthetic metabolism while stomata are closed (B), and dehydrated leaf showing accumulation of CO₂ because of inhibited photosynthetic metabolism while stomata are closed (C). In (C), the use of CO₂ is limited more than the entry of CO₂ through the closed stomata and CO₂ builds up inside the leaf, indicating that photosynthesis is more affected by metabolism than by stomatal closure.

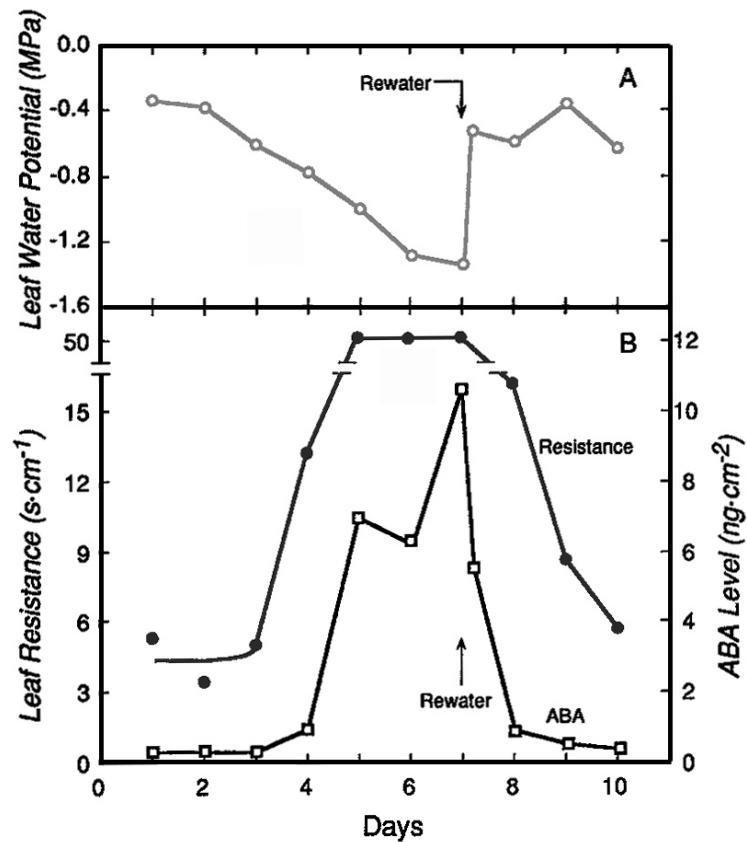


Figure 10.6 Leaf water potential (A) and abscisic acid level and leaf diffusive resistance (B) in maize from which water was withheld. The soil was rewatered on Day 7. After Beardsell and Cohen (1975).

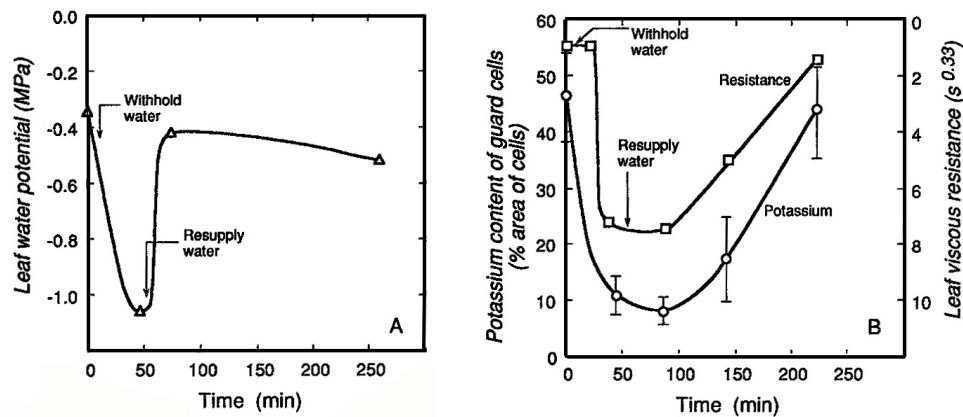


Figure 10.7 Leaf water potential (A) and guard cell K^+ content and stomatal resistance to the viscous flow of air (B) in a detached sunflower leaf from which water was withheld and resupplied. A numerically large resistance indicates stomatal closing. The authors also showed that high abscisic acid concentrations caused losses in K^+ and closure of stomata similar to those shown here for low water potentials. After Ehret and Boyer (1979).

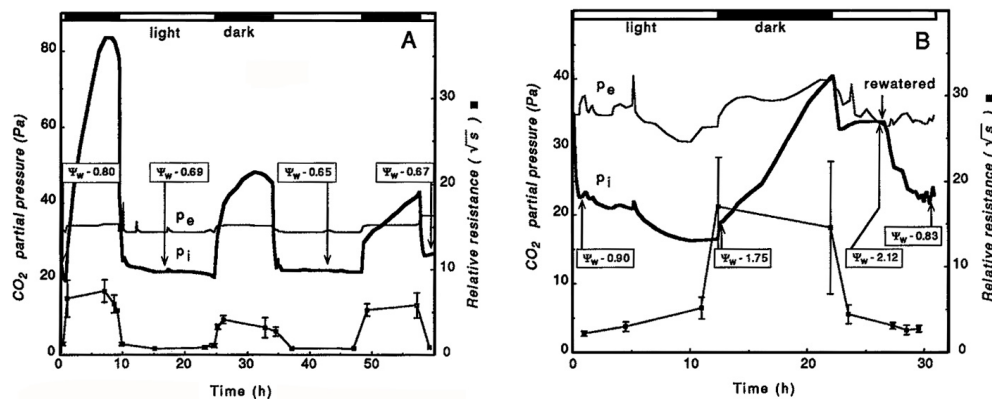


Figure 10.8 CO_2 partial pressure inside a sunflower leaf (p_i) and outside the same leaf (p_e), and stomatal resistance to the viscous flow of air through the same leaf in a hydrated control plant (A) and dehydrated plant (B). In (A), note the regular stomatal closure at night and the rise in p_i above p_e . During the day, p_i decreases below p_e because photosynthesis uses the CO_2 inside the leaf until an inward gradient forms that supplies CO_2 from the atmosphere as fast as it is used. In (B), water was withheld and p_i rises until it equals p_e . Water was resupplied as shown. Leaf water potentials are shown in boxes. The p_i was measured by equilibrating leaf CO_2 with the CO_2 in a cup attached to the underside of the leaf. After Lauer and Boyer (1992).

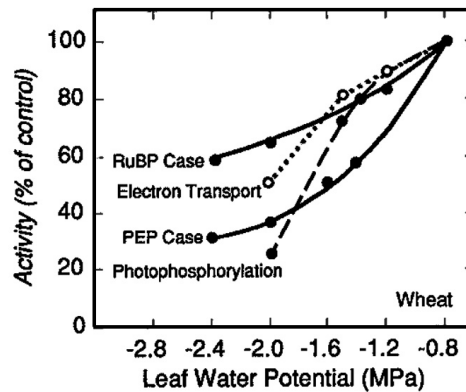


Figure 10.9 Activities for electron transport, photophosphorylation, ribulose biphosphate carboxylase (RuBP Case), and phosphoenolpyruvate carboxylase (PEP Case) in extracts from wheat leaves having various water potentials. Electron transport, photophosphorylation, and RuBP Case are chloroplast activities. PEP Case is a cytoplasmic enzyme in this species. Activities were measured in standard media. After Mayoral *et al.* (1981).

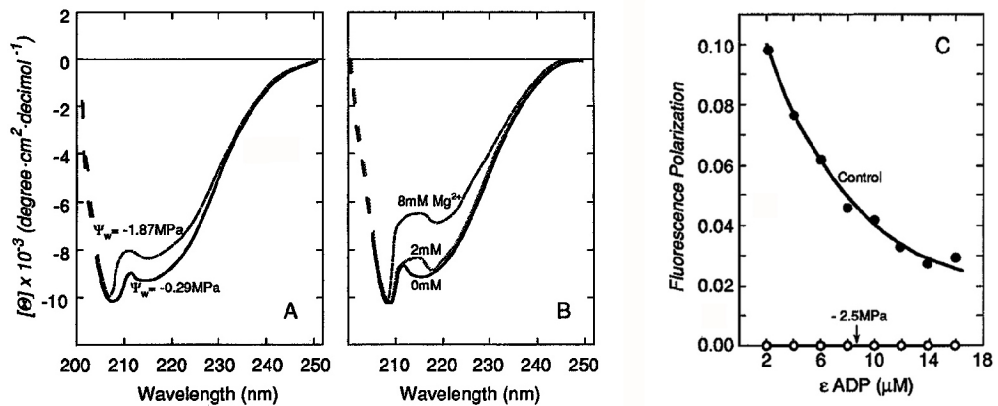


Figure 10.11 Conformation of chloroplast coupling factor (ATP synthetase) isolated from spinach leaves having high or low water potentials (A), or isolated from solutions having various Mg^{2+} concentrations (B). Isolation from Mg^{2+} solution simulated isolation from leaf. The 2 mM Mg^{2+} represents the concentration in control chloroplasts and 8 mM the possible concentration in dehydrated chloroplasts. Conformation was determined from differences in circular dichroism spectrum shown (θ). Note the similar conformation change caused by a low water potential and high Mg^{2+} concentration. (C) Binding of ADP analog (ϵ ADP) to coupling factor isolated from spinach leaves having high or low water potentials. The ϵ ADP binds to the active site of the enzyme. High binding is shown by high polarization at left that decreases with saturation of sites in control. Binding was undetectable when the coupling factor was isolated from leaves having a water potential of -2.5 MPa. After Younis *et al.* (1979) and Younis *et al.* (1983).

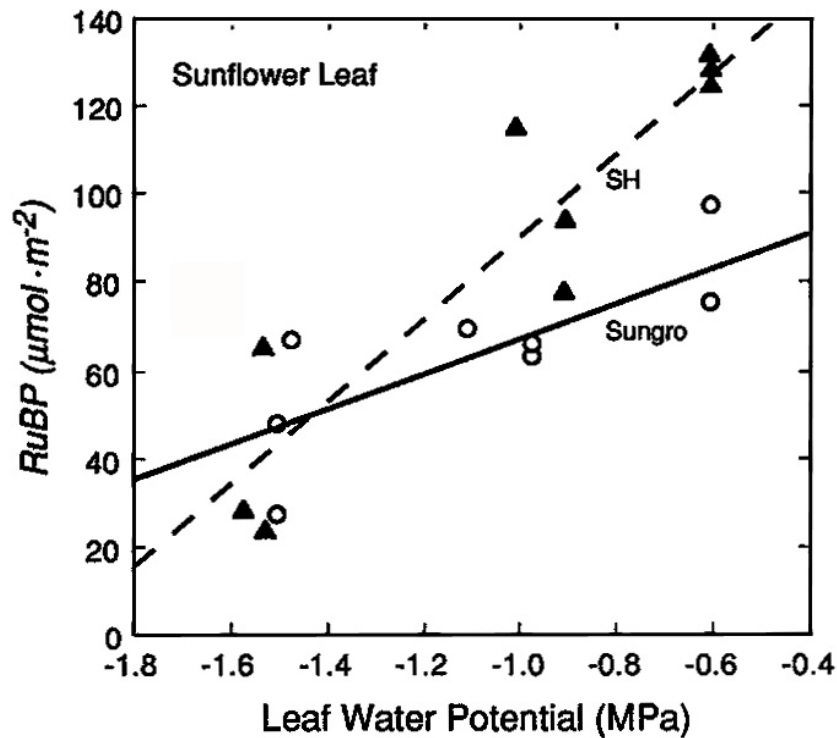


Figure 10.12 Ribulose biphosphate (RuBP) concentrations in leaves of two sunflower cultivars (SH and Sungro) from which water was withheld. RuBP is regenerated in the carbon reduction cycle (Calvin cycle) with an input of products of the photochemical reactions. Decreased RuBP levels indicate a block may be present in the photochemical reactions or carbon reduction cycle. From Gimenez *et al.* (1992).

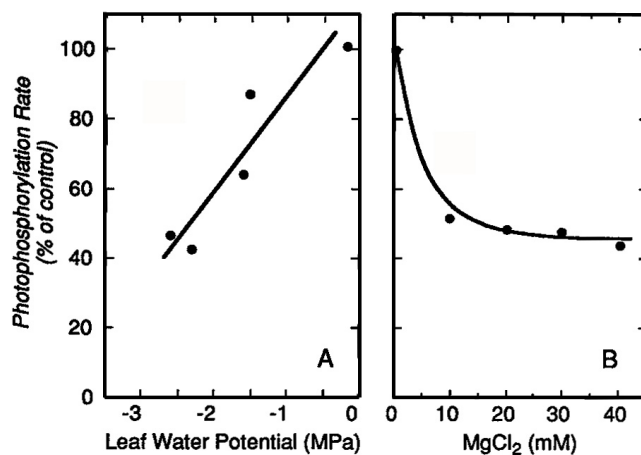


Figure 10.13 Photophosphorylation in thylakoid membranes isolated from spinach leaves having various water potentials (A) or isolated from solutions having various Mg^{2+} concentrations (B). Isolation from Mg^{2+} solutions simulated isolation from the leaf. Higher Mg^{2+} concentrations are expected at lower leaf water potentials. Concentrations of Mg^{2+} are normally about 3 mM around the thylakoid membranes in the light and could be significantly higher during dehydration. After Younis *et al.* (1979) and Younis *et al.* (1983).

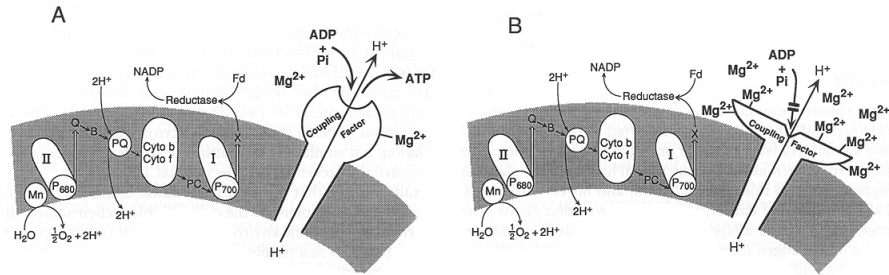


Figure 10.14 Ionic environment around chloroplast thylakoid membrane in a hydrated cell (A, high water potential) or a dehydrated cell (B, low water potential). Note the higher concentration of solutes in (B) than in (A) leading to the binding of more solute (Mg^{2+}) to the coupling factor protein required for photophosphorylation and the changed conformation of the coupling protein associated with a blocked access of ADP to the active site in (B). The binding of Mg^{2+} may account for the persistence of chloroplast inhibition after the membranes are isolated from the cell and for the changes in conformation of the membrane observed *in vivo* and *in vitro*.

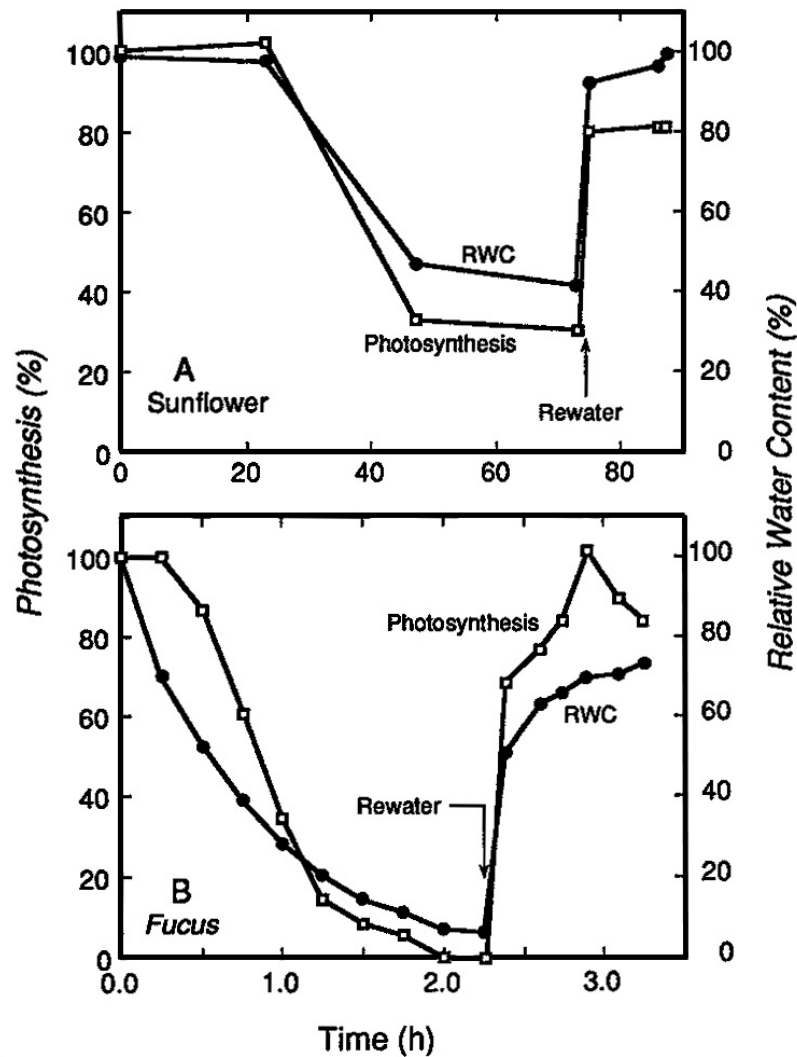


Figure 10.15 Photosynthesis and relative water content of sunflower (A) or *Fucus vesiculosus* (B) at various times after withholding and resupplying water. Sunflower was rehydrated by watering the soil whereas *Fucus* was rehydrated by submerging in seawater. Recovery was not observed in sunflower if relative water contents became as low as in *Fucus*.

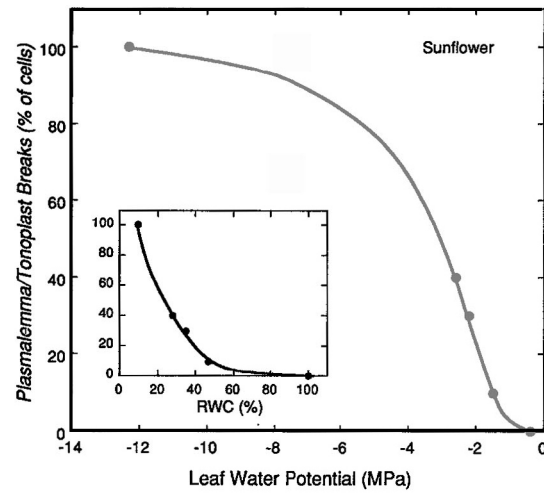


Figure 10.16 Plasmalemma and tonoplast breaks in cells of sunflower leaves having various water potentials (inset: various relative water contents). Breaks were observed under an electron microscope in tissue fixed at the same water potential as in the leaf. After Fellows and Boyer (1978).

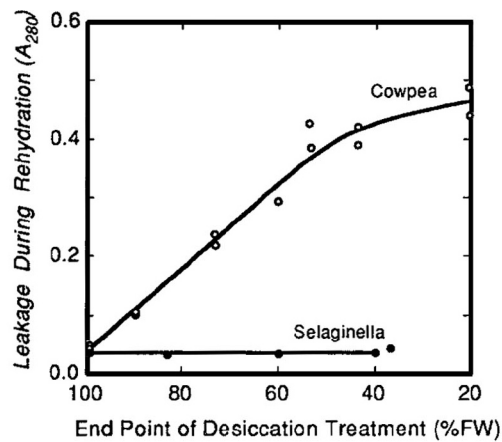
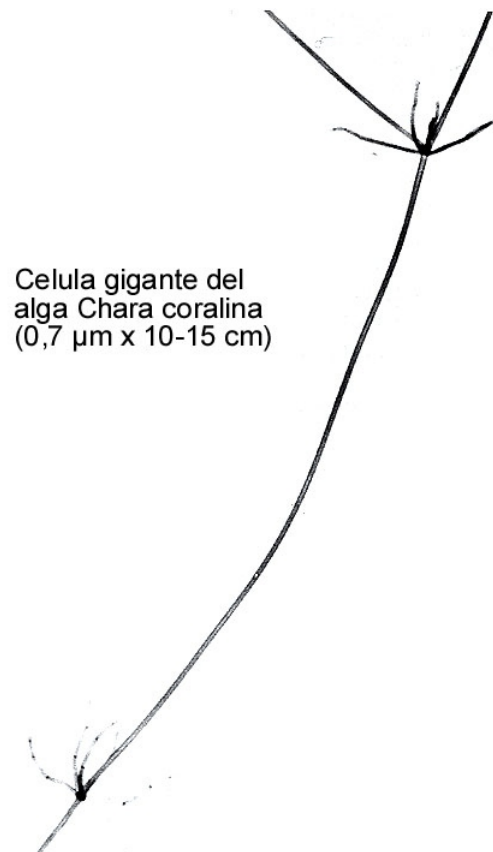


Figure 3.3 Leakage of proteins from leaf cells that had been desiccated to varying degrees and rehydrated. Proteins were detected in the rehydrating solution by measuring the absorbancy of the solution at $280 \mu\text{m}$ (A_{280}) after 20 min. Desiccation-sensitive cowpea showed a large leakage but desiccation-tolerant *Selaginella* did not. Adapted from Leopold *et al.* (1981).

Table 11.1 Growth Rates in Various Parts
of a Maize Plant^a

Part	Growth rate (mm · hr ⁻¹)
Leaf	4.0
Style (silk)	2.6
Stem	1.3
Root (nodal)	1.1

Note. The rates were measured for 24 hr in plants supplied with adequate soil water and growing in day temperatures of 30°C and night temperatures of 20°C. Root and leaf rates are from the same plants and style and stem rates are from older plants.



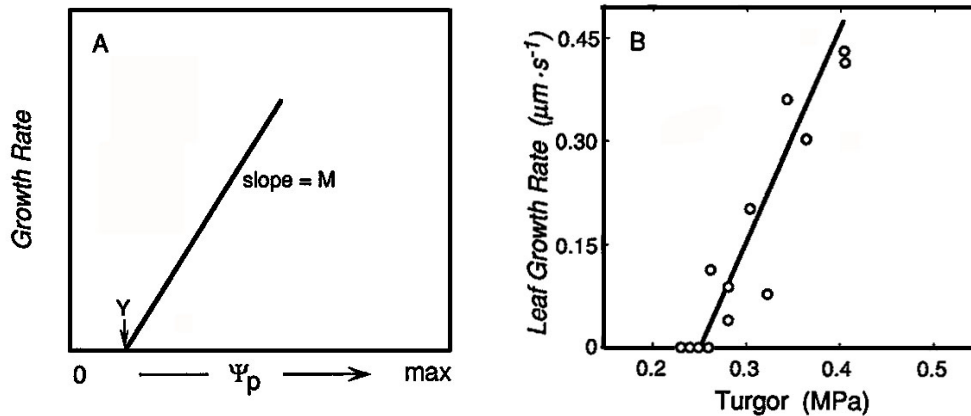


Figure 11.2 Relationship between turgor and growth. (A) Lockhart relationship showing yield threshold Y and wall extensibility M (slope of the line) obtained when the growth rate G is plotted as a function of the turgor Ψ_p . (B) Experiment showing growth of leaves at various turgor pressures in sunflower (from Matthews *et al.*, 1984). The experiment was done by withholding water from the soil and measuring growth for several days.

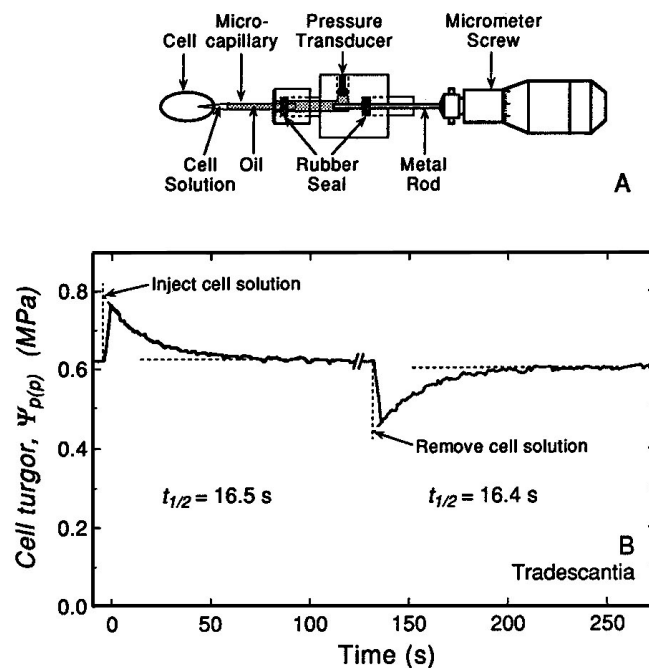


Figure 3.7 Pressure probe (A) for measuring and changing the turgor pressure inside plant cells (B). The probe is mostly filled with silicone oil (shaded), and a meniscus is visible between the cell solution and the oil in the tip of the microcapillary. When there is liquid continuity between the cell and the microcapillary, the pressure in the cell extends into the microcapillary and is sensed by the pressure transducer. The accurate measurement of cell turgor requires the meniscus to be returned to the position prior to entering the cell. Turning the micrometer screw forces the metal rod into the oil and moves the meniscus by changing the internal volume. The volume change causes the pressure to change as solution is injected into or removed from the cell (B) in a *Tradescantia* leaf. The volume of solution removed from or injected into the cell is determined from the distance the meniscus moves and the diameter of the microcapillary. Adapted from Tyerman and Steudle (1982).

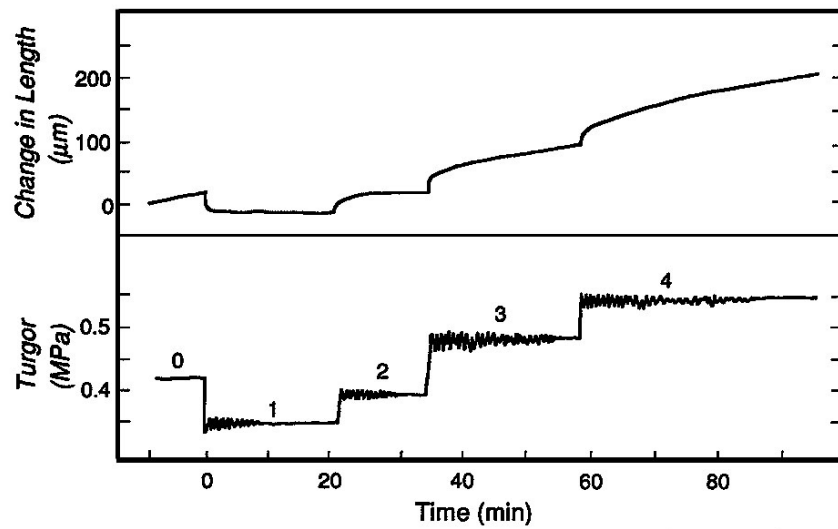


Figure 11.3 Relationship between enlargement and turgor pressure in *Chara*. Note that growth was zero at turgors 1 and 2 but growth occurred at turgors above a threshold (turgors 0, 3, 4). However, above the threshold, variations in turgor did not affect the growth rate. The initial shrinkage or swelling at each turgor step was caused by rapid elastic effects of the pressure change not related to growth. The turgor was changed by injecting the cell solution into the cell or removing the solution from the cell. After Zhu and Boyer (1992).

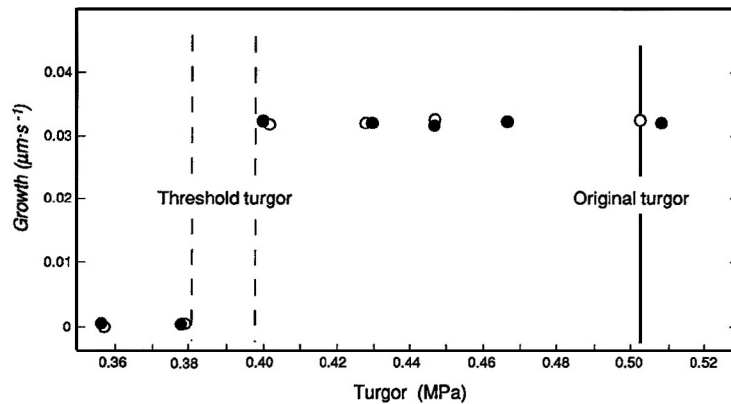


Figure 11.4 Growth at various turgor pressures in a *Chara* cell in an experiment similar to that in Fig. 11.3. The turgor pressure extends from zero to the original pressure in the cell, which was the maximum that could develop because of the cell osmotic potential. The turgor pressure was varied by injecting or withdrawing the cell solution as in Fig. 11.3. Solid points, injections; open points, withdrawals. Note that there is no growth at low pressures and that growth begins abruptly at a threshold pressure of 0.38 to 0.40 MPa. The growth rate remains constant at any pressure between this threshold and the original (maximum) pressure (adapted from Zhu and Boyer, 1992).

Table 11.2 Potentials Measured in the Cell Interior and in the Cell Exterior (Apoplast)

		Interior (MPa)		Apoplast (MPa)	
		Ψ_s	Ψ_p	Ψ_s	Ψ_p
<i>Chara</i> ^a	Growing	-0.60 ± 0.05	0.58 ± 0.06	-0.01 ± 0.00	0.0
	Mature	-0.62 ± 0.05	0.61 ± 0.05	-0.01 ± 0.00	0.0
Soybean ^{b,c}	Growing	-0.68 ± 0.05	0.42 ± 0.02	-0.04 ± 0.01	-0.24 ± 0.04
	Mature	-0.56 ± 0.02	0.50 ± 0.02	-0.04 ± 0.01	0.00 ± 0.00

Note. Measurements are in individual cells of intact plants: internode cells in *Chara* and stem cells in soybean. *Chara* cells were bathed in growth medium whereas soybean seedlings had roots in wet vermiculite and shoots in saturated air that prevented transpiration. For *Chara*, the cell apoplast was in growth medium under atmospheric pressure which is defined to have Ψ_p of zero. For soybean, apoplast Ψ_p was measured and was lower than zero (Nonami and Boyer, 1987).

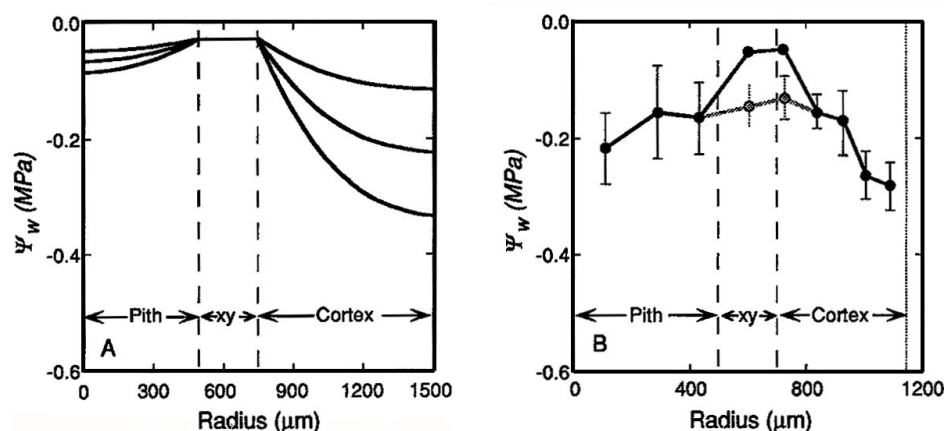


Figure 11.5 Water potential gradient in the growing region of soybean stems. The plants were grown in the dark in a water-saturated atmosphere so that the water potentials reflected only those for the growth process. The stem has a central pith in the center of a vascular cylinder and has cortical tissue covered by an epidermis on the outside, as shown. (A) Water potentials calculated at various positions along the radius of the stems assuming transport and anatomical properties characteristic of plant cells (adapted from Molz and Boyer, 1978). (B) Water potentials measured in cells at various positions along the radius of the stems by determining cell turgor and cell osmotic potential and summing the two. Values were corrected for mixing of solutions in the microcapillary used to sample for osmotic potential. Shaded values were uncorrected. From Nonami and Boyer (1993).

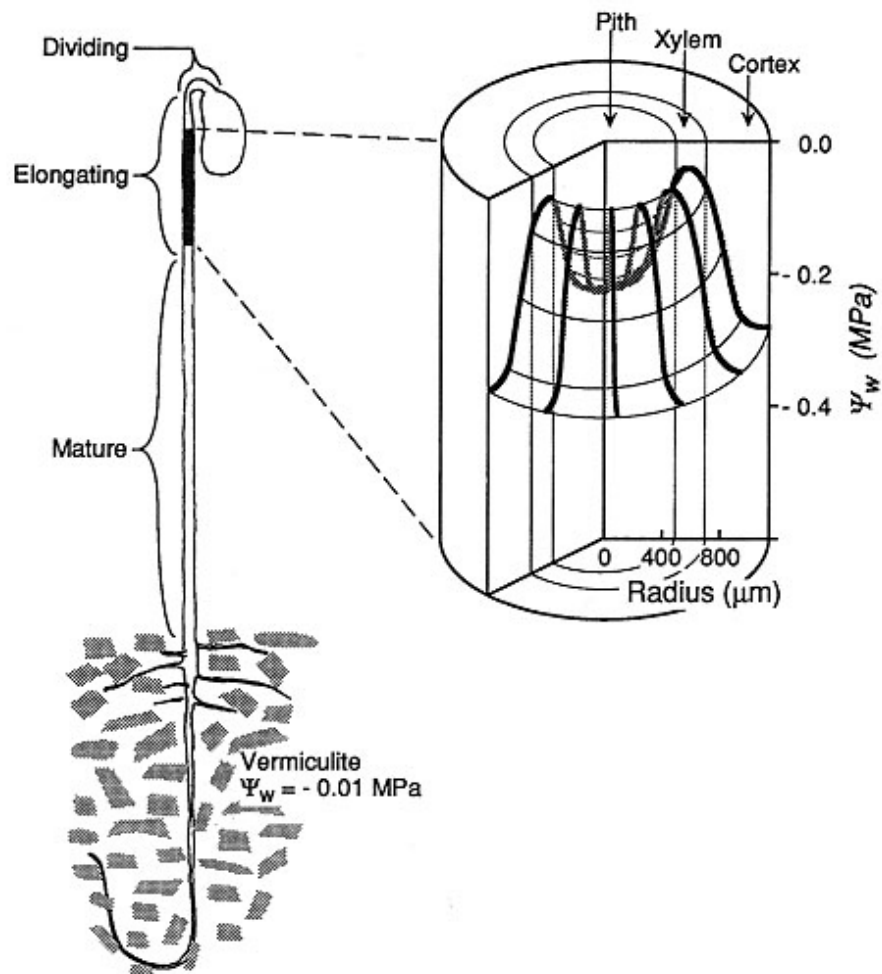


Figure 11.6 Three-dimensional water potential field induced by growth in the stem of soybean. The field is shown next to the stem in which it was measured, as in Fig. 11.5. The water potential is highest in the xylem and decreases in the surrounding pith and cortex tissues. Compare with the two-dimensional view of Fig. 11.5. After Nonami and Boyer (1993).

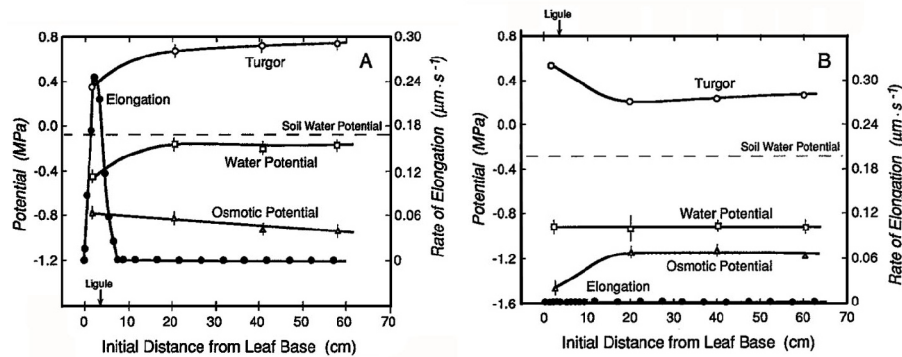


Figure 11.7 Water potential, turgor, osmotic potential, and elongation at various positions along a maize leaf at night. (A) High soil water potential. (B) Low soil water potential. Note in (A) that elongation occurred in basal tissue (left part of figure) but not in mature tissue far from the base (to the right in the figure). There was a low water potential in the basal tissue but not in the mature tissue, and a similar pattern was observed for the turgor pressure. The water potential of the mature tissue was similar to that of the soil (dashed line), indicating that the intervening xylem had a similar water potential. Thus, the low Ψ_w of the elongating tissue at the leaf base occurred in the tissues outside of the xylem. In (B), the decreased soil water potential prevented leaf elongation. Wilting was observed in the mature blade beyond 30 cm from the leaf base, and turgor pressure was low. There was a large decrease in the water potential of all leaf tissues compared to (A), and there was no difference in water potential between the elongating and mature tissue, indicating that the favorable water potential gradient for growth shown in (A) had collapsed. However, turgor pressure remained high in the elongating tissues. The collapse of the gradient thus appeared to inhibit leaf growth, and the turgor could not account for the effect. Adapted from Westgate and Boyer (1985b).

Potencial hídrico de noche y día en un tejido en elongación (base) y un tejido maduro (tip) en hoja de maíz

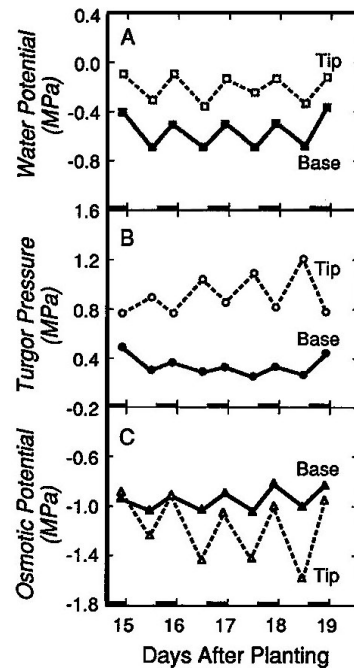


Figure 11.8 Night and day water potential, turgor pressure, and osmotic potential in the elongating tissue (leaf base, closed symbols) and mature tissue (leaf tip, open symbols) of a maize leaf. Night is shown by black bars on the X axis, day by open intervals between black bars. In (A), there was a lower water potential in the growing base than in the mature tip at night when transpiration was negligible and during the day when transpiration occurred. Assuming the mature tip indicated the xylem water potential (see text), the gradient between the xylem and growing base favored water uptake from the xylem during night and day. In (B), there was less turgor pressure in the growing base than in the mature tip during night and day. In (C), the osmotic potential tended to be lower (more negative) in the tip than in the base during the day, presumably because solute was produced by photosynthesis in the tip but not the base. However, the osmotic potential also was lower during the day than at night in the base, reflecting osmotic adjustment. Adapted from Westgate and Boyer (1984).

Crecimiento a bajo potencial hídrico.

Plántulas de poroto de soya germinada en oscuridad y transplantadas a bajo potencial hídrico. Reinicia crecimiento moderado a partir del día 2

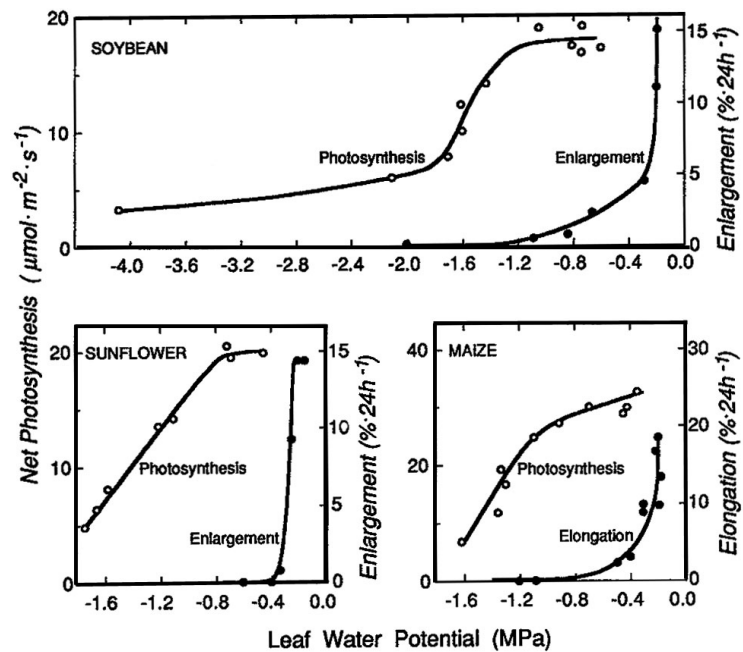
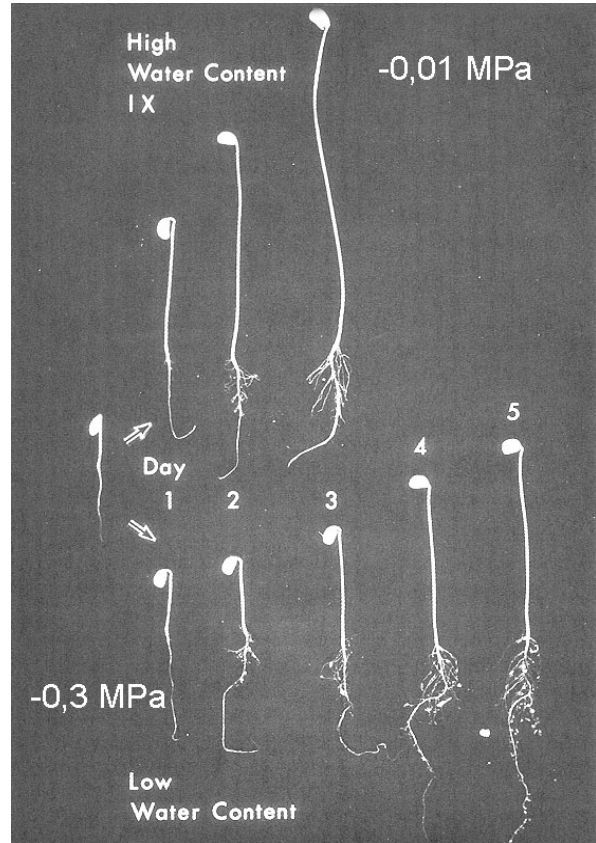


Figure 11.10 Leaf enlargement and photosynthesis at various leaf water potentials in soybean, sunflower, and maize plants. After Boyer (1970).

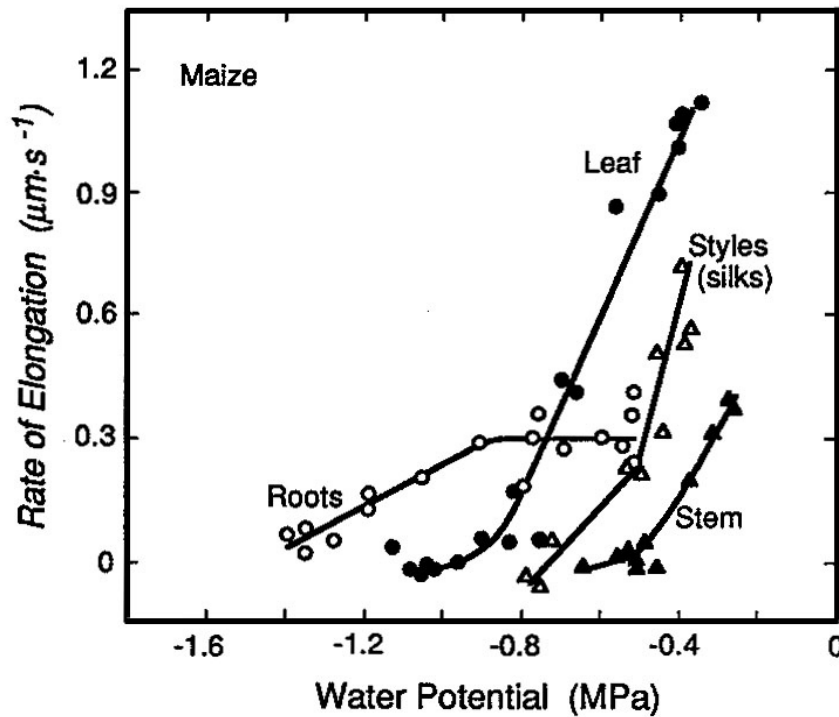


Figure 11.11 Elongation of various maize organs at various water potentials of the elongating tissues. At low water potentials, elongation often became negative, indicating that the tissue shrank.

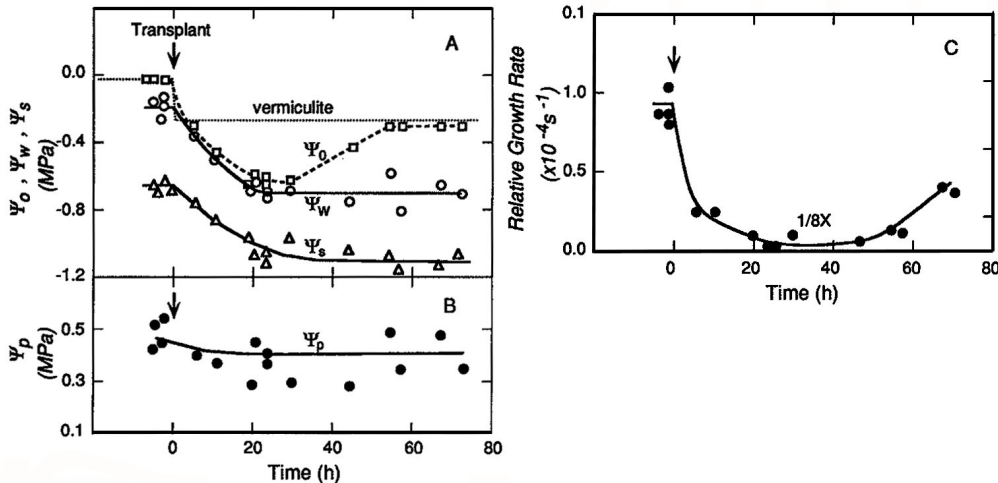


Figure 11.12 Tissue water potentials (Ψ_w), osmotic potentials (Ψ_o), turgor pressures (Ψ_p), and relative growth rates in the elongating region of soybean stems after transplanting to $1/8 \times$ vermiculite as in Fig. 11.9. Also shown are water potentials of the vermiculite (dotted line) and the basal nongrowing stem tissue (Ψ_o , dashed line). In (A), note that the basal tissue had Ψ_o close to that of the vermiculite before transplanting and at the end of the experiment, indicating that the Ψ_o monitored the xylem water potential. Before transplanting, the Ψ_w was below Ψ_o , indicating that a favorable water potential gradient existed for water uptake for growth. After transplanting, Ψ_o became similar to Ψ_w and the favorable water potential gradient collapsed. Growth was inhibited (C). Later, Ψ_o increased, reestablishing a favorable gradient and allowing growth to resume at a moderate rate. However, the lack of full recovery indicates that the growth limitation had shifted from the collapsed water potential gradient to a blockage of metabolism. (B) The tissue turgor pressure was virtually unchanged throughout the experiment. After Nonami and Boyer (1990a).

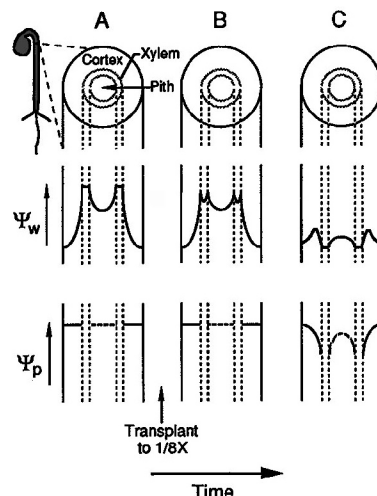


Figure 11.13 Diagrammatic representation of dynamics of water potential (Ψ_w) and turgor pressure (Ψ_p) at various radial positions in the elongating region of soybean stems before and after transplanting to dehydrated (1/8X) vermiculite as in Figs. 11.9 and 11.12. (A) Water potential gradient before transplanting when growth is rapid. In this case, turgor is uniform in the tissue. (B) Decreased xylem water potential immediately after transplanting to dehydrated vermiculite. Growth is inhibited because the gradient is inverted next to xylem and prevents water from being extracted. (C) Decreased water potentials after transplanting for several hours. Turgor is decreased next to xylem. Subsequent to (C), the gradient reestablishes and growth resumes slowly. Adapted from Nonami and Boyer (1989).

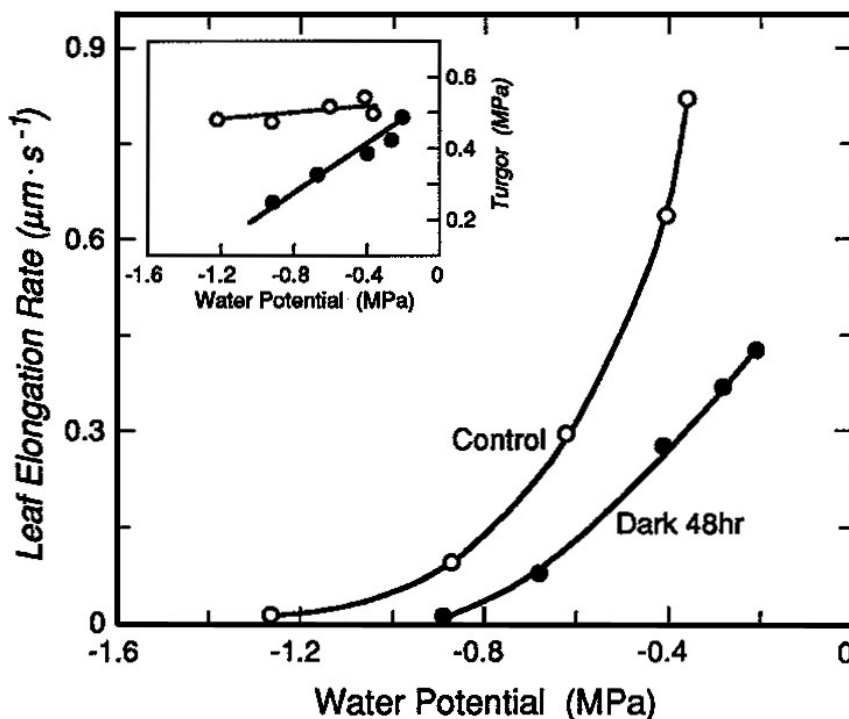


Figure 11.14 Rates of maize leaf elongation at various water potentials measured in the elongating tissues. (Inset) Turgor at various water potentials in the same elongating tissues. Darkening the plants for 48 hr (darkened points) prevented photosynthesis and decreased the transport of photosynthetic products to the elongating tissues. Osmotic adjustment was diminished and turgor was not maintained as much as in the undarkened controls (open points). After the dark treatment, leaf growth was slower and ceased at higher water potentials than in the controls.

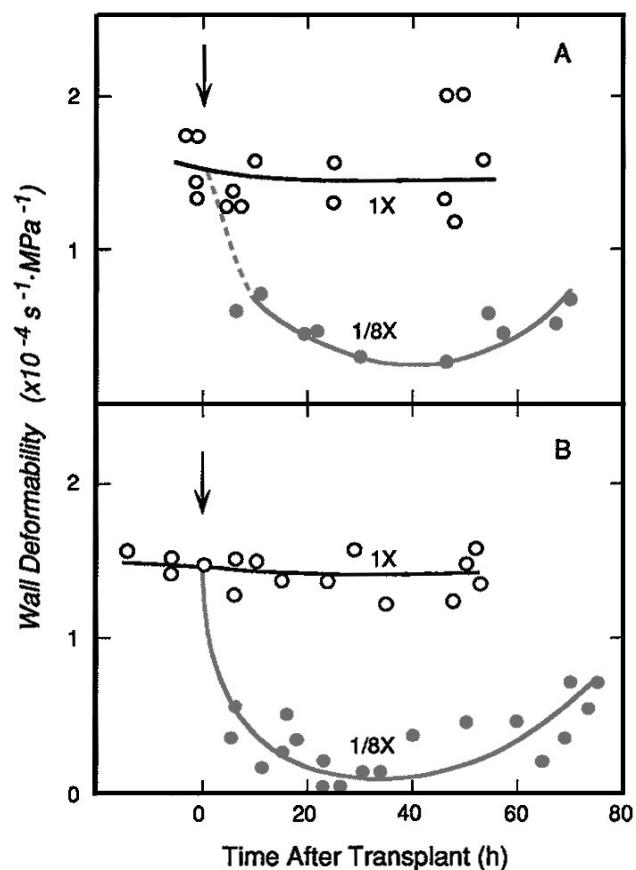


Figure 11.15 Wall deformability in elongating stem tissues at various times after transplanting soybean seedlings to vermiculite of low water content. (A) Wall deformability measured from wall relaxation after removing the water supply by excising the rapidly elongating tissues. (B) Wall deformability measured by pulling the stems in the direction of growth. Deformation was measured after subtracting the elastic component.

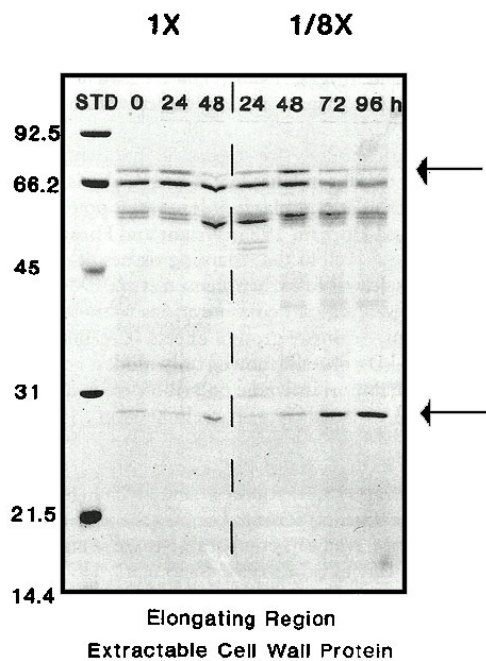


Figure 11.16 Accumulation of protein in cell walls of elongating stem tissues of soybean seedlings at various times after transplanting to vermiculite of low water content. Note the prevalence of a 28-kDa protein after several days in the drier vermiculite. From Bozarth *et al.* (1987).

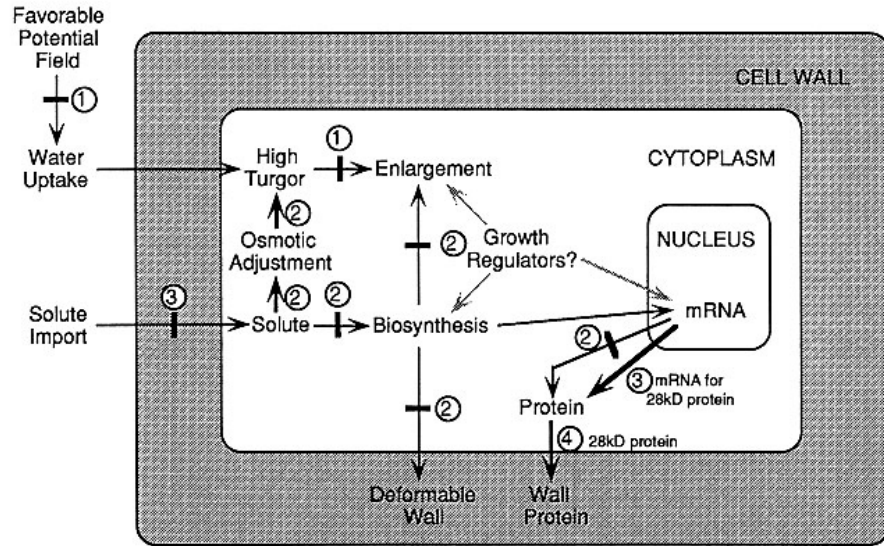


Figure 11.17 Sequence of events in elongating stem tissues after transplanting soybean seedlings to vermiculite of low water content. The order of events is shown by numbers 1–4. A block is shown by a heavy bar and enhancement is shown by increased arrow thickness. (1) Inversion of the potential field occurs first because of a decrease in water potential of the xylem which deprives the elongating cells of water and slows elongation. (2) Biosynthesis is blocked and osmotic adjustment occurs, maintaining turgor. Cell walls become less deformable. Less protein synthesis occurs. (3) Despite a decreased protein synthesis, an increased mRNA content occurs for a 28-kDa protein, a phosphatase, in soybean stems. Solute import slows, bringing import back into balance with solute use. (4) Phosphatase accumulates in cell walls. In roots, 1–3 occur rapidly but growth recovers to the control rate. The increased mRNA is for a 31-kDa protein and not the 28-kDa protein of the stem.

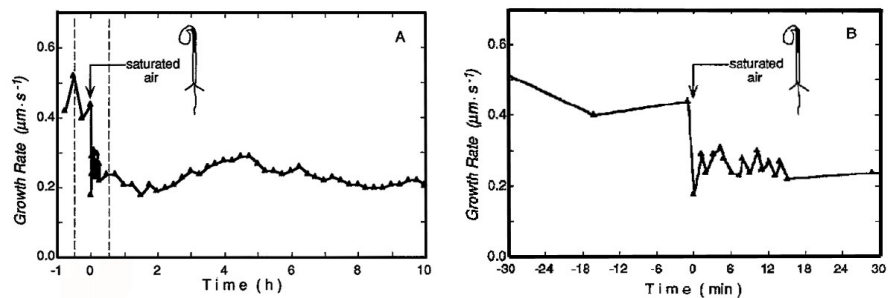


Figure 11.19 Stem growth of soybean seedling removed from the water supply and exposed to saturated air (arrow), preventing virtually all water exchange with the seedling. Continued stem growth relied on mobilization of internal water from nongrowing tissues mostly in lower parts of the stem. Expanded scale (B) shows that growth diminished immediately when the external water was removed. Adapted from Matyssek *et al.* (1991a).

Unidad III: EL AGUA Y LA PRODUCTIVIDAD VEGETAL

Capítulo 10: ESTRÉS HÍDRICO

A) Estrés hídrico

- * Distribución espacial de la sequía

- mundial
- latitudinal
- otros gradientes de sequía

- * La sequía como un factor de estrés

- índice relativo de sequía (RDI) = $WSD_{\text{actual}} / WSD_{\text{crítico}}$; donde WSD_{actual} y $WSD_{\text{crítico}}$ corresponden a déficit de saturación actual y el crítico para una especie dada, respectivamente.

- * Alteración funcional y patrones de daño

- * Sobrevivencia en sequía

- Resistente a la sequía

- Xerófitas que escapan a la sequía

- Evasión a la desecación

- absorción de agua
 - capacidad de conducción de agua
 - reducción de la transpiración
 - Área foliar específica (SLA) = $\text{área foliar} / \text{masa foliar}$
 - Peso específico foliar (PSF) = $\text{masa foliar} / \text{área foliar}$
 - Grado de succulencia = $(\text{contenido de agua a saturación}) / (\text{superficie foliar})$

- Tolerancia a la desecación

- especies sensibles a la desecación
 - especies tolerantes a la desecación

B) Efectos del déficit hídrico

- Efectos generales
- Estrés hídrico en relación a la ontogenia
- Efectos del déficit en el crecimiento
- Efectos fisiológicos (fotosíntesis, respiración en oscuridad, translocación, partición de metabolitos, apertura estomática).
- Efectos bioquímicos (metabolismo de carbohidratos, nitrógeno, hormonas)
- Efectos en el protoplasma
- Efectos del estrés hídrico sobre enfermedades y ataque de insectos
- Relación huésped - parásito

- Efectos benéficos del estrés hídrico (incrementa alcaloides, aceites aromático, proteína, resistencia de raíces, etc.)

C) Medidas del estrés hídrico

- Contenido de agua: Peso fresco / Peso seco

- Contenido Relativo de Agua (CRA)

Déficit hídrico= (Peso túrgido - Peso de Campo)/(Peso túrgido - Peso Seco).

CRA = ((Peso de Campo - Peso Seco)/ (Peso túrgido - Peso Seco))*100

- Medidas indirectas del contenido de agua

- Medidas del Potencial Hídrico

a) Equilibrio líquido

b) Equilibrio vapor

c) Termocupla - Psicrómetro $w = (RT/V) * \ln (e/e^o)$

d) Equilibrio de presión

LEER:

Larcher W. (1995) Physiological Plant Ecology. Springer, Berlin. Capítulo 6.

Jones HG 1992. Plants and microclimate. Cambridge. Capítulo 10.

Koide et al. 1991. En Pearcy et al. Plant Physiological Ecology. Capítulo 9

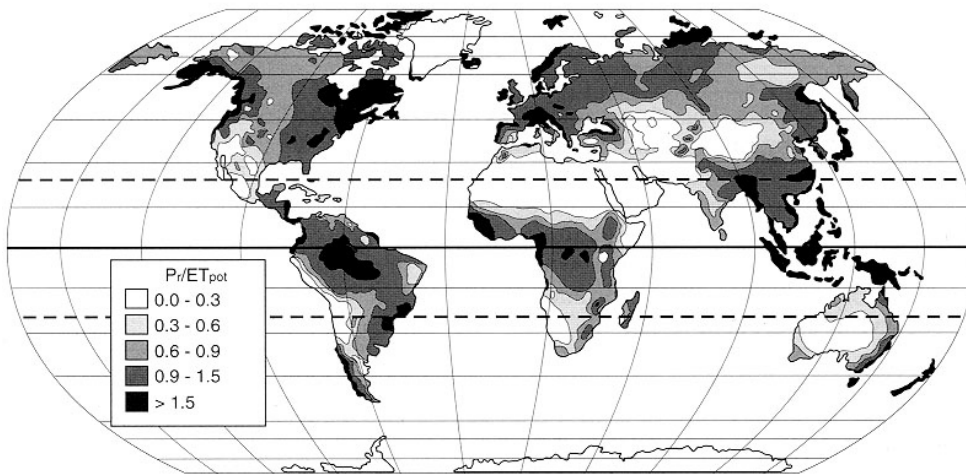


Fig. 6.54. The dry regions of the earth. The classification is based on the ratio of annual precipitation to regional potential evapotranspiration (Pr/ET_{pot}). *Arid climate* below 0.3; *semiarid* 0.3–0.6; *subhumid* 0.6–0.9; *humid* 0.9–1.5; *very humid* above 1.5. (UNESCO 1979; Box and Meentemeyer 1991)

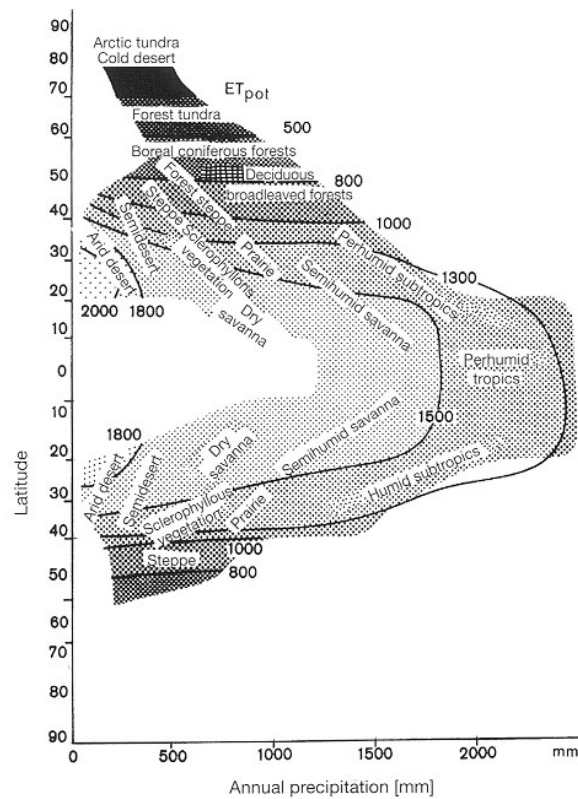
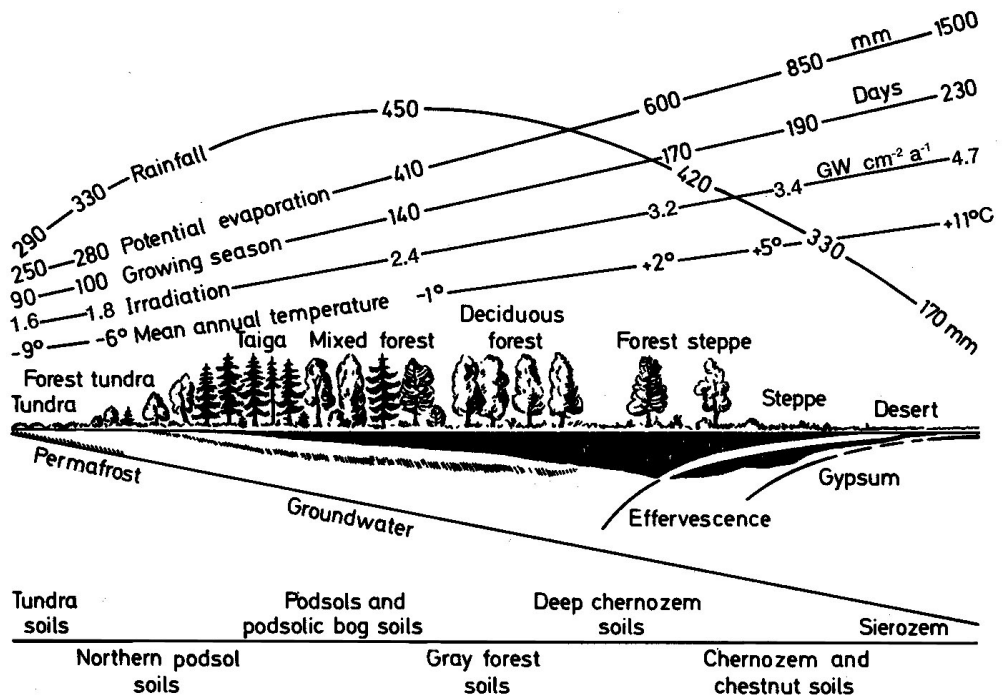
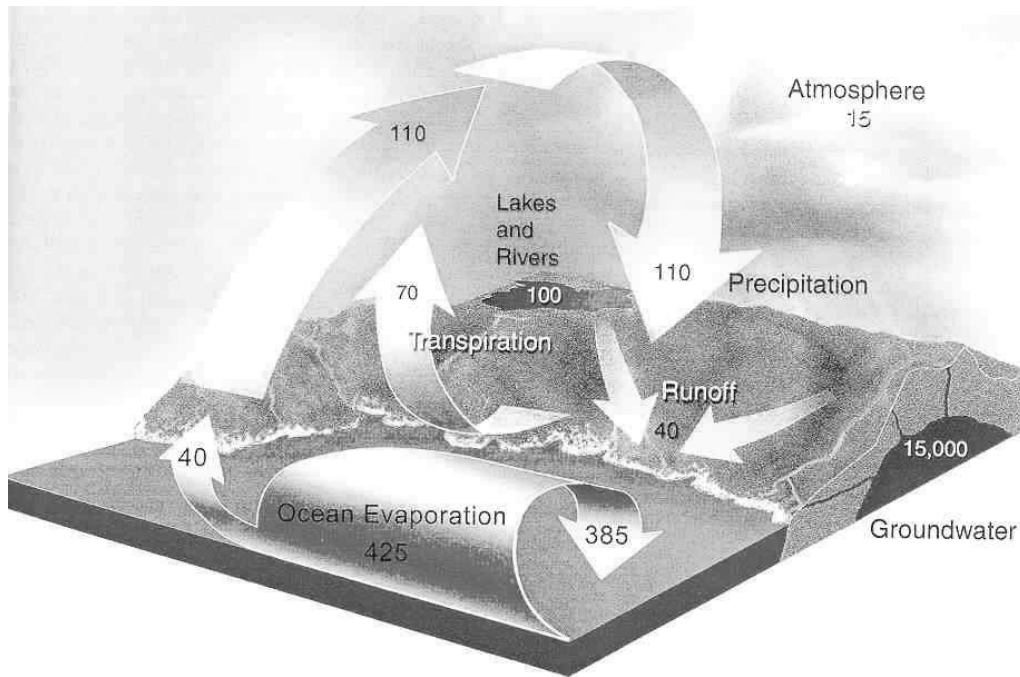
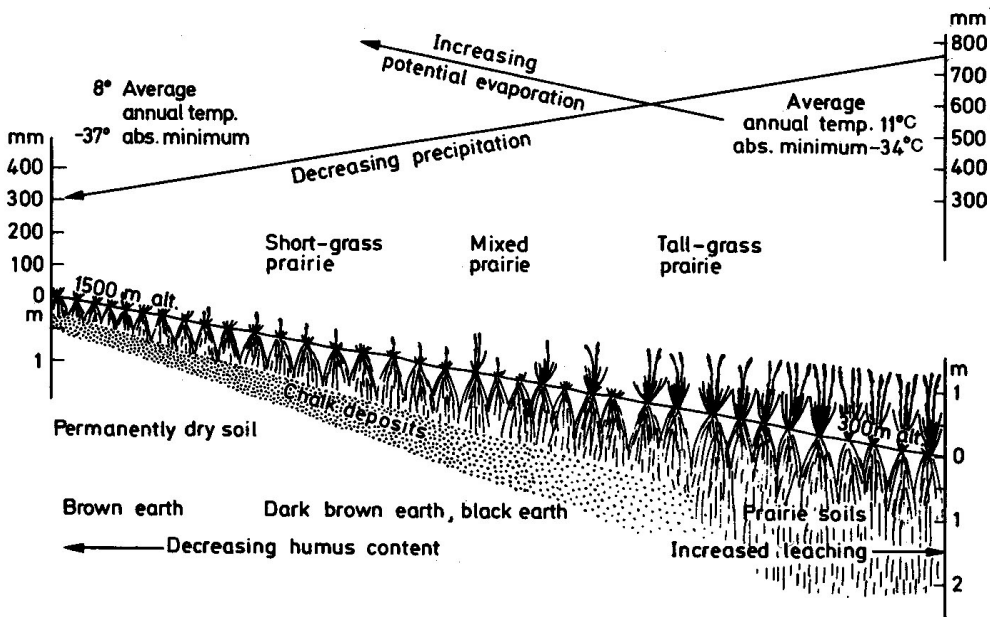


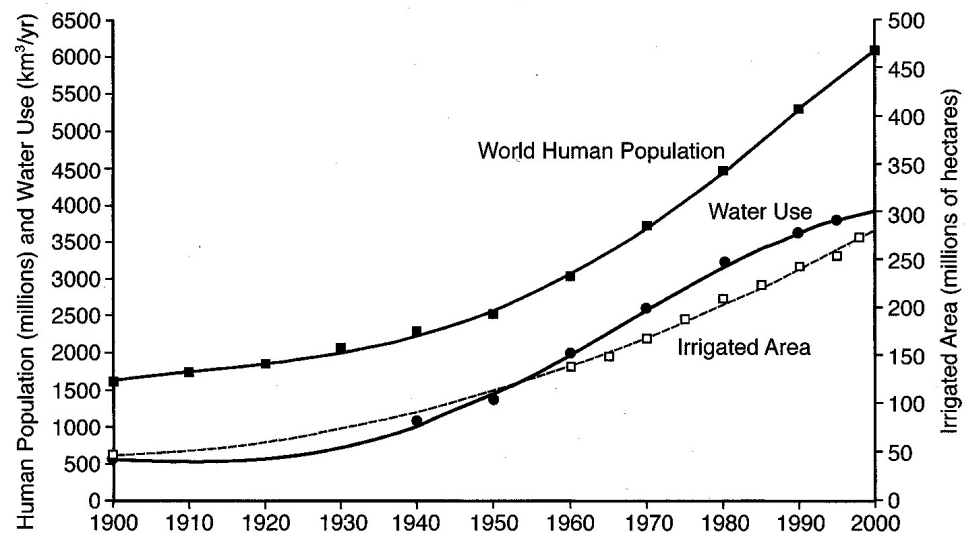
Fig. 6.55. Latitudinal distribution of annual precipitation and potential evapotranspiration (ET_{pot} in mm a^{-1}), and of characteristic plant formations. (After Schultz 1988)





Ciclo Global del Agua.

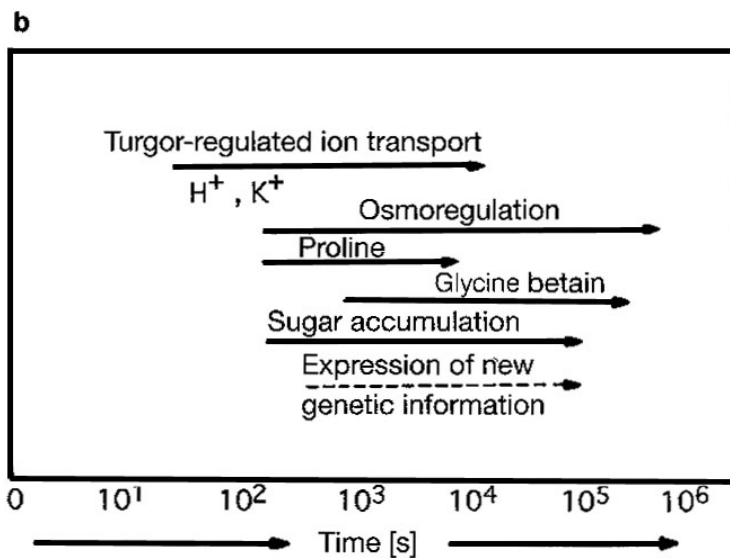
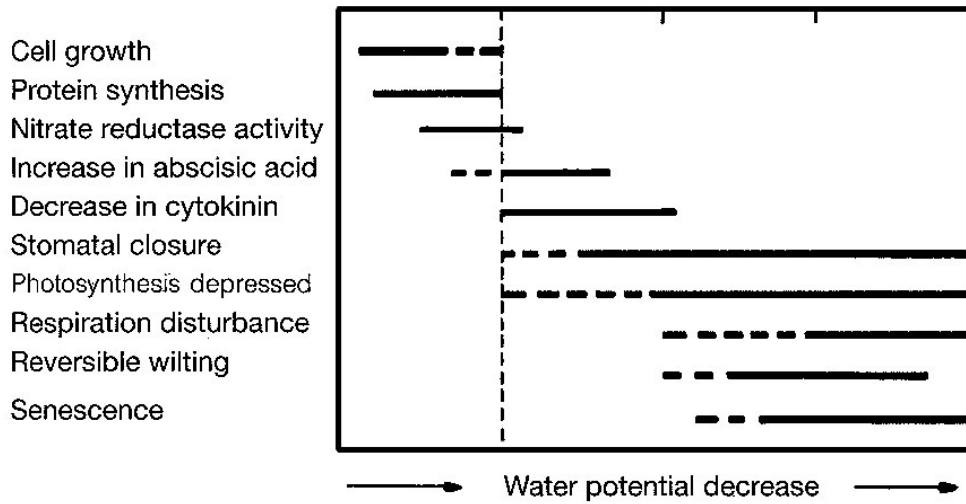
Agua Dulce: en miles de km³ (depósitos) o miles de km³/año (flujos)



Global data for human population, water withdrawals, and irrigated land area from 1900 to 2000

Table 6.6. Drought stress in plants of different types of vegetation, expressed as relative drought index (RDI %). (Data of numerous authors: Larcher 1973b; Bannister 1976; Sveshnikova 1979; Bobrovskaya 1985)

Type of vegetation	Provenance	Average maximal water saturation deficit WSD_{act} at the natural growing site in % of the WSD_{crit} at 5–10% damage
Mediterranean macchia	Dry limit	80–85
	Northern limit	40–70
Semishrubs	Mediterranean region	90–105
Ericaceous dwarf shrubs	Atlantic heaths	15–10 (88) ^a
Deciduous broadleaved trees and shrubs	Northern Europe	10–40 (50)
Herbs of the forest understorey	Northern Europe	6–25 (50)
Dicotyledonous herbs of xerothermic habitats	Central Europe	40–85
Meadow grasses	Central Europe	20–40 (75)
Steppe plants	Central Europe	50–90 (108)
	Central Asia	60–80
Desert plants		
Trees and shrubs	Karakorum	30–50
Semishrubs and forbs	Central Asia	50–65



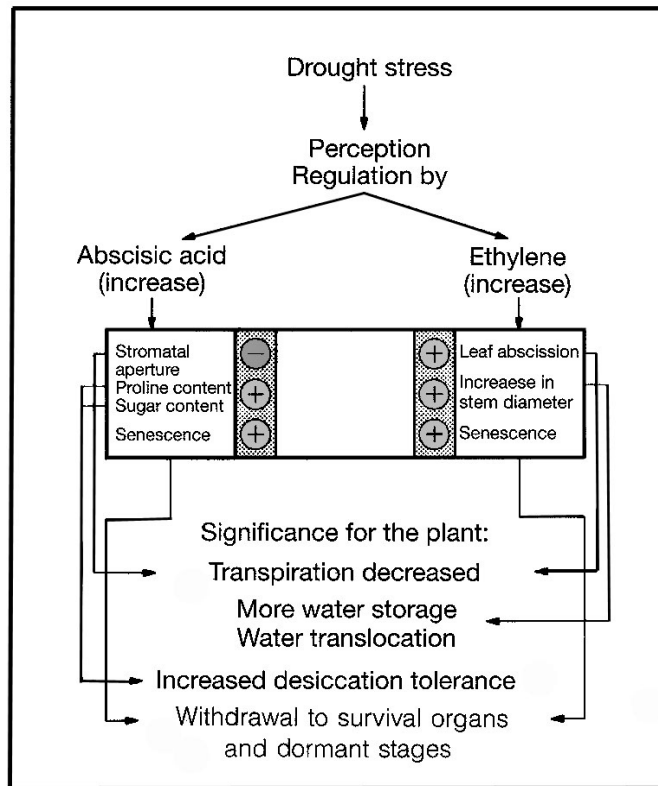


Fig. 6.59. A schematic presentation of hormonal regulation during drought stress: (+) responses enhanced, (–) reduced. (Tietz and Tietz 1982)

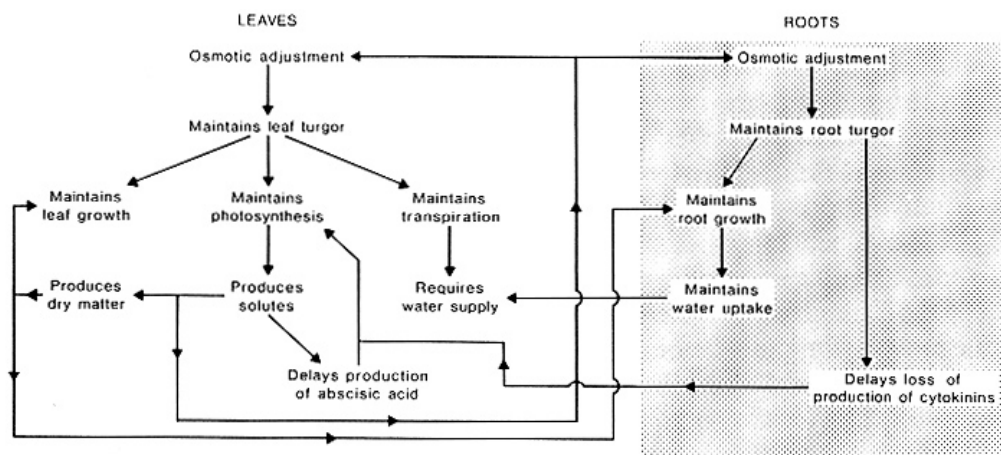


Fig. 6.60. Effects produced by osmotic adjustment in roots and leaves. (Turner 1986)

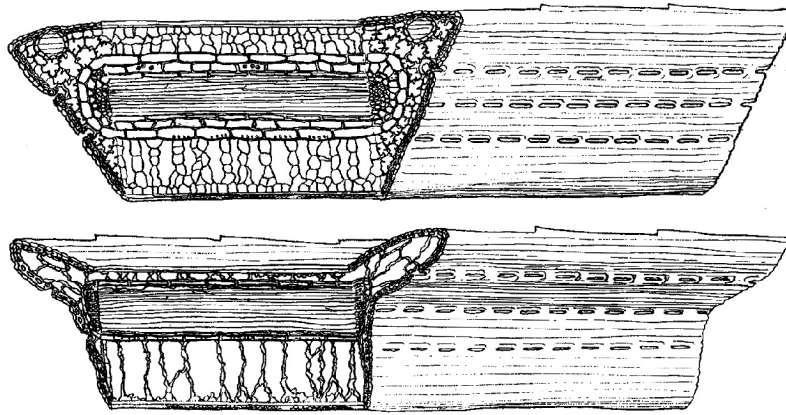


Fig. 6.61. Cell shrinkage in a needle of *Pinus strobus*. *Above* Water-saturated condition. *Below* After drying to 55% of its fresh weight. (Parker 1952)

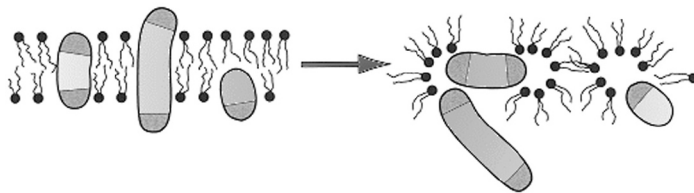
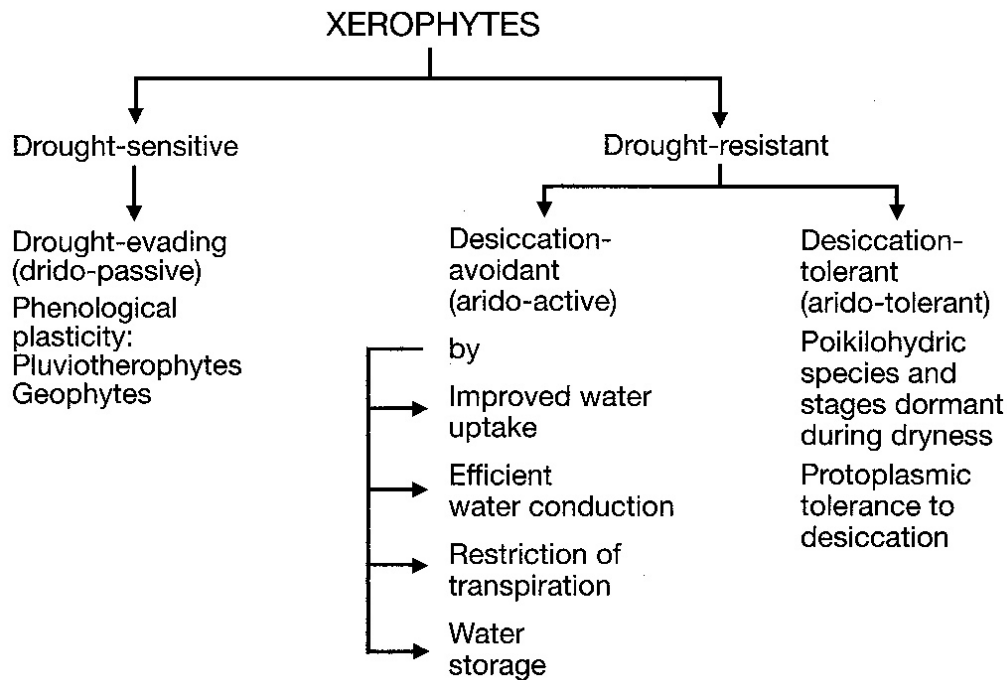


Fig. 6.62. Possible orientation of lipid and protein components in membranes in relation to their degree of hydration. Hydrated state (*left*) orientation of the hydrophilic poles (*heads*) of the phospholipids and of the membrane proteins (*stippled areas*) toward the external aqueous medium. Dehydrated state (*right*) reversed orientation of the polar ends of phospholipids and proteins toward interior water channels of the membrane. (Bewley and Krochko 1982)



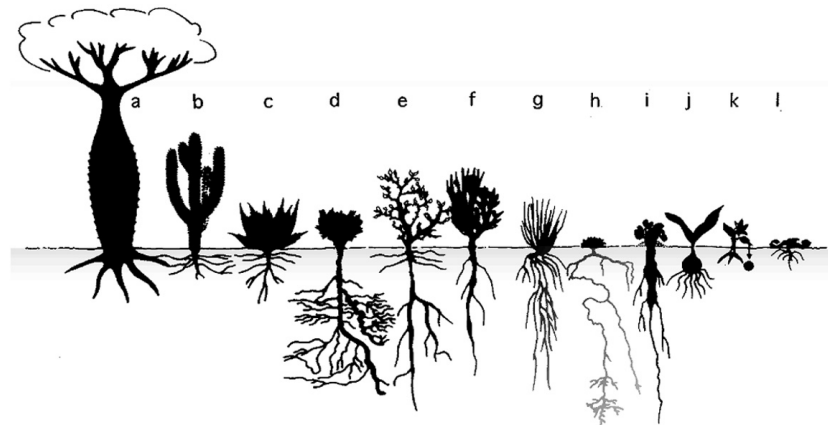


Fig. 6.64. Some examples of different growth forms allowing plants to survive drought. *a* Deciduous “bottle” trees with water-storing trunks (*Adansonia/Chorisia* type); *b* succulents storing water in the stem (Cacti/*Euphorbia* type); *c* succulents with water-storing leaves (*Agave/Crassulaceae* type); *d* evergreen trees and shrubs with deep tap root systems (sclerophyll type); *e* deciduous, often thorny shrubs (*Capparis* type); *f* chlorophyllous-stemmed shrubs (*Retama* type); *g* tussock grasses with renewal buds protected by leaf sheaths, and with wide-ranging root system (*Aristida* type); *h* cushion plants (*Anabasis* type); *i* geophytes with storage roots (*Citrullus* type); *j* bulb and tuber geophytes; *k* pluviotherophytes (annual plants); *l* desiccation-tolerant plants (poikilohydric type).

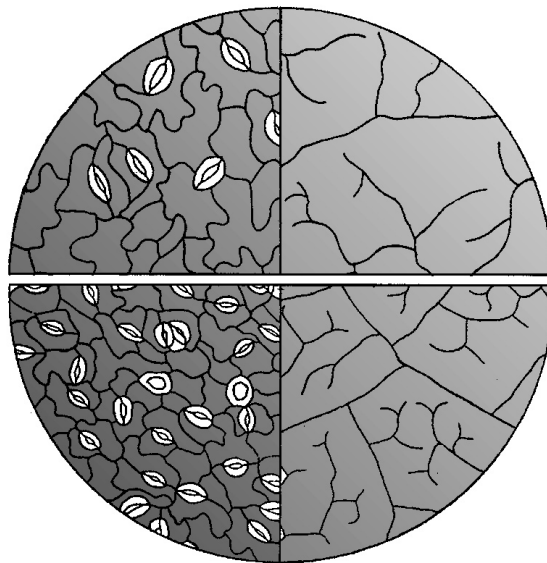


Fig. 6.65. Density of the stomata and venation on leaves of *Phaseolus vulgaris* grown with sufficient water (*top*) and with limiting soil moisture (*below*). (After Tumanov 1927). Morphological features of this kind can be the result of high endogenous levels of abscisic acid in drought stressed plants, or of treatment with ABA (Quarrie and Jones 1977; Ristic and Cass 1991)

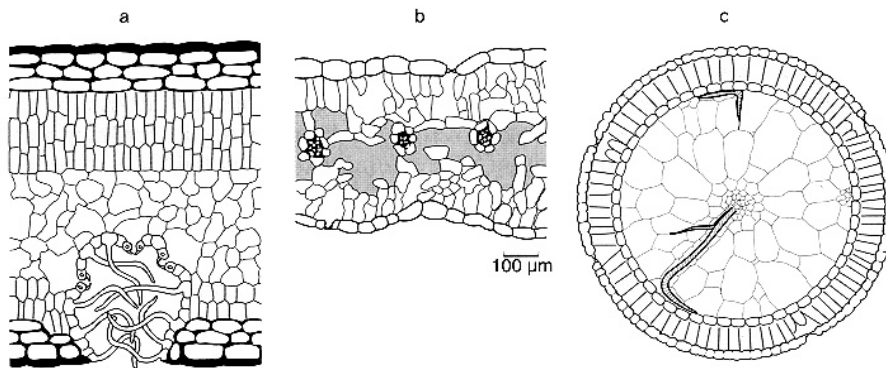
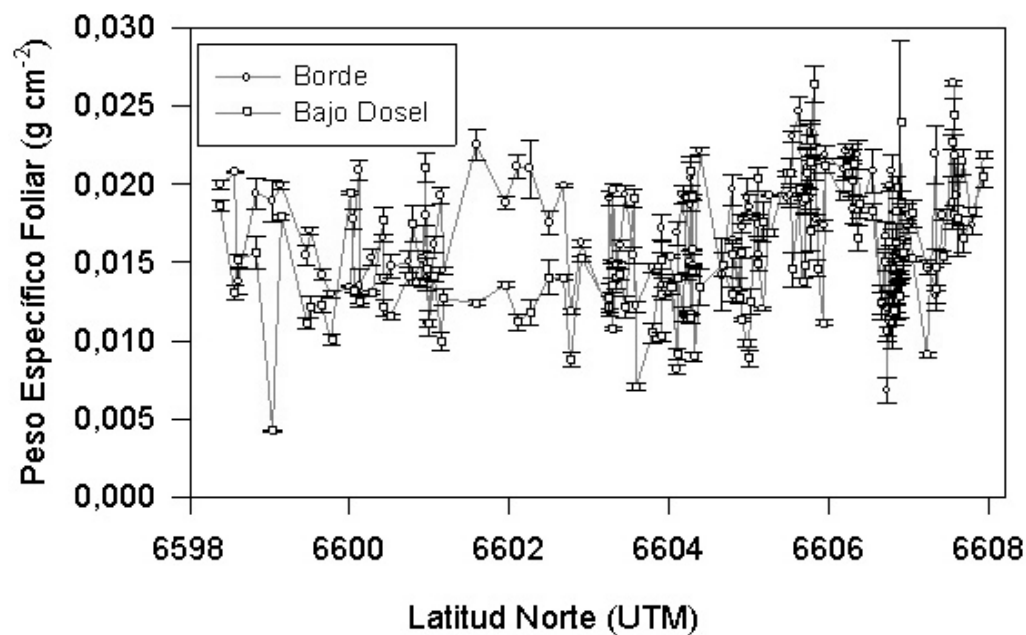


Fig. 6.66 a–c. Examples of leaf structures of xerophytes. **a** Cross section of a scleromorphic leaf of *Nerium oleander* with thickened hypodermis and multilayered palisade parenchyma (stippled); the stomata are protected from the effects of wind. **b** Leaf of the Californian Asteraceae *Hemizonia luzulifolia* ssp. *rudis*, which stores water in a pectinaceous intercellular substance (stippled). **c** Cylindrical leaf of *Zygophyllum simplex*, a succulent plant of the north African desert, with external chlorenchyma (stippled) which surrounds the extensive, centrally situated water-storing tissue. (After Stocker 1952; Morse 1990). Cacti contain water-binding mucilage: Nobel et al. (1992b)



Peso específico foliar en hojas de borde y bajo dosel de Olivillo, en P.N. Fray Jorge (Squeo et al., 2003). Peso específico foliar = Peso seco foliar / área foliar.

$$\text{Degree of succulence} = \frac{\text{water content at saturation (g)}}{\text{surface area (dm}^2\text{)}}$$

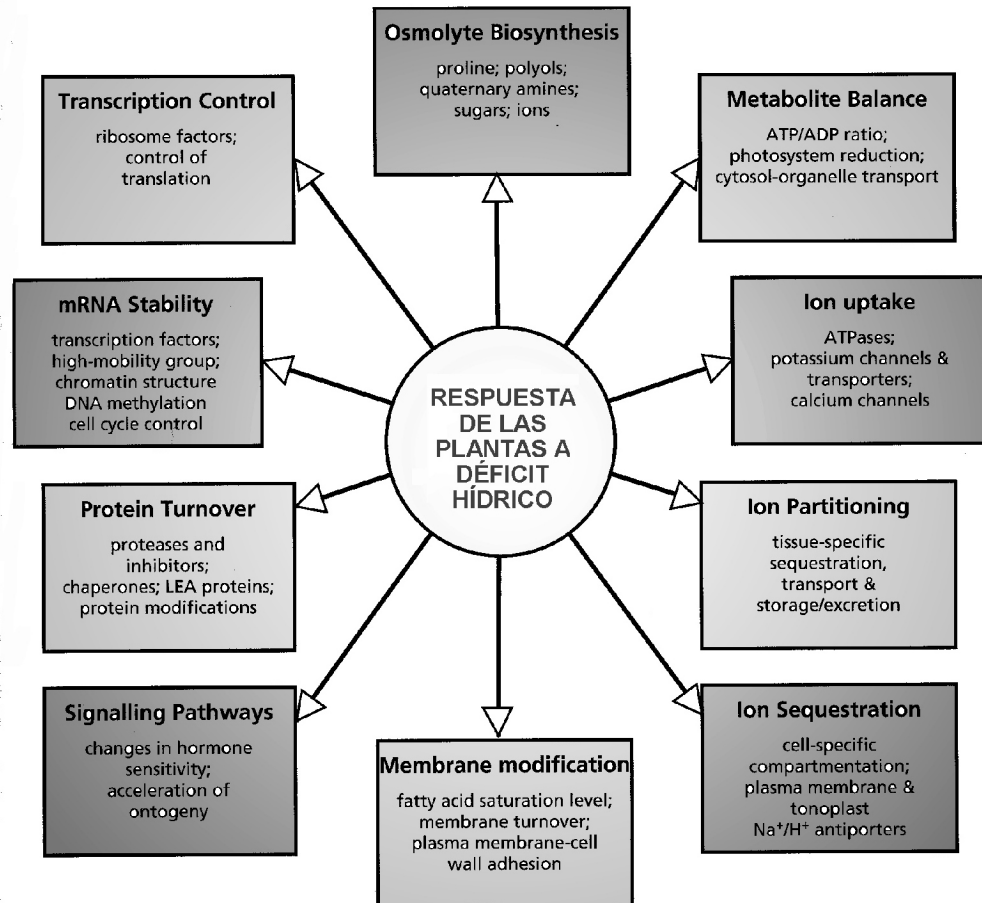


Table 10.1. *Evidence for the involvement of abscisic acid (ABA) in plant responses to water stress based on the similarity of responses to water stress and to exogenous ABA application (collated from Jones 1981a; Addicott 1983 and Davies & Jones 1991)*

Response	Water stress	ABA	
<i>Short term</i>			
Stomatal conductance	Decrease	Decrease	+++
Photosynthesis	Decrease	Decrease (Primarily a stomatal effect)	+++
Membrane permeability	Increase/decrease	Increase/decrease	+
Ion transport	Increase/decrease	Increase/decrease	+

Response	Water stress	ABA	Correlación
<i>Long term: biochemical and physiological</i>			
Specific mRNA and protein synthesis ¹	Increase	Increase	++
Proline & betaine accumulation	Increase	Increase	++
Osmotic adaptation ²	Yes	Yes	+
Photosynthetic enzyme activity	Decrease	Decrease	+
Desiccation tolerance ³	Increase	Increase	+
Salinity and cold tolerance	Induces	Induces	++
Wax production ⁴	Increase	Increase	+

Response	Water stress	ABA	Correlación
<i>Long term: growth</i>			
General growth inhibition	Yes	Yes	+++
Cell division	Decrease	Decrease	+++
Cell expansion	Decrease	Decrease	+++
Germination	Inhibits	Inhibits	++
Root growth	Increase/decrease	Increase/decrease	++
Root/shoot ratio	Increase	Increase	++
<i>Long term: morphology</i>			
Production of trichomes	Increase	Increase	++
Stomatal index	Decrease	Decrease	++
Tillering in grasses ⁵	Decrease	Decrease/increase	+
Conversion from aquatic to aerial leaf type	Yes	Yes	++
Induction of dormancy, terminal buds or perennation organs	Yes	Yes	++

Response	Water stress	ABA	Correlación
<i>Long term: reproductive</i>			
Flowering in annuals	Often advanced	Often advanced	+
Flower induction in perennials	Inhibited	Inhibited	+
Flower abscission	Increased	Increased	+
Pollen viability	Decreased	Decreased	+
Seed set	Decreased	Decreased	+

Table 10.2. *Drought tolerance mechanisms*

1. *Avoidance of plant water deficits*
 - (a) *Drought escape* - short growth cycle, dormant period.
 - (b) *Water conservation* - small leaves, limited leaf area, stomatal closure, high cuticular resistance, limited radiation absorption.
 - (c) *Effective water uptake* - extensive, deep or dense root systems.
2. *Tolerance of plant water deficits*
 - (a) *Turgor maintenance* - osmotic adaptation, low elastic modulus.
 - (b) *Protective solutes, desiccation tolerant enzymes, etc.*
3. *Efficiency mechanisms*
 - (a) *Efficient use of available water.*
 - (b) *Maximal harvest index.*

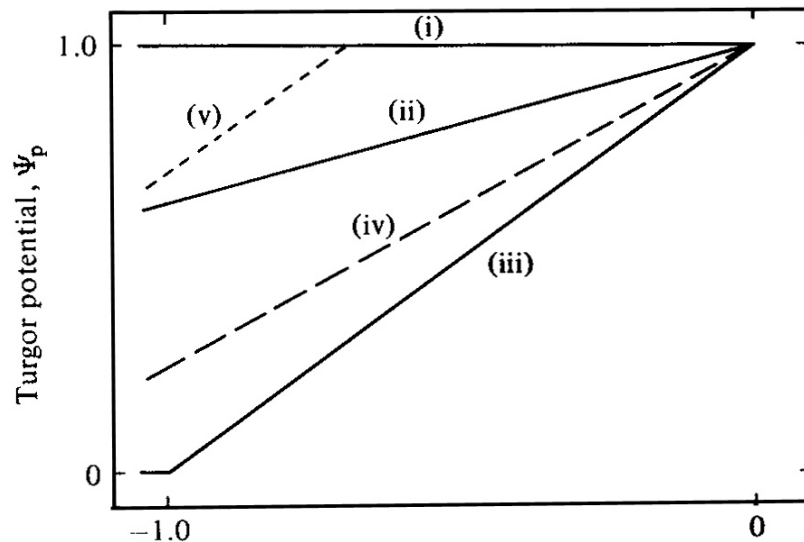


Fig. 10.1. Schematic representation of the relationship between turgor potential (normalised to 1.0 when $\Psi = 0$) and total water potential for (i) full turgor maintenance ($d\Psi_p/d\Psi = 1$); (ii) partial turgor maintenance ($0 < d\Psi_p/d\Psi < 1$); (iii) no turgor maintenance with constant solute concentration (extremely rigid walls); (iv) passive turgor maintenance with solutes concentrating as a result of cell shrinkage with elastic cell walls; (v) an example where turgor maintenance is only achieved over a limited range of Ψ .

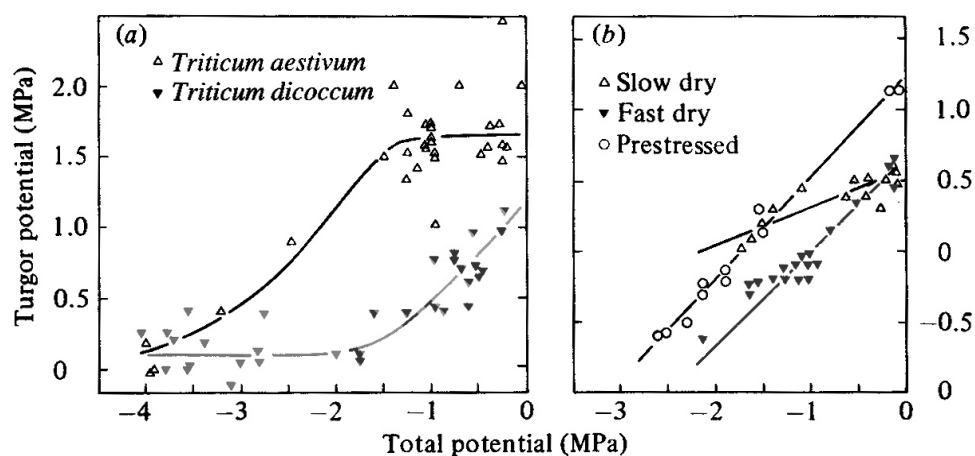


Fig. 10.2. Examples of relationships between turgor potential and leaf water potential for (a) two wheat genotypes and (b) sorghum plants: $\blacktriangledown$ previously well-watered and dried rapidly; $\triangle$ previously well-watered and dried slowly; $\circ$ previously stressed to -1.6 MPa and dried rapidly. (Data from Turner & Jones 1980.)

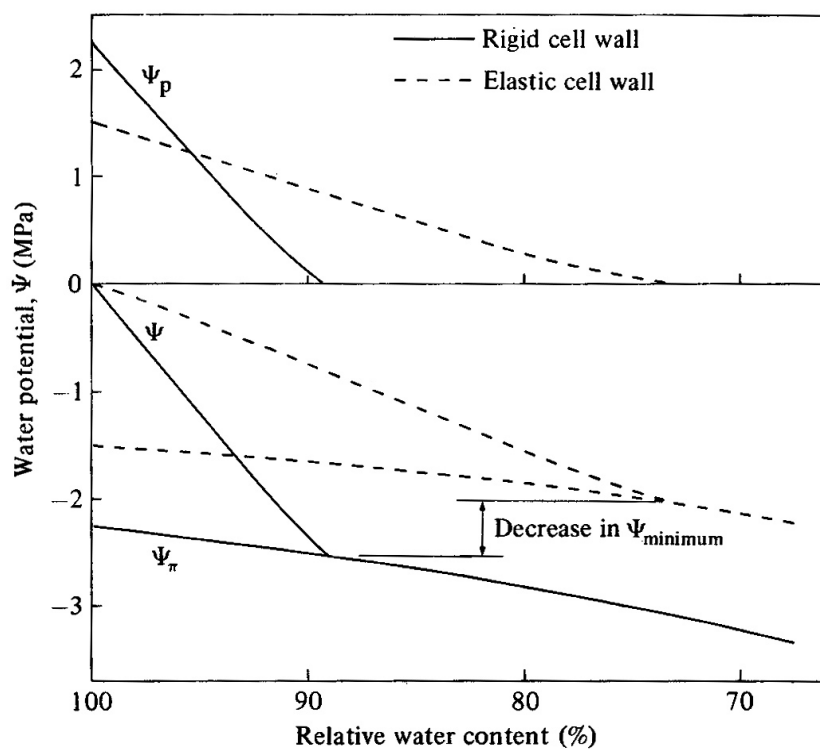


Fig. 10.3. Höfler diagrams for cells with elastic or rigid cell walls, illustrating the potentially lower minimum Ψ for positive turgor with rigid cell walls and the smaller volume changes for a given change of Ψ .

Unidad III: EL AGUA Y LA PRODUCTIVIDAD VEGETAL

Capítulo 11: USO DEL AGUA A NIVEL EVOLUTIVO Y AGRONÓMICO

* Introducción

* Medición de la presión evolutiva (P_{ev})

$P_{ev} = 1 - (R_{promedio} / R_{potencial})$, donde $R_{promedio}$ es la reproducción promedio en condiciones de campo, $R_{potencial}$ es la reproducción potencial que puede alcanzar la especie bajo condiciones óptimas. Si $P_{ev} = 1$ implica que la especie no se reproduce y se extinguirá en la próxima generación; $P_{ev} = 0$ implica que no hay presión selectiva.

* Limitaciones ambientales en terreno

* Eficiencia en el uso del agua (EUA)

$EUA = \text{materia seca producida (D)} / \text{agua transpirada (W)}$

- Mediciones de EUA

- $EUA_{instantánea} = \text{Fotosíntesis (A)} / \text{Transpiración (E)}$.

- $A = (ci - ca) D_{CO_2} / (r_a + r_s + r_m)$, donde $(ci - ca)$ es la diferencia de concentración de CO_2 entre la hoja (intracelular) y la atmósfera, D_{CO_2} es el coeficiente de difusión del CO_2 ($= 0,64 D_{H_2O}$).

- $E = ([H_2O]i - [H_2O]a) D_{H_2O} / (r_a + r_s)$

- $EUA = A / E = 0,64 ((ci-ca)/([H_2O]i - [H_2O]a)) * ((r_a + r_s) / (r_a + r_s + r_m))$

- uso de isótopos estables de carbono ($\delta^{13}C$)

$\delta^{13}C_{hoja} = \delta^{13}C_{aire} - a - (b - a)(ci/ca)$, donde $\delta^{13}C_{hoja}$ y $\delta^{13}C_{aire}$ son la composición isotópica del carbono en la hoja y el aire, **a** es una constante que depende de la diferencia de difusión ($^{13}CO_2$ es más lento que el $^{12}CO_2$, $a = 4.4\%$), **b** constante asociada a la discriminación de la Rubisco ($b = 27\%$); ci/ca es la proporción de CO_2 intracelular con respecto al ambiente.

$\Delta = a (ca-ci)/ca + b(ci/ca) = a + (b-a)(ci/ca)$, dado que ca es relativamente constante: $\Delta \propto ci$. ($\Delta = (\delta^{13}C_{air} - \delta^{13}C_{hoja}) / (1 + \delta^{13}C_{hoja})$; $\delta^{13}C_{air} = -8\%$)

* Tolerancia a la sequía

- aumento de la tolerancia a la sequía

* Déficit hídrico y reproducción

* Desecación

* Antitranspirantes (cierre de estomas, cubierta, reflectantes)

* Incremento de la productividad

- nuevas variedades + mejoramiento en el manejo

- selección de nuevas variedades

- definición de ideotipo (genotipo + ambiente)

- $\text{producción} = (\text{plantas} / m^2) * (\text{espigas/planta}) * (\text{granos/espiga}) * (\text{peso/grano})$

- Modelación y determinación del ideotipo

-cambio entre desarrollo vegetativo y reproductivo

- validación del ideotipo

- Desarrollo de pruebas en busca del ideotipo

- Atributos

- morfológicos y anatómicos
- composición (p.e., proteínas)
- tasa de procesos (p.e., A, E, vernalización)
- control de procesos (p.e., actividad enzimática, estomas)

* Ejemplos de aplicaciones

- cruzamiento para tolerancia a la sequía
- uso de caracteres estomáticos
 - frecuencia de estomas
 - conductancia estomática
 - respuesta estomática
 - producción de ABA
- fotosíntesis y productividad de cultivos
- ejemplo de un ideotipo

LEER:

Kramer P.J. y J.S. Boyer (1995) Water Relations of Plants and Soils. Academic Press, San Diego. Capítulo 12.

Jones HG 1992. Plants and microclimate. Cambridge. Cap. 10 y 12.

Squeo F.A. y J.R. Ehleringer (2003) Isótopos Estables: una Herramienta Común para la Ecofisiología Vegetal y Animal. En (F Bozinovic y HM Cabrera, eds): Fisiología Ecológica y Evolutiva en Animales y Plantas.

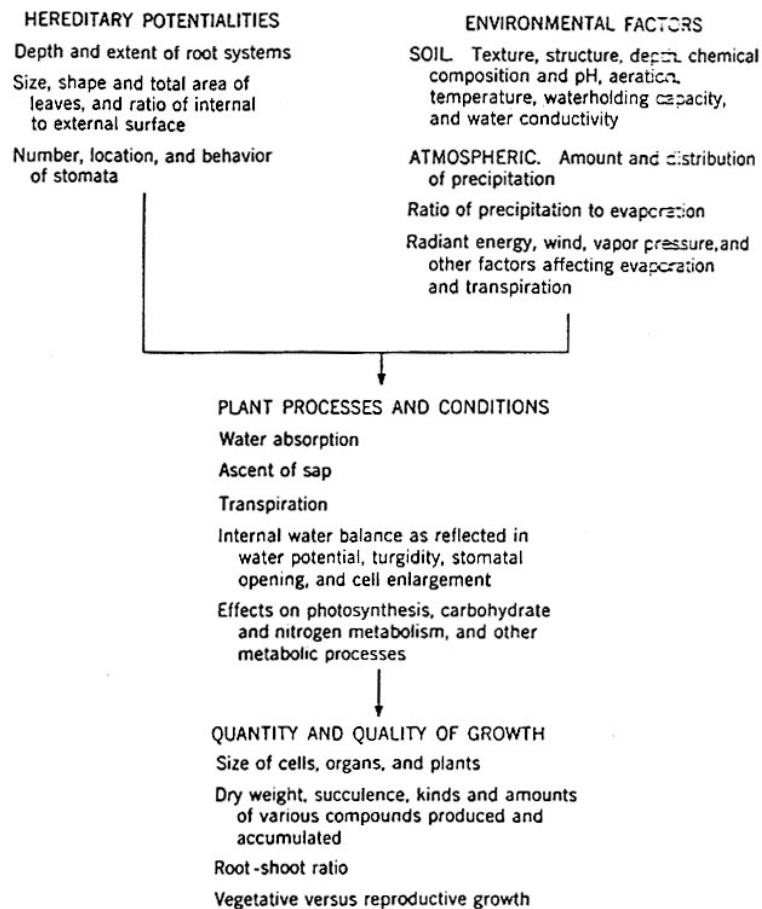


Fig. 1.1. Diagram showing how the quantity and quality of plant growth are controlled by hereditary potentialities and environmental factors operating through the internal processes and conditions of plants. Special attention is given to factors and conditions affected by water relations.

Record Yields, Average Yields, and Yield Losses Due to Diseases, Insects, Weeds, and Unfavorable Physicochemical Environments for Major U.S. Crops^a

Crop	Record ^b yield	Average ^b yield	Average losses ^c			
			Diseases	Insects	Weeds	Physicochemical ^d
Maize	19,300	4,600	836	836	697	12,300
Wheat	14,500	1,880	387	166	332	11,700
Soybean	7,390	1,610	342	73	415	4,950
Sorghum	20,100	2,830	369	369	533	16,000
Oat	10,600	1,720	623	119	504	7,630
Barley	11,400	2,050	416	149	356	8,430
Potato	94,100	28,200	8,370	6,170	1,322	50,000
Sugar beet	121,000	42,600	10,650	7,990	5,330	54,400
Mean percentage of record yield	100	21.5	5.1	3.0	3.5	66.9

Note. Values are kilograms per hectare. Record and average yields are as of 1975.

^aIn the original work (Boyer, 1982), weed losses were considered to be physicochemical because the losses were attributable to competition for light, nutrients, and so on. On the other hand, weeds are of biological origin and it may be argued that the losses should be included with insects and diseases. For simplicity, the latter approach is taken here, which slightly alters the values calculated for each loss in comparison with Boyer (1982).

^bFrom Wittwer (1975).

^cCalculated according to U.S. Department of Agriculture (1965).

^dPhysicochemical losses calculated as record yield—(average yield + disease loss + insect loss + weed loss).

Table 12.2 Area of the U.S. Land Surface
Subject to Environmental
Limitations of Various Types^a

Environmental limitation	Area of U.S. affected (%)
Drought	25.3
Shallowness	19.6
Cold	16.5
Wet	15.7
Alkaline salts	2.9
Saline or no soil	4.5
Other	3.4
None	12.1

^aFrom U.S. Department of Agriculture (1975).

Table 12.3 Distribution of Insurance
Indemnities for Crop Losses
in the United States from 1939
to 1978^a

Cause of crop loss	Proportion of payments (%)
Drought	40.8
Excess water	16.4
Cold	13.8
Hail	11.3
Wind	7.0
Insect	4.5
Disease	2.7
Flood	2.1
Other	1.5

^aFrom U.S. Department of Agriculture (1979).

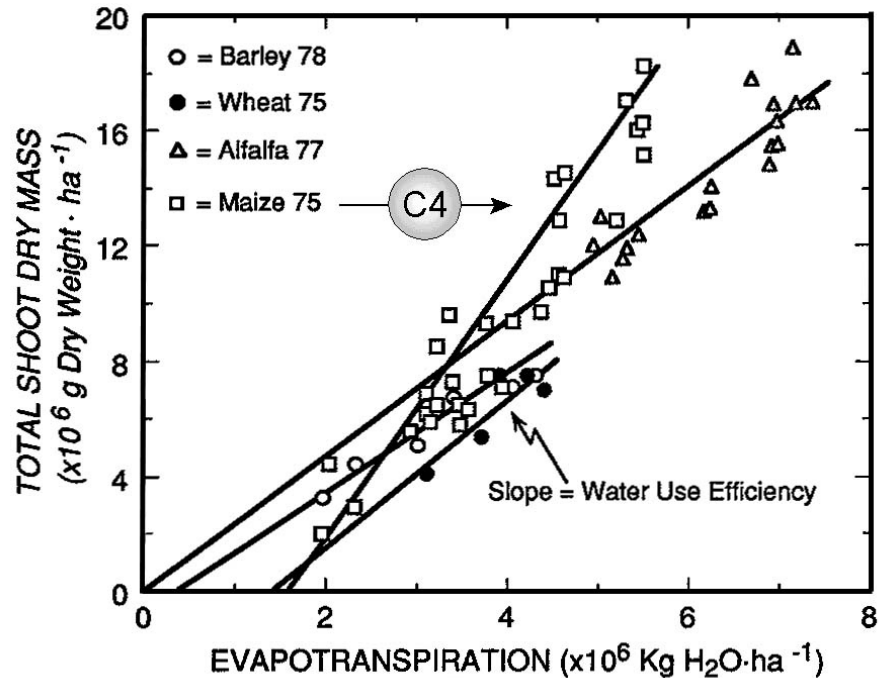
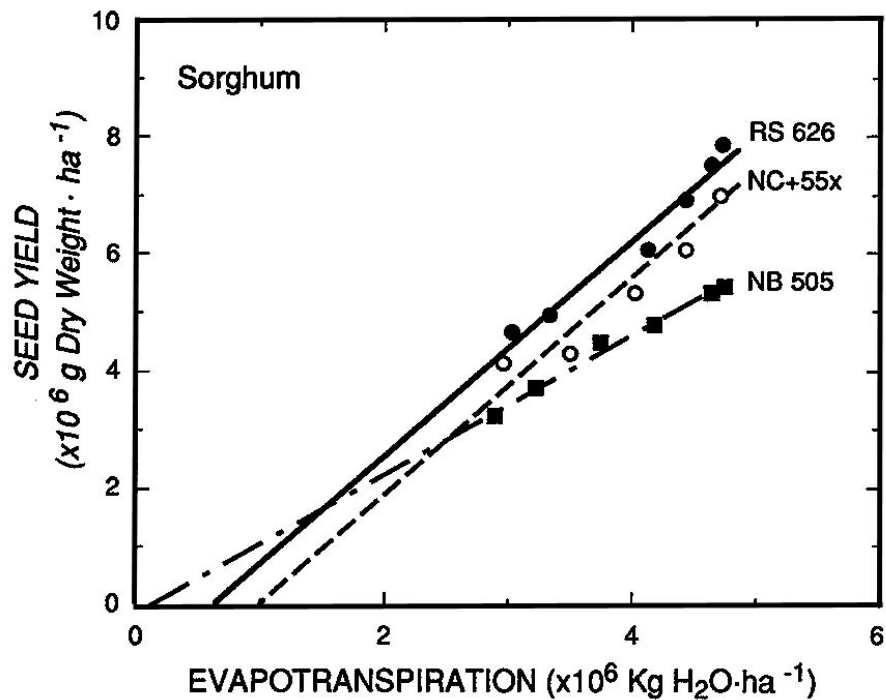
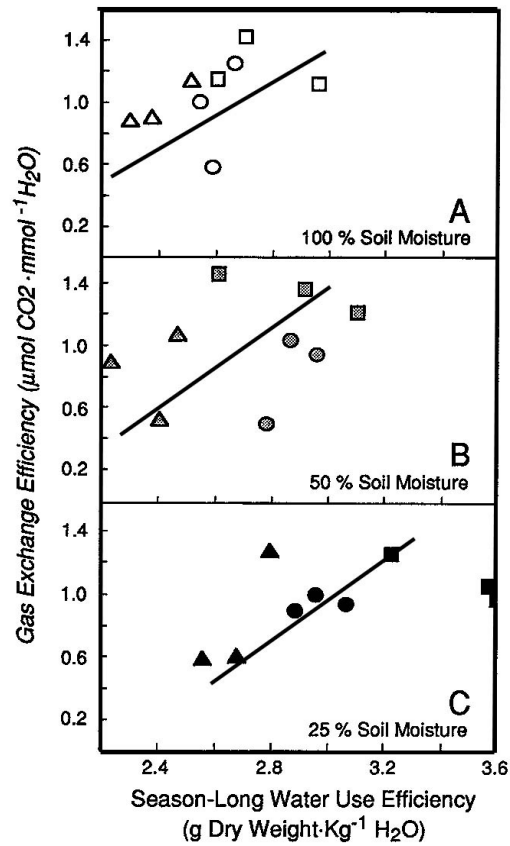


Figure 12.1 Production of aboveground shoot dry matter at various levels of water use in several crops near Logan, Utah. The years in which the crops were grown are shown in the symbol key. Water use was controlled by varying the amount of irrigation and is shown as combined evaporation from the soil and transpiration from the plants. A positive evapotranspiration intercept indicates the amount of water obtained from soil stores. The slope of the linear relation is the water use efficiency which was 2.11 g of dry weight per kg of H_2O for barley, 2.50 for wheat, 2.36 for alfalfa, and 4.49 for maize. Note that maize is a C_4 plant and the others are C_3 . Maize and wheat were grown in the same year. Adapted from Hanks (in Taylor *et al.*, 1983).

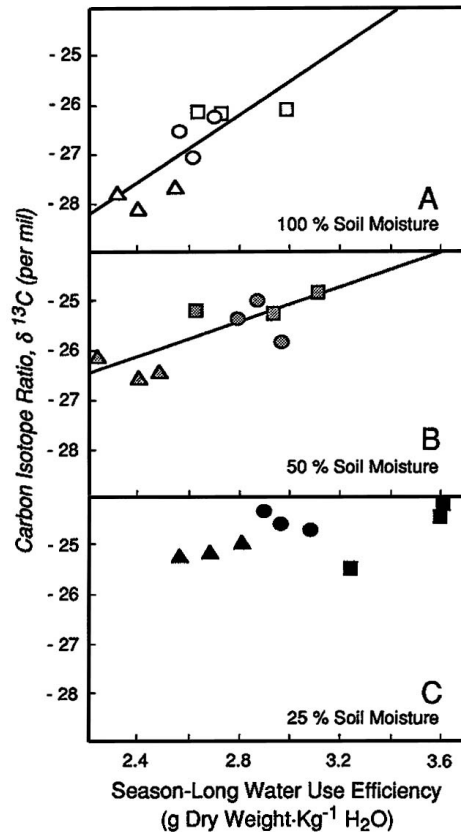
Producción de semillas en tres variedades de sorgo en un gradiente evapotranspirativo (pendiente = EUA)



EUA en el corto plazo (A/E) versus largo plazo (PS Producido / Agua Usada) en tomate



EUA en el largo plazo medida como $\delta^{13}\text{C}$ y como PS producido / Agua Usada en tomate.
Lycopersicon esculentum (Δ), *L. pennelli* ($\square$) e híbrido ($\circ$)



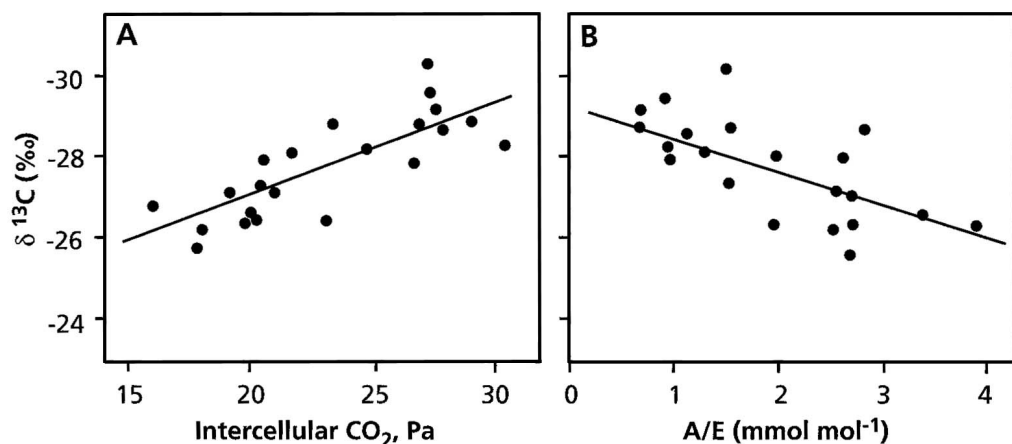


FIGURE 36. The relationship between carbon isotope composition ($\delta^{13}\text{C}$) and (A) average intercellular CO_2 concentration, and (B) daily photosynthetic water-use efficiency, assimilation/transpiration (A/E). The data points refer to mistletoes and host plants in central Australia

TABLE 8. The photosynthetic water-use efficiency of plants with different photosynthetic pathway* and belong to different functional groups.[†]

Functional type	Water-use efficiency (mmol mol^{-1})
CAM-plants	4–20
C_4 plants	4–12
Woody C_3 plants	2–11
Herbaceous C_3 plants	2–5
Hemiparasitic C_3 plants	0.3–2.5

Source: Kluge & Ting 1978; Morrison 1993; Osmond et al. 1982; Shah et al. 1987.

* C_3 , C_4 and CAM; for CAM-plants the high values refer to gas exchange during the night and the low values to the light period.

[†]All species are nonparasitic, unless stated otherwise, grown at an ambient CO_2 partial pressure of around 35 Pa and not exposed to severe water stress.

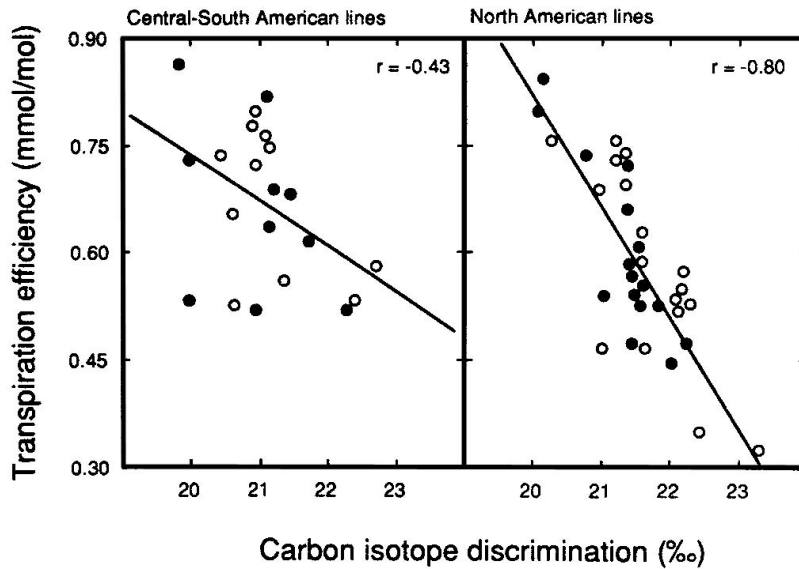


Fig. 2. Correlations between transpiration efficiency (mmol C per mol H_2O) and leaf carbon isotope discrimination (Δ) in different lines of *Phaseolus vulgaris*. The left plate is for common bean lines developed for Central-South America and the right plate is for common bean lines developed for North America. Open circles represent means of lines that were irrigated; filled circles represent unirrigated lines.

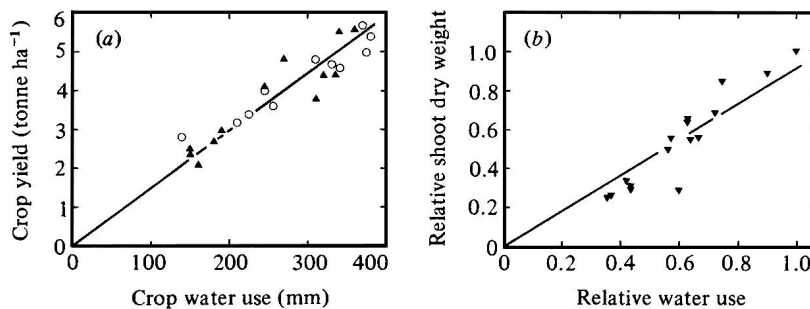


Fig. 10.4. (a) Grain yield as a function of water used under a range of irrigation treatments for barley in 1976 (○) and wheat in 1979 (▲) in south-eastern England (data from Day *et al.* 1978 and Innes & Blackwell 1981). (b) Relative shoot dry weight as a function of relative water use for cowpea in California in 1976 (after Turk & Hall 1980). The water use efficiency (WUE) for any point is given by the slope of a line joining that point to the origin, so that the lines join points of equal WUE.

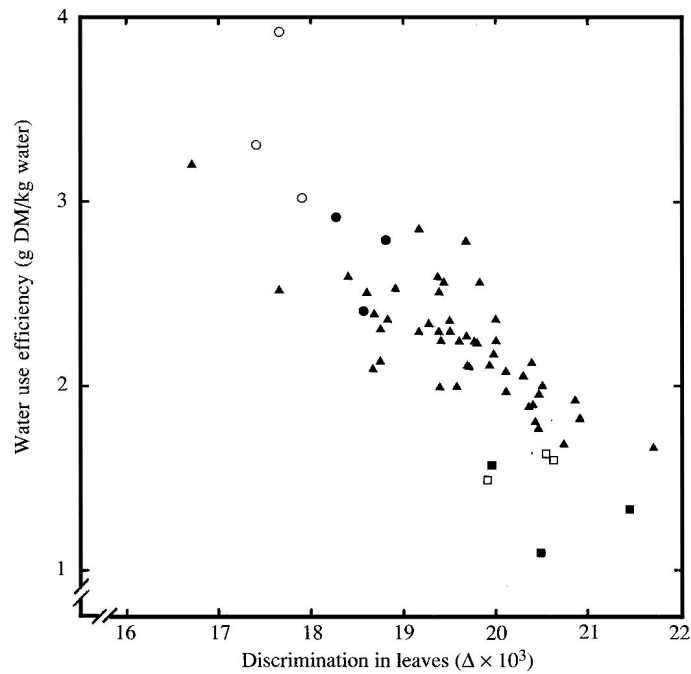


Fig. 10.5. Water use efficiency of whole peanut plants plotted against carbon isotope discrimination measured in dried leaf material. Solid symbols: well-watered plants; open symbols: water-stressed plants; Chico ($\square$); Tifton-8 ($\circ$); F2 progeny of Chico $\times$ Tifton-8 (Δ). (Data from Hubick *et al.* 1988.)

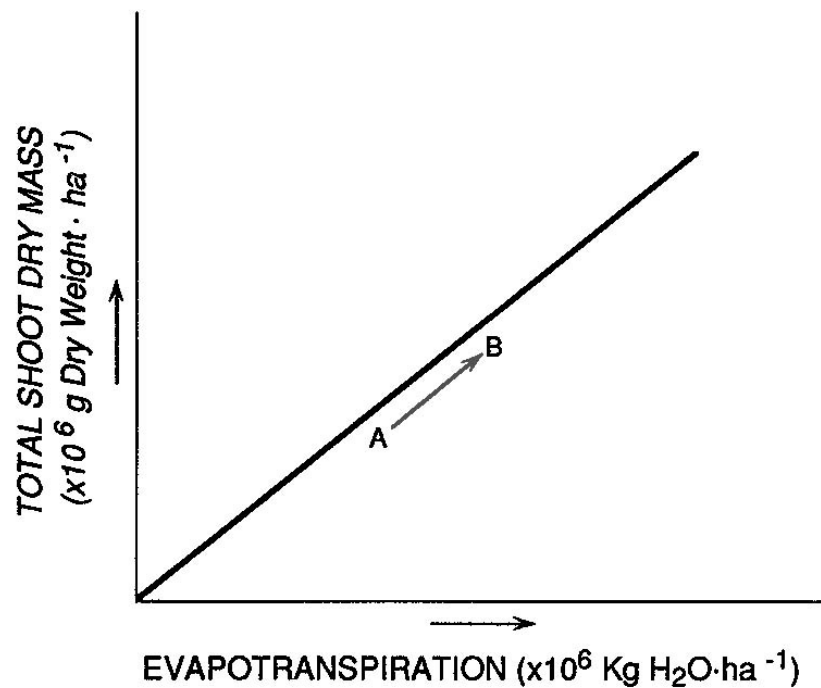


Figure 12.5 Effect of increasing the amount of water available to a crop without changing the water use efficiency. Production moves from A to B. An example might be increasing rooting depth.

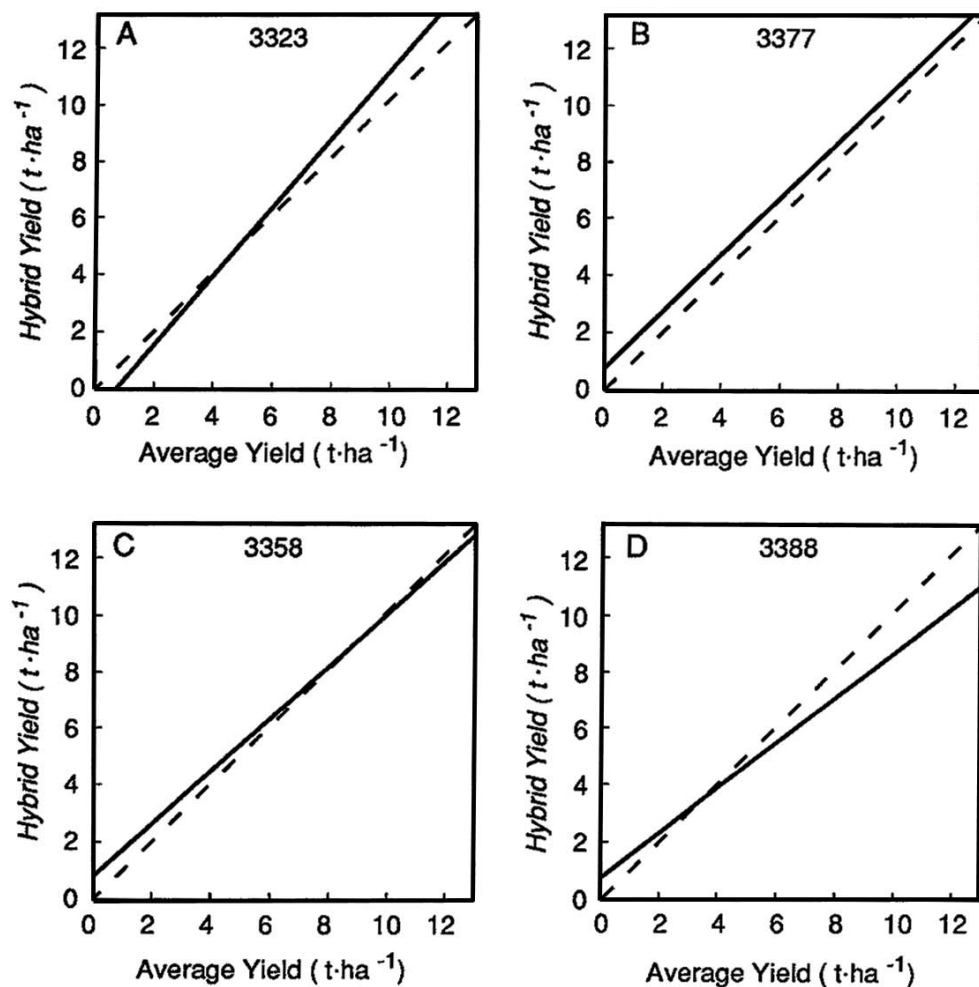


Figure 12.6 Regressions of seed yield of four maize hybrids grown at various locations in the United States over 3 years. The dashed line indicates the average yield for all hybrids at each location (1:1) and the solid line shows the yield of an individual hybrid for comparison. A solid line above the dashed line indicates a better than average yield for the hybrid. (A) Hybrid 3323, (B) hybrid 3377, (C) hybrid 3358, and (D) hybrid 3388. Except for (B), the slopes of each hybrid regression differed significantly from the slope of the dashed line ($P < 0.01$). The r^2 values were between 0.67 and 0.82 for the regressions of the four hybrids. Regressions were formed for 399 genotypes and, in most instances, for over 500 sites.

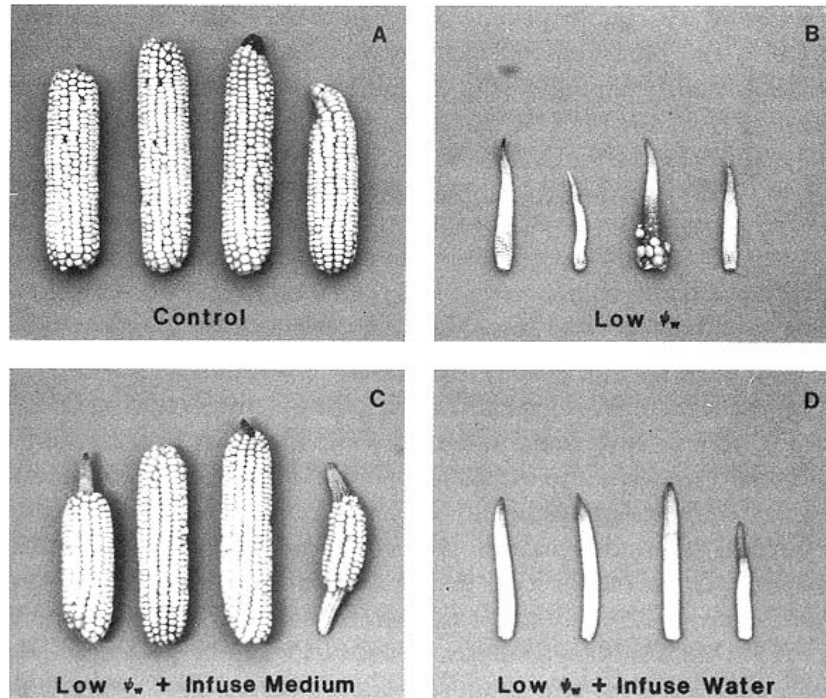


Figure 12.7 Grain yield at maturity for soil-grown maize plants subjected to a water deficit during pollination. Treatments were adequately watered controls (A), water-deficient plants from which water was withheld for 6 days (B), plants treated as in (B) but with stem infusion of a complete medium for embryo culture (C), and plants treated as in (B) but with stem infusion of water (D) in the same amount as in (C). All plants were rewatered on the sixth day. Plants were hand-pollinated. The grain weight of the plants infused with medium at low water potentials was about 80% of the weight of the controls. The infusion did not change the water potential or photosynthesis of the plants. From Boyle *et al.* (1991b).

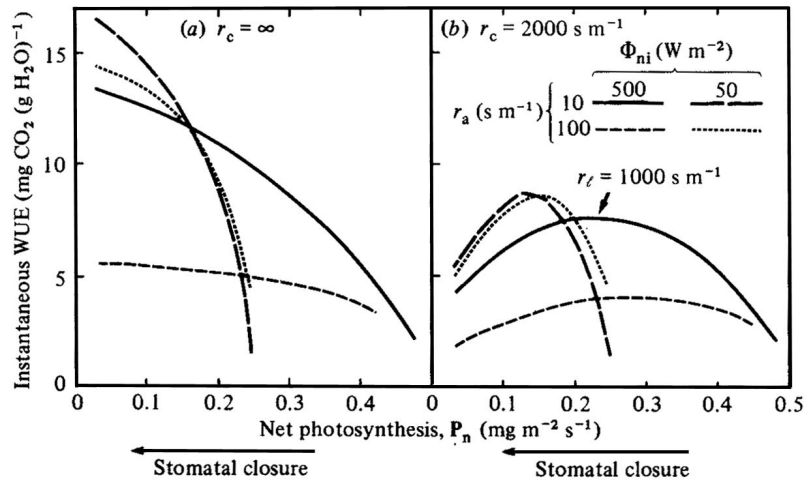


Fig. 10.6. Variation of instantaneous water use efficiency (WUE) with photosynthesis rate (which increases as stomata open) for C_3 leaves (a) assuming an infinite cuticular resistance (r_c); (b) assuming an r_c of 2000 s m^{-1} (after Jones 1976). The right-hand end of each curve corresponds to a leaf resistance of 50 s m^{-1} , and the left-hand end to 6400 s m^{-1} . The value of r'_l giving maximum WUE for $\Phi_{ni} = 500 \text{ W m}^{-2}$ and $r'_a = 10 \text{ s m}^{-1}$ is shown by the arrow.

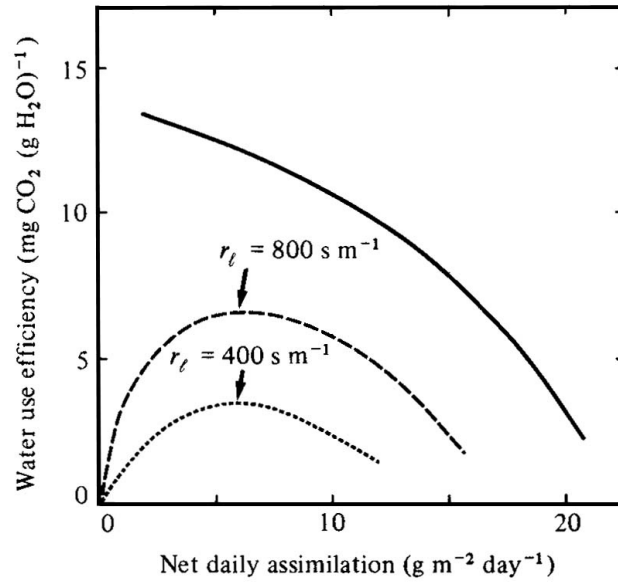


Fig. 10.7. Variation of daily water use efficiency (WUE) with photosynthetic rate for C_3 leaves with $\Phi_{at} = 500 \text{ W m}^{-2}$ and $r'_s = 10 \text{ s m}^{-1}$ for different amounts of respiration at night (R , $\text{mg m}^{-2} \text{ s}^{-1}$). — $R = 0$; ---- $R = 0.14 P_n + 0.05$; $R = 0.14 P_n + 0.15$. The arrows show values of r'_l giving maximum WUE.

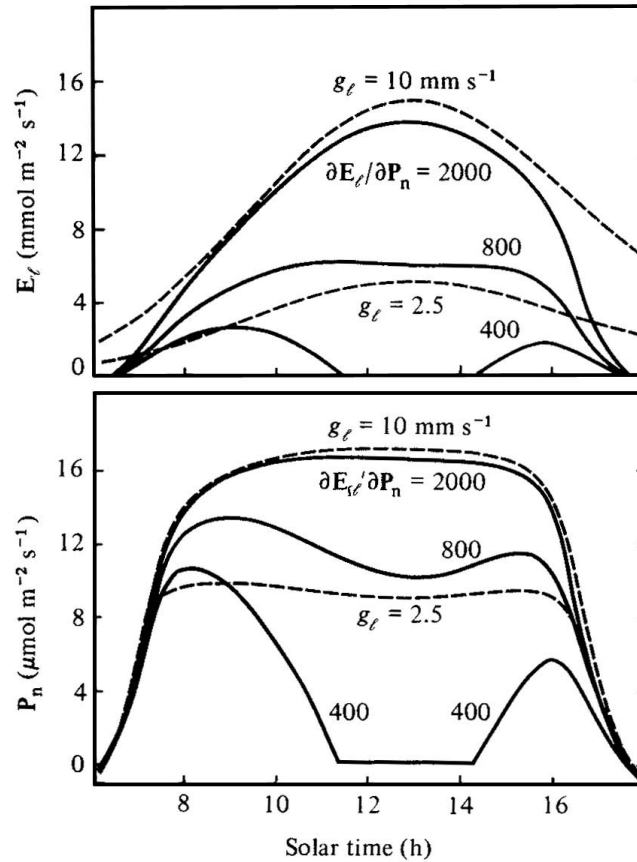


Fig. 10.9. Optimal time courses for transpiration (E_l) and assimilation (P_n) in a typical day for various magnitudes of $\partial E_l / \partial P_n$ (solid lines). These curves show that midday stomatal closure is an optimal behaviour when water is limiting and $\partial E_l / \partial P_n$ is small. Also shown are E_l and P_n for various constant values of leaf conductance (g_l) (dashed lines) (after Cowan & Farquhar 1977).

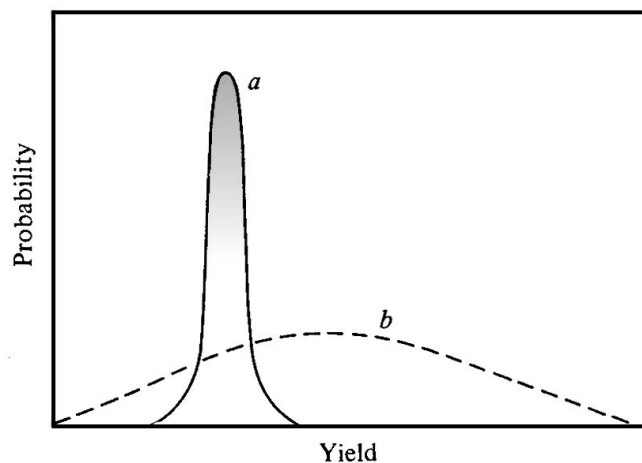


Fig. 10.10. Hypothetical yield probability distributions over many years at one site for two contrasting crop varieties: (a) stable but low yield; (b) more variable variety with higher mean yield.

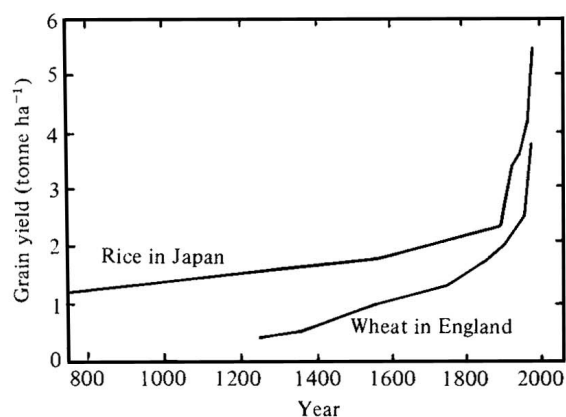


Fig. 12.1. Historical trends in grain yields of rice in Japan and of wheat in England. (From data collected by Evans 1975.)

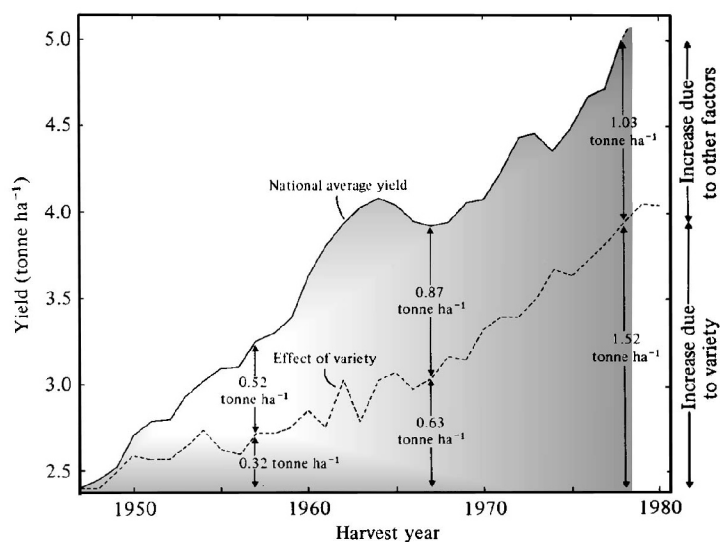


Fig. 12.2. Variation of the five-year moving average of national yields of wheat in England and Wales 1947–78. The dotted line represents the contribution of the variety grown. (After Silvey 1981.)

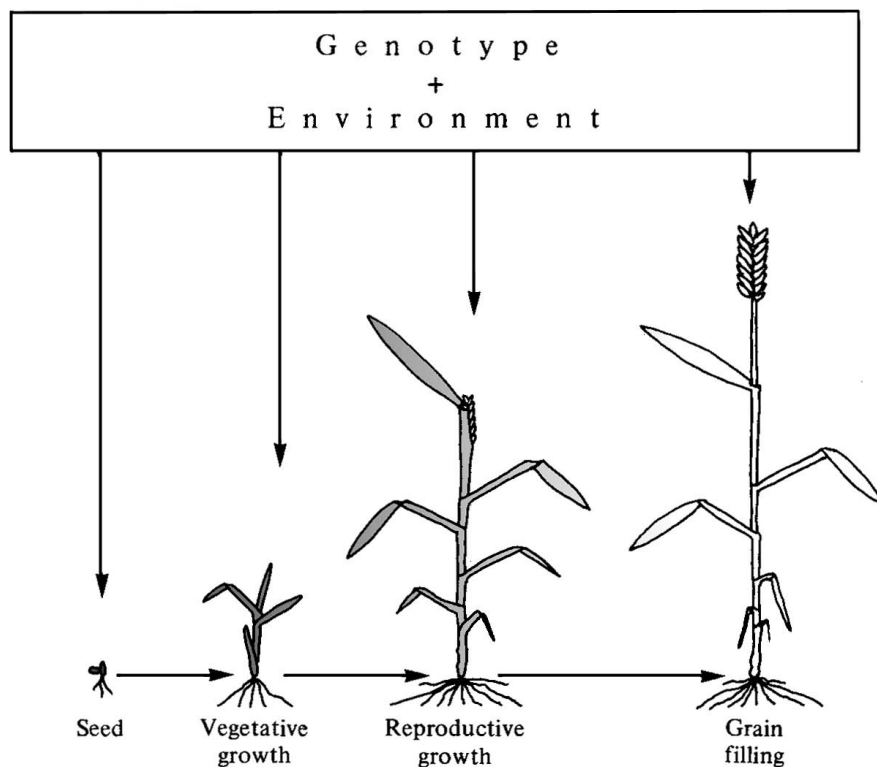


Fig. 12.3. Final grain yield for a cereal integrates the effects of genotype and environment over the whole growth cycle.

Table 12.1. *Yield characteristics of some winter wheat varieties (data Austin 1978)*

Variety	Date released	Height to base of ear (cm)	Relative yield	Harvest index (%)
Little Joss	1908	130	100	30
Holdfast	1935	112	94	31
Maris Huntsman	1970	95	148	40
Maris Kinsman	1975	82	145	38
Hobbit	1975	67	166	45

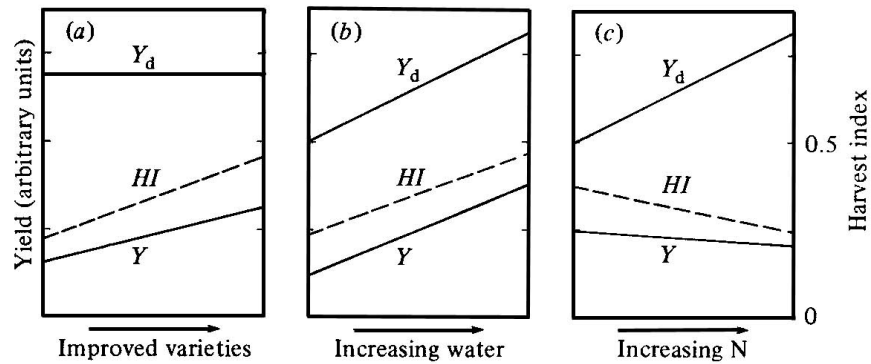


Fig. 12.4. Contribution of changes in total dry matter production (Y_d) and harvest index (HI) to economic yield (Y): (a) with improved varieties (largely increased HI); (b) increasing water (both Y_d and HI increase); (c) increasing nitrogen fertilisation (Y_d increases but HI decreases). (After Donald & Hamblin 1976.)

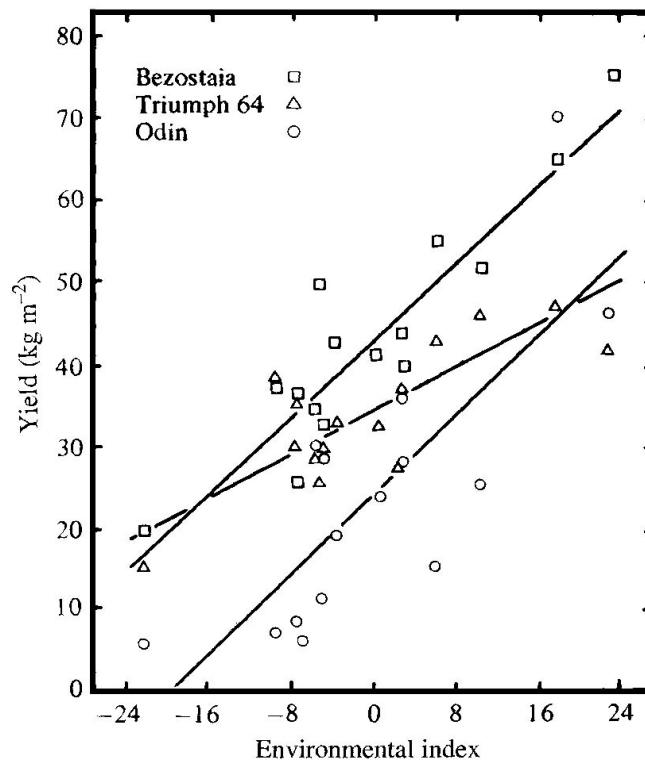


Fig. 12.5. Genotype $\times$ environment interactions in wheat yields in a multi-site international yield trial. Yield is plotted against an environmental index, the site mean yield determined over all varieties. (After Stroikey & Johnson 1972.)

Desarrollo de criterios de búsqueda (según Jones 1992, pag. 344-346)

To be of value, a useful screening test must satisfy a number of criteria:

1. The character must be easier to assess than yield itself.
2. There must be correlation (preferably causal) between the character and yield in the field.
3. The test should be simple, rapid, cheap and preferably capable of being used on seedlings at any time of year.
4. There must be heritable variation in the character.
5. A test involving a single measurement is likely to be better than the more complex tests usually required for estimates of responses.

Los atributos a ser utilizados en la búsqueda deben ser de una de las siguientes cuatro clases (según Jones 1992, pag. 344-346):

Morphological and anatomical, for example plant height, leaf size or stomatal frequency. In practice, these are the easiest and most widely used by breeders.

Compositional. Screening for grain composition, such as protein or lysine content, is widespread. Also included in this class is screening for hormone content, such as concentration of abscisic acid as a test for drought tolerance (see below).

Process rates, for example photosynthesis, respiration or vernalisation.

Process control, for example enzyme activity or stomatal aperture and its behaviour.

Table 12.2. *Characters for drought tolerance of possible use in a sorghum improvement programme (modified from Seetharama et al. 1982)*

	Techniques	Genetic variability	Prospects for breeding
<i>Morphological/phenological</i>			
1. Maturity	Visual	+++	+++
2. Developmental plasticity	Visual	+?	+?
3. Glossy leaf	Visual	+++	+++
4. Leaf number, size, shape	Visual	++	++
<i>Physiological – constitutive</i>			
5. Desiccation tolerance	Survival tests	+++	+++
6. Heat tolerance	Survival tests, ion leakage	+++	+++
7. High growth rates	Visual, growth analysis	++?	++
8. Low respiration	Gas exchange	++?	+?
9. Recovery after stress	Visual	+++	+++
10. Anatomical (e.g. stomatal density)	Microscope	++?	?
11. Root/shoot ratio	Growth analysis	++	+
12. Liquid phase resistance	Pressure chamber, anatomy	?	?
13. Deep roots	Root boxes	++	+?
<i>Physiological – facultative</i>			
14. Stomatal closure	Leaf temperature, porometer	++	?
15. Leaf rolling	Visual	+++	++
16. Epidermal wax production	Visual, chemical analysis	++	++?
17. Leaf area increase	Visual	++	+?
18. Leaf senescence	Visual	+++	+++
19. Remobilisation of stem reserves	¹⁴ C, growth analysis	++?	+++?
20. Osmotic adjustment	Psychrometry, chemical analysis	++?	+?
21. Relative increase in root growth	Root box, growth analysis	++	++

Table 12.3. *Effect of selection for stomatal frequency on water use by barley (data from Jones 1977b). Transpiration rate quoted is for 45 days after sowing*

	Whole plant		Flag leaf			
	Trans- piration (g day ⁻¹)	Leaf area (cm ²)	Stomatal frequency (mm ⁻²)	Pore length (μ m)	Leaf area (cm ²)	Leaf conductance (mm s ⁻¹)
<i>High frequency lines:</i>						
Minn. 92-43	73	329	83.4	16.7	24.9	4.6
CI 5064	75	412	97.6	17.7	18.3	4.6
<i>Low frequency lines:</i>						
Minn. 161-16	110	513	67.8	19.1	29.0	5.1
CI 4176	128	522	65.8	20.4	21.7	4.7

Table 12.4. *Breeding for ABA accumulation. Interpretation of differences in ABA accumulation in response to stress in different species*

<i>High ABA accumulation</i>	
(a) leads to good control of stress	– Tolerant varieties of maize, sorghum
or	
(b) is a measure of stress	– Susceptible varieties of wheat
<i>Low ABA accumulation</i>	
(a) because good avoider of stress	– Tolerant varieties of wheat
(b) because poor ability to synthesise ABA	– Susceptible varieties of maize, sorghum

Table 12.5. *Physiological attributes of the ideal model wheat plant for British conditions (modified from Austin & Jones 1975)*

Attribute	Possible benefits	Possible disadvantages
<i>Seed</i>		
Large seed	Rapid seedling emergence. Reduced sensitivity to sowing depth	Unknown
High concentration of seed protein	High grain quality and seedling vigour	May be low yield of seed per hectare
<i>Root growth</i>		
Adequate investment in root growth	Plants less susceptible to drought	Rapid depletion of soil water. Root growth may occur at expense of shoot growth
Low root hydraulic conductivity	Water conservation in drought	Adverse effects in conditions of ample water supply
Continued root growth during the critical phase of ear development and during grain growth	Supply of water and nitrogen assured. May delay demand for nitrogenous compounds from upper leaves, and so prolong their photosynthetic life	May be adverse competitive effects on ear development and grain growth
<i>Nitrogen economy</i>		
Ability to take up and reduce nitrate rapidly; ability to store nitrate and reduced nitrogen compounds	Minimises loss of soil nitrogen by leaching and denitrification	Possible toxic accumulation of nitrogen compounds at high levels of nitrogen fertilisation
Rapid export of nitrogen from leaves when senescing	Particularly important if soil nitrogen or water is limiting	Unknown
<i>Photosynthesis and gas exchange</i>		
Highest possible dry weight per unit ground area at anthesis, concentrated in the ear-bearing tillers	Favours maximum uptake of nitrogen and, in turn, grain protein yield per hectare	May be adverse competitive effects and reduced efficiency of water use. May be associated with late anthesis
High rates of photosynthesis per unit leaf area	Increases potential for dry matter production	May be compensating changes in leaf size and thickness which offset any benefits
May be achieved by		
(a) low mesophyll resistance to CO ₂ uptake	Increases efficiency of water use, especially important in drought	Unknown
(b) low photorespiration rate	Particularly advantageous at high temperatures and in drought	Unknown
(c) low stomatal resistance. High stomatal frequency	Useful only in conditions of ample water supply	In dry situations, there may be an unacceptably high rate of water loss
Stomata, sensitive to water stress, but reopening quickly after stress is relieved	Prevents irreversible damage in periods of drought	Undesirable with short periods of water stress
High cuticular resistance to water loss	Reduces transpiration rate. Particularly advantageous in drought	Unknown

Attribute	Possible benefits	Possible disadvantages
<i>Tillering and development</i>		
Early and near synchronous formation of tillers; absence of late-tiller production	No competition from late-formed tillers. Avoidance of 'wasteful' use of water, minerals and assimilates	Reduced ability to compensate for death of main shoot and tillers
Homeostasis of tiller number per unit area of ground (perhaps 800 m ⁻² in winter wheat)	Compensation for variation in seeding rates and seedling survival	Homeostasis mechanism may be dependent on tiller death
In spring wheats, photoperiod and temperature responses giving constant ear size but smaller tiller number with later sowings	Yield per hectare can be maintained in later sowing by increased seeding rate	Need for information on how seeding rates should be adjusted to allow for variation in sowing date
Response to photoperiod and temperature to give slow growth rates during cold spells and in midwinter	Favours development of winter-hardiness	Small plants, possibly with smaller ear primordia and fewer, or later developing, tillers
<i>Morphology</i>		
Canopy structure (e.g. erect upper leaves and lax lower leaves) to give maximum interception of light	Maximises canopy photosynthesis rates	Erect leaves give poor interception if leaf area index is less than 3
Dwarf habit	Confers resistance to lodging. High harvest index	May adversely affect crop microclimate and have agronomic disadvantages
High stem density (dry weight per unit stem length) and resistance to flexing	Confers resistance to lodging. Stem reserves can provide some 'insurance' against shortfall in assimilate during late grain filling (caused by drought or disease)	May be adverse competitive effects on ear development. Too extensive mobilisation of stem reserves could lead to lodging and brackling

ASIGNATURA

RELACIÓN SUELO - AGUA - PLANTA

ACTIVIDADES PRACTICAS

PAUTAS PARA REDACTAR UN INFORME CIENTÍFICO

Un factor esencial en cualquier investigación científica es la comunicación de los resultados a otros interesados en el campo que se investiga. Por lo tanto, la preparación de los informes de trabajos prácticos y seminario, en la forma de un ensayo científico, es considerada como parte importante de su entrenamiento en este curso.

En este curso, es aconsejable que el estudiante se ciña a un formato y estilo como el que se usa en las revistas científicas, para la preparación de informes de laboratorio y seminario. Las normas adoptadas por las revistas no son necesariamente las mejores; de tal modo que no implica que deben ser totalmente aceptadas. Sin embargo, en el interés de uniformar criterios, es aconsejable seguir las prácticas de ciertas revistas de divulgación científica.

Por lo tanto, a Ud. se le instruirá en detalle de la organización encabezamiento de sección, métodos de presentación de datos, formas de citas y listados de referencia.

La siguiente es una breve guía, la cual podría ser de ayuda para su trabajo.

Título

Es importante que el nombre:

- a) dé una idea clara del contenido y/o objetivos del trabajo.
- b) sea, a la vez, breve.

Autor(es)

Indicar el nombre completo de los autores del trabajo, y su filiación (lugar de trabajo).

Resumen

Esta sección será una breve condensación de todo el ensayo, estableciendo de qué forma fue hecho, qué procedimientos generales se usaron, cuales fueron los hallazgos más importantes y las conclusiones extraídas de los resultados. **Precaución:** limitar sus conclusiones a aquellos postulados que pueden ser inferidos directamente de los resultados de su investigación (escribir el resumen en pasado). Esta sección puede aparecer: a) antecediendo a la introducción o, b) precediendo la discusión.

Introducción

Esta sección podría contener:

- a) Una descripción de la naturaleza del problema y el estado del problema al comienzo de la investigación.
- b) Un breve establecimiento de los hallazgos más significativos de la investigación.

c) Un establecimiento de los objetivos de la investigación.

Materiales y métodos

Describir en detalle los materiales, equipos empleados y los métodos seguidos en la investigación. Esta sección podría ser escrita en forma completa y explícita de manera que un investigador competente pueda repetir sus experimentos. Para su informe de laboratorio Ud. debe extraer la información pertinente de la guía de laboratorio y de una revisión bibliográfica.

Resultados

Las observaciones y datos experimentales son registrados en esta sección. Una recomendación importante, es graficar los datos siempre que sea posible, ya que las relaciones son más fácilmente visualizables en una representación gráfica que en una tabla. Recordar que algunos datos que no pueden ser graficados sobre coordenadas pueden, sin embargo, ser expresados en tablas o histogramas. En esta sección tiene importancia el análisis estadístico de los resultados.

Discusión

Discutir los principales aspectos de la investigación (hallazgos - descubrimientos). Presentar la evidencia para cada conclusión. Fundamentar los resultados inesperados y excepciones, comparar sus resultados o interpretaciones con aquellos de otro profesional investigador y otros miembros de su clase. Obviamente esta sección podría incluir información pertinente de libros, literatura periódica y otros recursos. Indicar el significado de los procesos o fenómenos estudiados y relacionar sus resultados a los encontrados por otros. En suma cada pregunta planteada podría ser respondida en esta sección.

Literatura citada

Esta es la última sección de un ensayo científico. Las referencias son anotadas alfabéticamente por autor o número consecutivo (optativo); y deben corresponder exclusivamente a los trabajos citados en el texto, como indica el ejemplo de la siguiente lista:

Gutiérrez, J., L. Aguilera y R. Moreno 1989. Seed germination in *Atriplex* species. Rev. Ch. Hist. Nat. 39: 22-34.

Olivares, S. y F.A. Squeo. 1999. Patrones fenológicos en especies arbustivas del desierto costero del norte-centro de Chile. Revista Chilena de Historia Natural 72: 353-370.

Torres, R., F.A. Squeo, C. Jorquera, E. Aguirre y J.R. Ehleringer. 2002. Evaluación de la capacidad estacional de utilizar eventos de precipitación en tres especies de arbustos nativos con distintos sistemas radiculares. Revista Chilena de Historia Natural 75: 737-749.

Squeo, F.A., G. Arancio, L. Cavieres, J.R. Gutiérrez, M. Muñoz y C. Marticorena. 2001a. Análisis del Estado de Conservación de la Flora Nativa de la IV Región de Coquimbo. En: (Squeo, F.A., G. Arancio y J.R. Gutiérrez, eds.). Libro Rojo de la Flora Nativa de la Región de Coquimbo y de los Sitios Prioritarios para su Conservación. Ediciones de la Universidad de La Serena, La Serena. 53-62.

Squeo, F.A., G. Arancio, C. Marticorena, M. Muñoz y J.R. Gutiérrez. 2001b. Diversidad Vegetal de la IV Región de Coquimbo, Chile. En: (Squeo, F.A., G. Arancio y J.R. Gutiérrez, eds.). Libro Rojo de la Flora Nativa de la Región de Coquimbo y de los Sitios Prioritarios para su Conservación. Ediciones de la Universidad de La Serena, La Serena. 149-158.

Nota: Los trabajos citados en el texto deben indicar apellido del autor y año, en caso de existir 2 ó más trabajos citados del mismo autor y año se coloca una letra luego de la fecha. Cuando existen más de dos autores se indica el apellido del primer autor seguido de "et al." . Ejemplos:

“La floración en el norte chico esta concentrada en primavera (Olivares y Squeo, 1999) y la germinación de semillas de *Atriplex* en invierno (Gutiérrez et al., 1989).”

“Olivares y Squeo (1999) proponen una respuesta rápida a las precipitaciones”

“Squeo et al. (2001a) postulan que..., mientras que otros autores (p.e., Gutiérrez et al., 1989, Squeo et al. 2001b, ...) dicen otra cosa.”

“Actualmente se conoce que cerca de un 15% de la flora regional tiene problemas de conservación (Squeo et al. 2001a, b).”

PAUTA PARA LA PRESENTACIÓN DE SEMINARIOS

Según lo establecido en el programa del curso, esta actividad será evaluada de acuerdo a la calidad de la exposición y la presentación de un resumen escrito del tema el día de la exposición. El seminario bibliográfico tiene una ponderación de un 12% de la nota del curso.

Durante la exposición, que tendrá una duración de 15 minutos + 5 minutos para preguntas, el alumno podrá utilizar el apoyo de transparencias, carteles y otros materiales audiovisuales. Prepare y ejercite su exposición. Recuerde que debe proveer copias de su resumen para cada alumno del curso. Considere la alternativa de fotocopia.

El resumen debe incluir obligatoriamente lo siguiente (ver además ejemplo):

- a) referencia completa del trabajo: autor, año, título, revista, volumen, páginas.
- b) nombre del expositor.
- c) introducción del problema.
- d) objetivo del trabajo
- e) resultados y conclusiones más relevantes

El resumen no debe superar una página. Si lo desea puede agregar figuras en otra hoja página.

En caso de dudas, consultar al profesor antes del día de la presentación.

Resumen de Seminario Bibliográfico

Torres, R., F.A. Squeo, C. Jorquera, E. Aguirre y J.R. Ehleringer. 2002. Evaluación de la capacidad estacional de utilizar eventos de precipitación en tres especies de arbustos nativos con distintos sistemas radiculares. *Revista Chilena de Historia Natural* 75: 737-749.

Se evaluó la capacidad estacional de utilizar un evento de precipitación en tres especies arbustivas con diferentes sistemas radiculares (dimórficos: *Balbisia peduncularis*, *Senna cumingii*; profundo: *Haplopappus parvifolius*) en la Quebrada El Romeral, Norte Centro de Chile. El sitio posee un clima tipo mediterráneo árido con influencia de neblinas costeras y una precipitación promedio anual de 80 mm en los últimos 30 años. La utilización de precipitación artificial (i.e., 25 mm en otoño, invierno y primavera) por parte de las plantas se estimó por la composición de isótopos de hidrógeno (^2H) en el agua del xilema y los potenciales hídricos de pre-alba (ψ_{pa}) antes y después del riego. Los resultados indican que las tres especies utilizan una mezcla de dos fuentes de agua (agua superficial proveniente de las precipitaciones, y en mayor proporción, agua subterránea). A excepción de invierno, sólo las especies de sistemas radiculares dimórficos son capaces de reducir su déficit hídrico después de la aplicación de la precipitación artificial. La reducción en las precipitaciones observada en los últimos 100 años afectaría diferencialmente la productividad de las especies con sistema radicular dimórfico, y en especial al arbusto forrajero *Balbisia peduncularis*.

Expositor: Rodrigo Ordenes

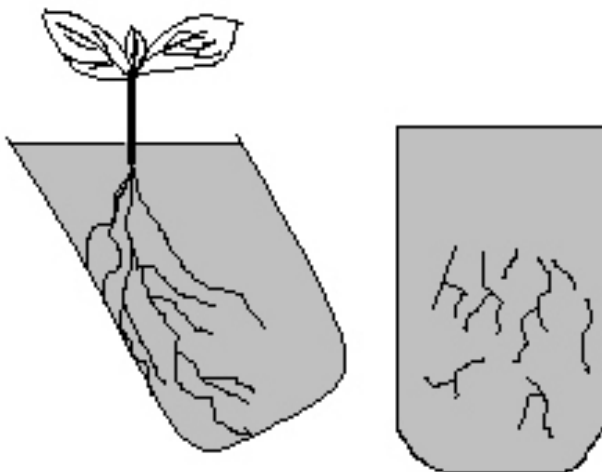
LABORATORIO 1: Sistema Radicular

Experiencia 1: Dinámica de crecimiento radicular en mini-rizotrón

a) Montaje: Llene con una mezcla de suelo una botella desechable transparente cuyo extremo fue previamente cortado en diagonal. Plante dos plántulas recién germinadas de las especies seleccionadas (p.e., tomate, maíz, trigo, poroto). Coloque la botella en una sanja, tal que quede inclinada en un ángulo de 45°. Tape completamente la botella con tierra. Riegue dos veces por semana. En la primera semana elimine una de las plántulas, dejando la más vigorosa.

b) Mediciones: semanalmente saque cuidadosamente la botella y dibuje a escala las raíces visibles en el lado inferior. Distinga entre raíces absorbentes (con pelos radiculares) y lignificadas. Mida en cada ocasión la longitud total de ambos tipos de raíces. Mida también la altura de la plántula, cuente el número de hojas y estime el área foliar.

c) Al término de la experiencia, saque cuidadosamente la plántula y mida los siguientes parámetros: ramificación y longitud total de las raíces, altura de la plántula, número y área foliar, peso seco radicular y aéreo. Haga un dibujo a escala de la plántula (puede sacar una fotocopia a la plántula). Compare los parámetros medidos entre las especies.



Experiencia 2: Efecto de la profundidad de riego y ambiente sobre el crecimiento radicular

Diseño experimental: Con la finalidad de evaluar el efecto de la profundidad de riego y ambiente sobre el crecimiento radicular se preparará un diseño experimental que consta de dos tratamientos de profundidad de riego (superficial y profundo) y dos ambiente (aire libre y sombreadero). Cada unidad experimental consiste en un macetero profundo (tubo de PVC de 1 m de profundidad) con suelo arenoso. Para realizar riego profundo se entierra dentro del macetero un tubo de PVC de pequeño diámetro. El riego debe realizarse una vez por semana (equivalente a una lluvia de 10 mm).

Montaje: llene un macetero con suelo arenoso y coloque una plántula recién germinada. En el caso de riego profundo ubique el tubo para regar. Al inicio del experimento todas las plantas se riegan superficialmente. En las semanas sub-siguientes, las plantas con riego profundo se van cambiando paulatinamente de superficial a profundo (Semana 1: 75% superficial: 25% profundo; semana 2: 50:50, semana 3: 25:75), para llegar a la semana 4 con 100% riego profundo.

Mediciones: semanalmente se debe registrar el crecimiento de la parte aérea (altura, número de hojas) y estimar el área foliar. Al final de la experiencia se sacará cuidadosamente la planta del macetero y se medirá, cada 25 cm de profundidad, los siguientes parámetros: ramificación y longitud total de las raíces, peso seco radicular (según clase de diámetro). Para la parte aérea mida la altura de la plántula, número y área foliar, peso seco de tallos y hojas.

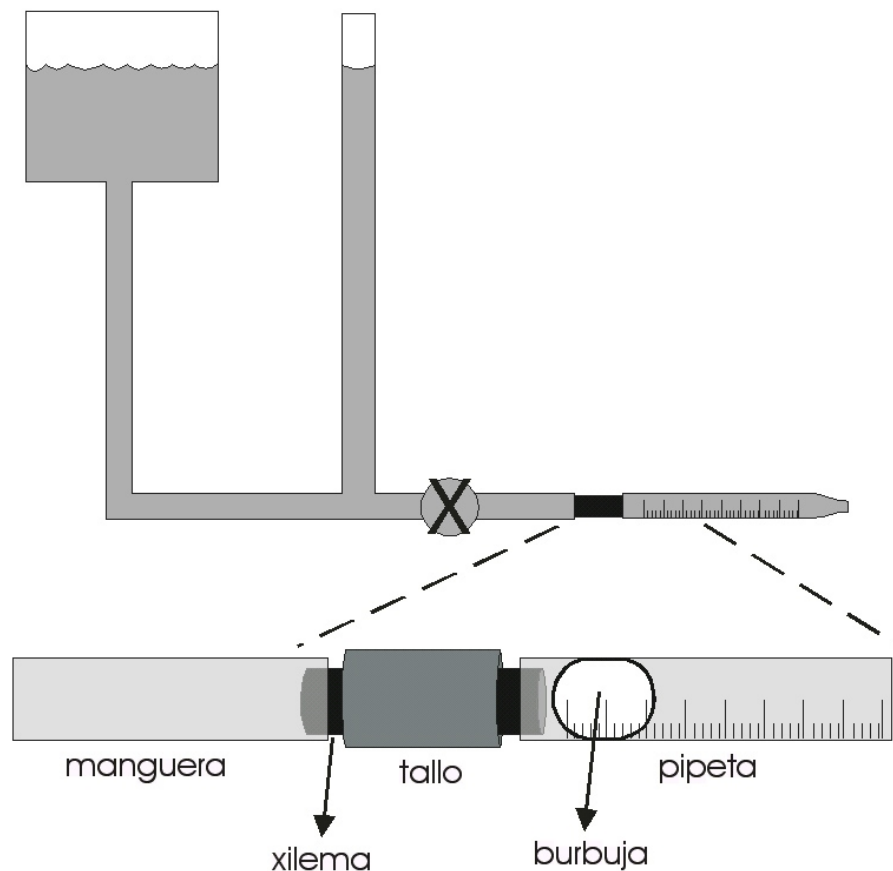
Compare estadísticamente los parámetros medidos utilizando un análisis de varianza (ANDEVA), para esto se utilizan todos los datos del curso. Las fuentes de variación son: ambiente (sombreadero - aire libre), riego (superficial - profundo) y especie.

LABORATORIO 2: Conductancia por Xilema

Conductividad Hidráulica del Xilema

Montaje: Corte bajo agua una rama de *Eucalyptus* u otro material indicado. Guarde las hojas para medir posteriormente el área foliar de la rama. Instale una sección de la rama de 5 cm de longitud en el sistema de mangueras, tal como se le indicará. Recuerde el eliminar el aire del interior del sistema de mangueras. Abra la válvula para que el agua comience a pasar a través de la sección de tallo.

Mediciones: Evalúe la conductancia hidráulica (K) utilizando una columna de agua destilada de un metro de altura. Expresa K en términos de $\text{ml H}_2\text{O} / \text{área de xilema que conduce (cm}^2\text{)} / \text{tiempo (segundos)}$. Compare la K de dos o más especies. Discuta sus resultados en términos de las potenciales tasas de transpiración y/o área foliar que sostiene cada rama. Compare entre distintas especies.



LABORATORIO 3: Transpiración

Experiencia 1.- Utilización de Potómetro.

En esta experiencia se evalúa la cantidad de agua transpirada por unidad de tiempo (tasa de transpiración) de una rama instalada en un potómetro. Se propone realizar las siguientes observaciones:

- a) Comparación de la transpiración entre ramas con distinta área foliar. Para estos debe mantener constante las variables ambientales. Mida el área de foliar una vez terminada la experiencia. Expresé sus resultados en un gráfico de transpiración versus área foliar.
- b) Comparación de la transpiración bajo distintas condiciones ambientales: (p.e., Bien iluminada, Sombreada, Viento). Debe mantener constante el área foliar. Expresé sus resultados en una tabla indicando la tasa de transpiración promedio bajo las distintas condiciones experimentales.

Discuta los mecanismos que permitan explicar las diferencias encontradas.

Experiencia 2. Utilización del Sistema Portátil de Fotosíntesis.

Evalúe la tasa de transpiración ($\text{mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$) de sus plantas instaladas en los maceteros de 1 m. Registre además la radiación ($\mu\text{mol Fotones m}^{-2} \text{ s}^{-1}$), tasa de fotosíntesis neta ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$), temperatura de la hoja y del aire ($^{\circ}\text{C}$).

Cada sección de Laboratorio (Grupos 1 y 2) deben reunir sus resultados para permitir comparar la tasa de transpiración entre especies en estudio (tomate, poroto, etc.) y tratamiento (aire libre e invernadero). Considere esto para el análisis estadístico de sus resultados.

Mantenga ordenadamente todos los datos de fotosíntesis hasta el laboratorio 5 (Eficiencia en el uso del agua).

LEER:

Percy RW, ED Schulze y R Zimmerman (1990) Measurement of transpiration and leaf conductance. En: Pearcy R.W., J. Ehleringer, H.A. Mooney y P.W. Rundel (eds) Plant Physiological Ecology: Field Methods and Instrumentation. Chapman and Hall. Capítulo 8.

Field CB, JT Ball y JA Berry. Photosynthesis: principles and field techniques. En: Pearcy R.W., J. Ehleringer, H.A. Mooney y P.W. Rundel (eds) Plant Physiological Ecology: Field Methods and Instrumentation. Chapman and Hall. Capítulo 11.

Laboratorio 4: Caracterización hídrica (Curvas PV)

Preparación previa: Corte bajo agua ramillas terminales de una especie. Deje por 24 horas en oscuridad en un ambiente saturado de agua.

Mediciones: obtenga el peso fresco a saturación (PFsat), y en medidas repetidas obtenga potencial hídrico (Ψ , con bomba de presión) y peso fresco (PF). Una vez estabilizada las mediciones, obtenga el peso seco (PS) de la ramilla que utilizó (seque en una estufa por 48 h a 75°C).

Cálculos:

a) Calcule el contenido relativo de agua en cada medida:

$$CRA = (PF - PS) / (PF_{sat} - PS)$$

b) Haga un gráfico de $1/\Psi$ versus $1 - CRA$. Haga una regresión con la parte lineal de la curva (por debajo del punto de pérdida de turgor). Determine el potencial osmótico a máximo turgor (Ψ_{π}^{100}), el potencial osmótico en el punto de pérdida de turgor (Ψ_{π}^0), el CRA en el punto de pérdida de turgor, y el contenido de agua apoplástico.

c) Reste el componente osmótico y grafique el potencial de presión (turgor) versus $1 - CRA$. Calcule el módulo de elasticidad.

d) Calcule la capacitancia del tejido analizado (ver Koide et al. 1990, pág. 177-178)

LEER:

Koide RT, RH Robichaux, SR Morse y CM Smith (1990) Plant water status, hydraulic resistance and capacitance. En: Pearcy R.W., J. Ehleringer, H.A. Mooney y P.W. Rundel (eds) Plant Physiological Ecology: Field Methods and Instrumentation. Chapman and Hall. Capítulo 9. Pág. 168-173, 177-178.

Laboratorio 5: Eficiencia en el uso del agua (EUA)

Experiencia 1: EUA y radiación.

Utilizando el sistema portátil de fotosíntesis, haga mediciones de fotosíntesis (A) y transpiración (E) utilizando como variable la radiación. Grafique A, E y A/E versus radiación.

La fotosíntesis se expresa en $\text{mol m}^{-2} \text{s}^{-1}$, mientras que la transpiración en $\text{mmol m}^{-2} \text{s}^{-1}$

Experiencia 2: EUA en experimento de sistema radicular.

Utilizando las mediciones de fotosíntesis y transpiración, obtenga la EUA cada muestra. Haga un análisis de varianza, utilizando el mismo diseño del laboratorio 1.

LEER:

Field CB, JT Ball y JA Berry. Photosynthesis: principles and field techniques. En: Pearcy R.W., J. Ehleringer, H.A. Mooney y P.W. Rundel (eds) Plant Physiological Ecology: Field Methods and Instrumentation. Chapman and Hall. Capítulo 11.

SALIDA A TERRENO

En esta actividad práctica el alumno debe integrar los conocimientos adquiridos en el presente curso y en las otras asignaturas cursadas. Dado que la decisión final del lugar y actividades a desarrollar se tomarán durante el desarrollo del curso, y también dependerán de sus intereses y contribución a la formulación de hipótesis, la pauta de trabajo será entregada más adelante.

Sin embargo, es importante tener en cuenta las siguientes recomendaciones generales.

- 1) Vestimenta adecuada para terreno (pensar en todo tipo de clima). No son recomendables zapatos abiertos o con tacos.
- 2) Alimento y agua. Recuerde preparar una colación de terreno consistente en emparedados, fruta y mucha agua. No es recomendable comida preparada.
- 3) Asistencia y puntualidad. Las salidas a terreno tienen un alto costo y son consumidora de tiempo. Por respeto a sus compañeros debe llegar antes de la hora de salida. No es posible recuperar esta actividad, por lo que no corra el riesgo de perderla. La asistencia es obligatoria.
- 4) Análisis de los datos. El análisis de los datos debe ser consecuente con el objetivo de la investigación que realizará en terreno. Tenga muy claro el objetivo antes de la salida a terreno, esto facilitará la toma de datos y el posterior análisis e interpretación.
- 5) Para entregar el informe, utilice la Pauta para redactar un informe científico.