Plants in Action

ADAPTATION IN NATURE, PERFORMANCE IN CULTIVATION

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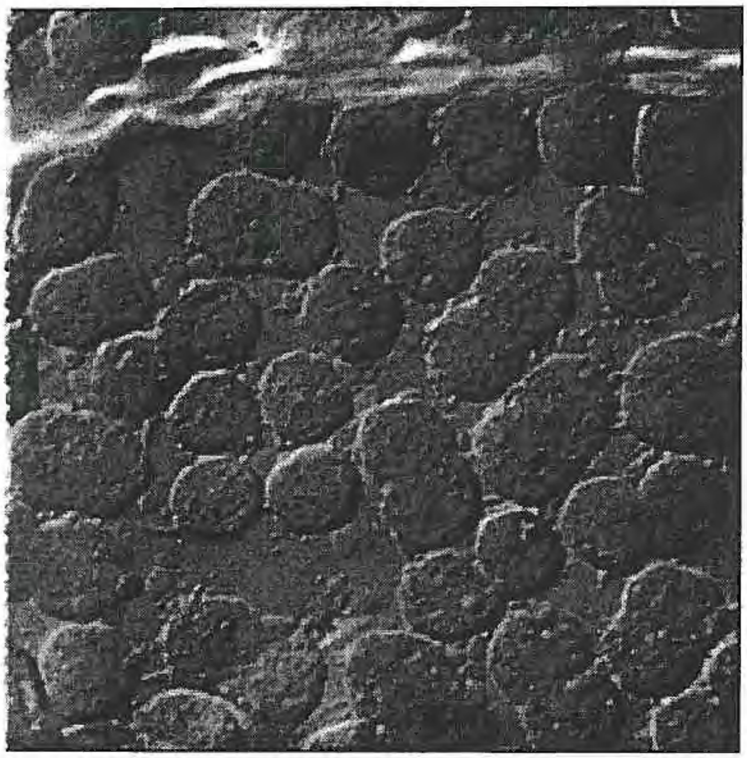
Part II Contents

1 *Light use and leaf gas exchange*



…leaves seem also designed for many other noble and important services, plants very probably drawing thro' their leaves some part of their nourishment from the air. May not light also, by freely entering the expanded surfaces of leaves and flowers, contribute much to the enobling the principles of vegetables?…

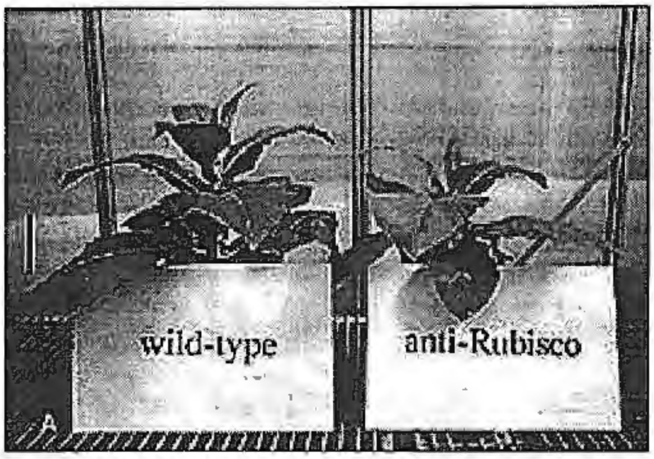
(Stephen Hales, 'Vegetable Staticks' 1727)

Chloroplasts dividing (dumbell figures) within an enlarging cell of a young spinach leaf, resulting in about 200 chloroplasts per cell at leaf maturity (Nomarski optics)
(Light micrograph courtesy John Possingham)

Chapter outline

2 *Carbon dioxide assimilation and respiration*

Chapter 2 quote to come



Rubisco (ribulose-1,5-bisphosphate carboxylase/oxygenase) is the most abundant single protein on earth and is pivotal for CO_2 assimilation by all plants. In higher plants, the holoenzyme consists of eight large subunits, each with a molecular mass of 50–55 kD (identified in (b) below), and eight small subunits of molecular mass 12–18 kD (not shown). Large subunits are encoded by a single gene in the chloroplast genome while a family of nuclear genes encode the small subunits.

Any loss of catalytic effectivess or reduction in amount translates to slower photosynthesis and reduced growth. Tobacco plants (a) transformed with an antisense construct against Rubisco (anti-Rubisco) grow more slowly than wild types due to a 60% reduction in photosynthetic rate. Immunodetection of the large subunit polypeptide of Rubisco with an anti-Rubisco antiserum (b) shows that the anti-Rubisco transgenic plants contain less than 50% of the Rubisco detected in wild-type tobacco plants. (Vertical bar in (a) = 10 cm)

(Photo courtesy Susanne von Caemmerer; original immunoblot courtesy Martha Ludwig)

Chapter outline

3 *Gaining water and nutrients (root function)*

A radicle may be compared with a burrowing mole, which wishes to penetrate perpendicularly into the ground. By continually moving its head from side to side, or circumnutating, he will feel any stone or other obstacle, as well as any difference in the hardness of the soil, and he will turn from that side; if the earth is damper on one than the other side he will turn thitherward as a better hunting-ground. Nevertheless, after each interruption, guided by the sense of gravity, he will be able to recover his downward course and burrow to a greater depth.

(Charles Darwin, The Power of Movement in Plants, *1881)*

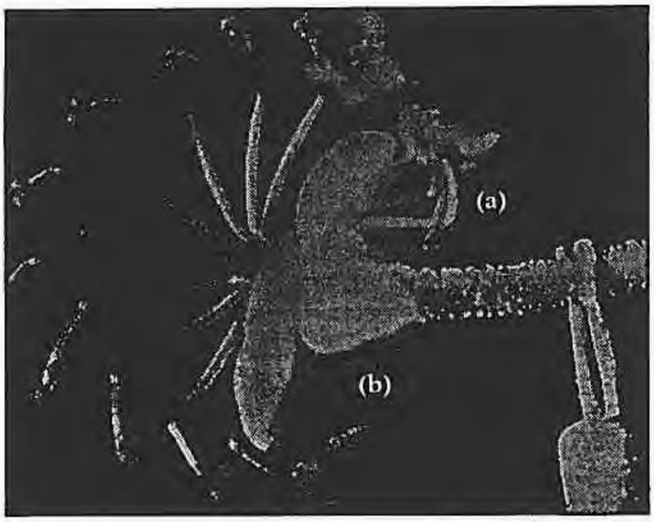
Seedlings of *Eucalyptus globulus* which have formed an ectomycorrhizal association with the fungus, *Hebeloma*, whose white mycelium can be seen ramifying through the soil and forming basidiomes (toadstools) above the soil. (see Colour Plate xx)

Chapter outline

4 Using water and nutrients (cell growth)

The almost infinite variety of vegetable forms, which have been grouped into no less than 82,606 distinct species, is formed of but one elementary material, made up of multitudes of little vesicles or bladders, called CELLS. The tissue of which they are composed, when first formed, is called cellulose. The different forms of this TISSUE are held together by a living mucus, a gummy fluid, out of which the tissue itself is made.

(C. Baker Plants, the Earth and Minerals, mid-nineteenth Century)

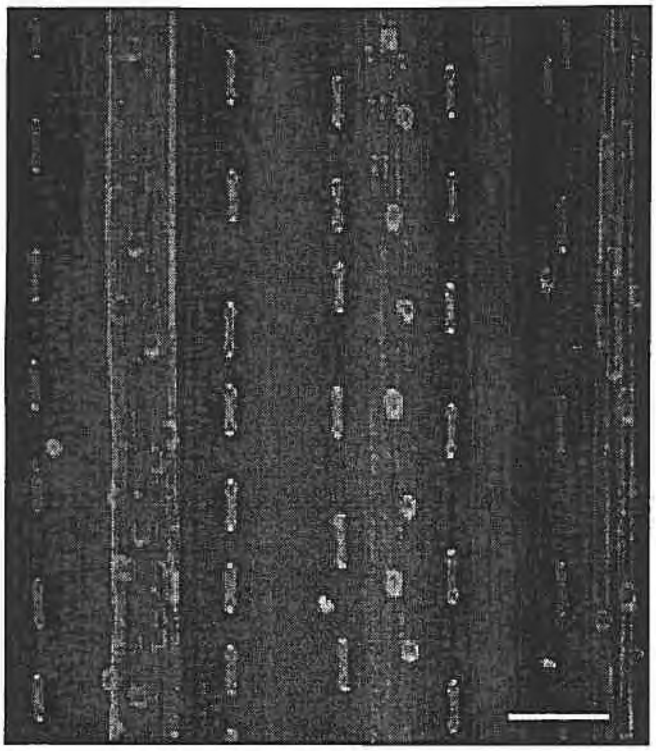


A sequence of superimposed images captures the flower column of a trigger plant (Stylidium crassifolium) as it 'fires' in response to a physical stimulus (in nature, an insect). A 1 cm column rotates through more than 200° from a]cocked position' in 10–30 ms (photographs taken at 2 ms intervals). The kinetic energy manifested in this rapid firing is derived from events controlled at a membrane levels. Ions transported into specialised cells cause hydrostatic (turgor) pressure to develop which is suddenly dissipated following mechanical stimulation. Similar rapid movemeents occur in mimosa (sensitive plant) and some carnivorous plants

(Based on Findlay and Findlay 1975, and reproduced with permission)

Chapter outline

5 Vascular integration and resource storage



Surface view of cleared whole mount of a wheat leaf showing large and small parallel veins (mauve). Lines of stomata (orange guard cells) lie along the flanks of these veins. Water evaporates from the wet walls of mesophyll cells below the stomata, drawing water from the veins through sheath cells. Bar represents 100 µm (see Colour Plate xx)
(Photograph courtesy Margaret McCully)

... what quantities of moisture trees do daily imbibe and perspire: now the celerity of the sap must be very great, if that quantity of moisture must, most of it, ascend to the top of the tree, then descend, and ascend again, before it is carried off by perspiration.

(S. Hales, Vegetable Staticks, 1727)

Chapter outline

6 *Growth analysis: a quantitative approach*

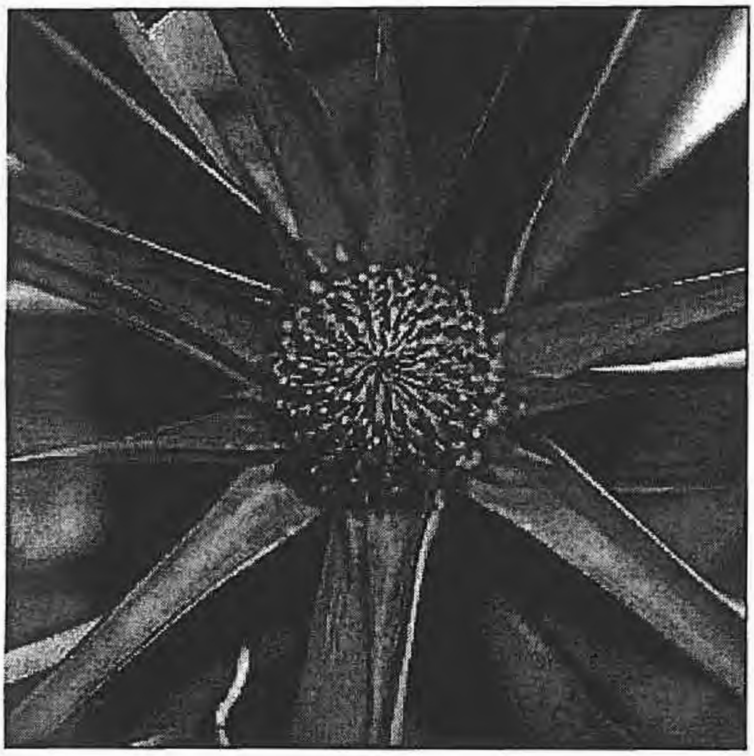
...and he gave it for his opinion, that whosoever would make two ears of corn or two blades of grass to grow where only one grew before would deserve better of mankind, and do more essential service to his country, than the whole race of politicians put together...

(Jonathan Swift, Gulliver's Travels, 1726)

Highly productive multiple cropping in a CO_2-enriched greenhouse at CSIRO Merbein, 1978
(Original photograph courtesy Ted Lawton)

Chapter outline

7 Plant growth and options for reproduction



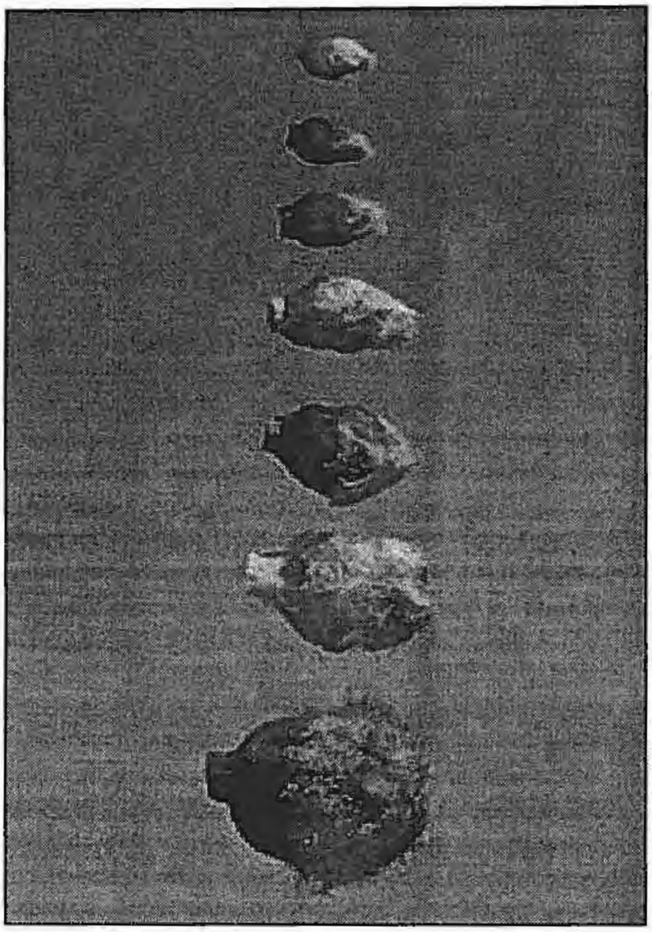
We should always keep in mind the obvious fact that the production of seed is the chief end of the act of fertilisation; anthat this end can be gained by hermaphrodite plants with incomparably greater certainty by self-fertilisation, than by the union of the sexual elements belonging to two distinct flowers or plants. Yet it is unmistakably plain that innumerable flowers are adapted for cross-fertilisation.

(Charles Darwin, The Effects of Cross and Self Fertilisation in the Vegetable Kingdom, 1876)

Figure 7.0 Developing pineapple inflorescence showing spiral phyllotaxis
(Photograph courtesy C.G.N. Turnbull)

Chapter outline

8 *Physical cues for growth and reproduction*



Amongst other fundamental properties, the protoplasm of plants is endowed with that of irritability, a certain sensitiveness, that is, to the influence of external agents.

(Sydney Howard Vines, Lectures on the Physiology of Plants, 1886)

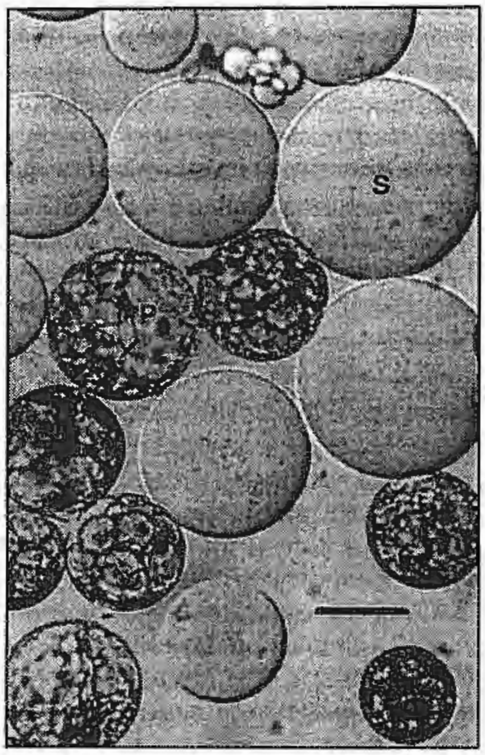
On the one hand, the farmer is concerned with the living plant; on the other, with that complex set of factors we call the environment ... A plant, like an animal, is a sensitive living thing. Plants make responses to their environment [which] ... may be expressed in tons of leaves and stems, in tons of roots, in pounds of seed or grain, in barrels of fruit, or in per cent of sugar, or starch, or acid ... First, we must understand something of the structure and functions of the plant. Second, we must have a knowledge of the various factors of the environment. And, third, we must know the manner in which the plant behaves under a given set of conditions. This is a big order. It is asking much.

(Wilfred W. Robins, Principles of plant growth, 1927)

Adaptation of a temperate plant, peach, to cropping in the sub-tropics. This variety, Flordaking, has been bred with reduced dormancy which confers a 'low chill' requirement. This allows the reproductive cycle to proceed at latitudes (29°S in this instance) where winters are insufficiently cold to break the deeper dormancy of normal 'high chill' varieties. Developing flowers were excised from within the protective bud scales over a period from early autumn (March, left) to mid-winter (July, right) and show continued slow growth throughout (? see Colour Plate xx)
(Photograph courtesy J.J. Lloyd and C.G.N. Turnbull)

Chapter outline

9 *Plant hormones: chemical signalling in plant development*



Consider... a plant not as a packaged collective of independent processes but as a highly interactive network of perception, control and feedback. Every plant has a genetic blueprint that specifies its whole range of morphology and physiology, but the individual is shaped, sometimes literally, by the environment it experiences. Integration of development and adjustment to the external environment are achieved through multiple coordinating signals throughout the plant.

Perception of gibberellin in germinating cereals. Protoplasts (P) isolated from aleurone cells of wild oat (Avena fatua) were incubated with Sepharose beads (S) to which gibberellin molecules had been covalently attached. The gibberellin therefore could not enter the cells, but was still able to induce production of α-amylase enzyme. This means that perception of gibberellin probably occurs via and outward-facing receptor in the plasma membrane. Scale bar = 60 μm (? see Colour Plate xx) *(Reproduced, with permission, from Hooley et al. (1991)*

Chapter outline

10 *Differentiation and gene expression*

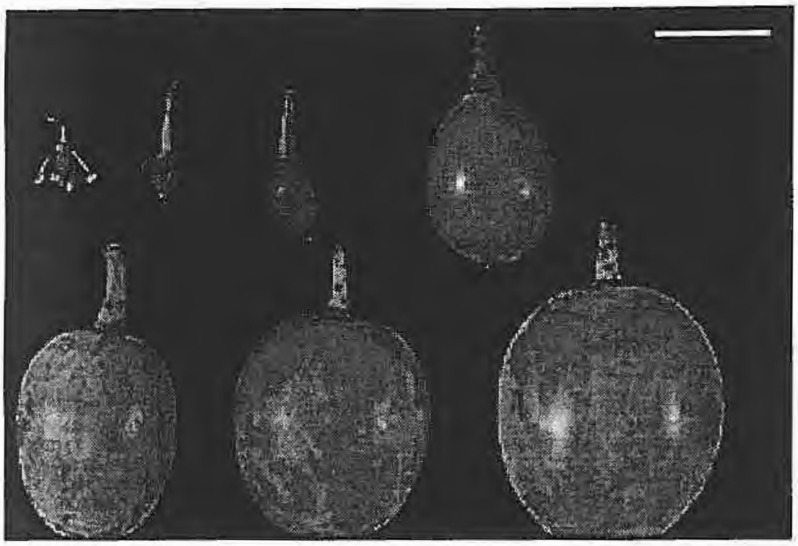
Simply, the organism is a unique result of both its genes and the temporal sequence of environments through which it has passed, and there is no way of knowing in advance, from the DNA sequence, what the organism will look like, except in general terms.

(R.C. Lewontin (1997) 'Genes, environment, and organisms', Hidden Histories of Science, ed. R.B. Silvers, 115–140, Granta Books: London)

Ripening of fruit such as tomato involves a tightly regulated sequence of physiological transitions and changes in expression of several genes, with the plant hormone ethylene playing a coordinating role. The visible colour change from green to red is due to chlorophyll degradation and synthesis of red lycopene pigment. Around this time respiration rate increases, ethylene synthesis accelerates, cell wall softening genes are expressed, aroma and flavour compounds are synthesised, and acids and starch are converted to sugars. Overall, this packaging is an attractive food to many animals and the benefit to the plant is increased probability of seed dispersal (see Colour Plate xx) *(Photograph courtesy J.D. Hamill)*

Chapter outline

11 *Fruit growth and postharvest physiology*



A grape is a 'berry', so that fruits on Sultana grapevines are stenospermocarpic berries! Pollination and fertilisation were successful, but embryos so formed soon aborted. Pericarp tissues none the less continued their development to produce the familiar item of commerce about 100 d later. A range of stages in that development is shown here. Upper-row fruit illustrate stages in preveraison development where fruit are small, hard, green and accumulating organic acid. Postveraison fruit (lower row) are translucent, soft textured, enlarging rapidly and accumulating sugar. (Vertical bar = 5 mm)

(Original photograph courtesy Ted Lawton, CSIRO Horticulture, Merbein, Victoria)

Whence it is probable, that the use of these leaves, (which are placed, just where the fruit joins the tree) is to bring nourishment to the fruit. And accordingly, I observe ... that all peach leaves are pretty large before the blossom goes off; And that in apples and pears the leaves are one third or half grown, before the blossom blows: So provident is nature in making timely provision for the nourishing the yet embrio fruit...

(Stephen Hales, Vegetable Staticks, 1727)

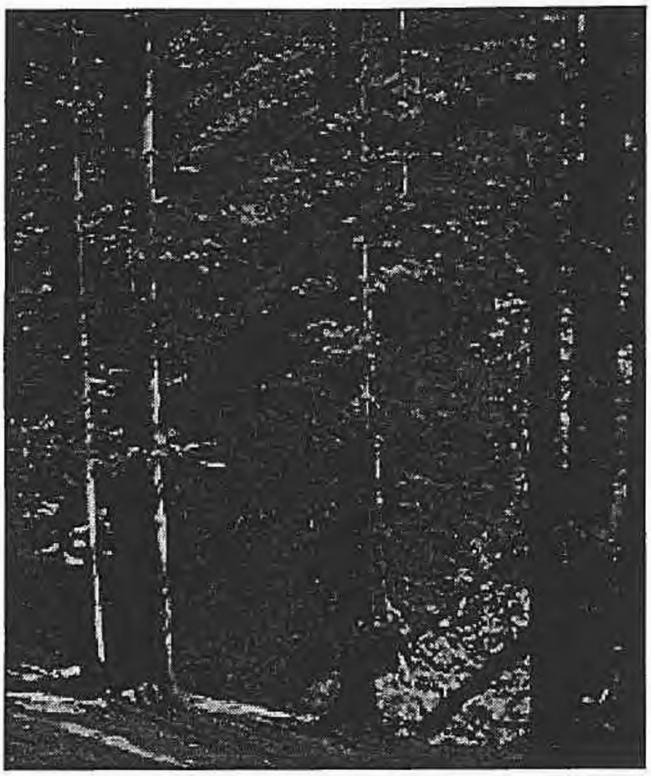
Most of the exaggerated developments of certain parts of the basic fruit structure arose naturally but have been accentuated by modern breeding programs to maximize the desirable features of each fruit and minimize the superfluous features. The production of seedless cultivars of certain fruits represents an extreme development in this latter respect.

(Wills et al., Postharvest 1989)

Chapter outline

Part IV Contents

12 Sunlight: an all-pervasive source of energy



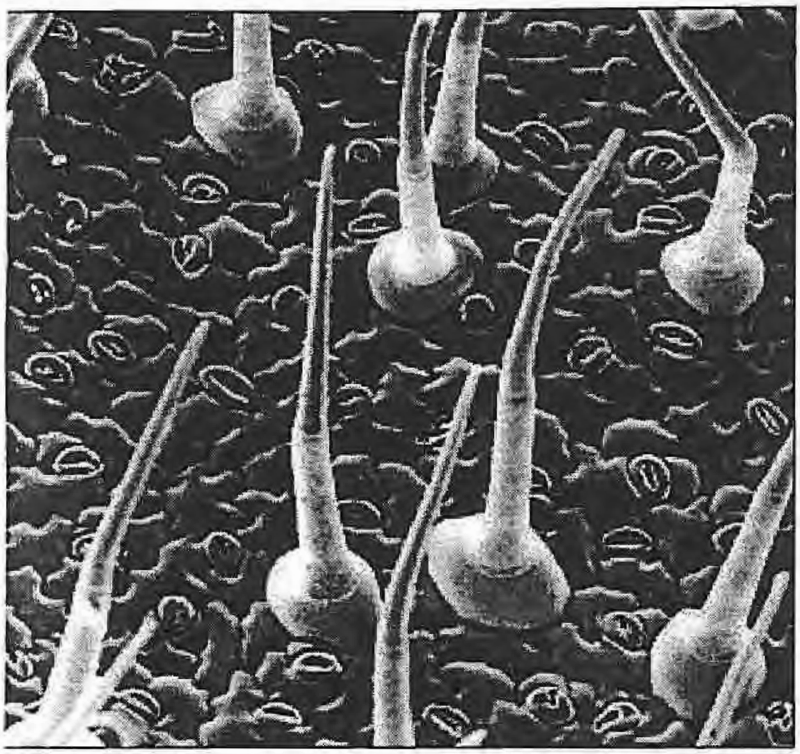
The device by which an organism maintains itself stationary at a fairly high level of orderliness (= fairly low level of entropy) really consists in continually sucking orderliness from its environment... plants... of course, have their most powerful supply of 'negative entropy' in the sunlight

(Schrödinger 1944)

Shafts of sunlight penetrate a forest of *Araucaria heterophylla* at Point Blackbourne on Norfolk Island
(Original photograph courtesy D.H. Ashton)

Chapter outline

13 *Carbon dioxide: a universal substrate*



...it is through their leaves that plants...draw some part of their nourishment from the air...

Stephen Hales, Vegetable Staticks', (1727)

Lower surface of a tomato leaf showing a 'forest' of epidermal hairs and an abundance of tiny stomata through which plants 'draw some part of their nourishment'! (Scale bar = 100 µm) *(Original scanning electron micrograph courtesy Stuart Craig and Celia Miller, CSIRO Plant Industry, Canberra 1997)*

Chapter outline

14 *Temperature: a driving variable for plant growth and development*

Habit is hereditary with plants, ... and this leads me to say a few words on acclimatisation. As it is extremely common for distinct species belonging to the same genus to inhabit hot and cold countries, if it be true that all the species in the same genus are descended from a single parent-form, acclimatisation must be readily effected during a long course of descent. It is notorious that each species is adapted to the climate of its own home: species from an arctic or even from a temperate region cannot endure a tropical climate or conversely ... But whether or not this adaptation is in most cases very close, we have evidence with few plants, of their becoming, to a certain extent, naturally habituated to different temperatures; that is, they become acclimatised: ...

(Charles Darwin, The Origin of Species, 1910 edition)

Fighting ice with ice! Alleviating frost damage in a New Zealand orchard with overhead sprinklers. Plant tissues encased in ice that is continuing to form will remain at 0°C, that is, just above the threshold for injury
(Original photograph courtesy E. W. Hewett, Massey University)

Chapter outline

15 *Water: a limiting factor*

With perceptive phrasing, Les Murray (1991) summarises structural aspects of a gum forest as:

'Flooded-gums on creek ground, each tall because of each'

and in conceptualising water relations,

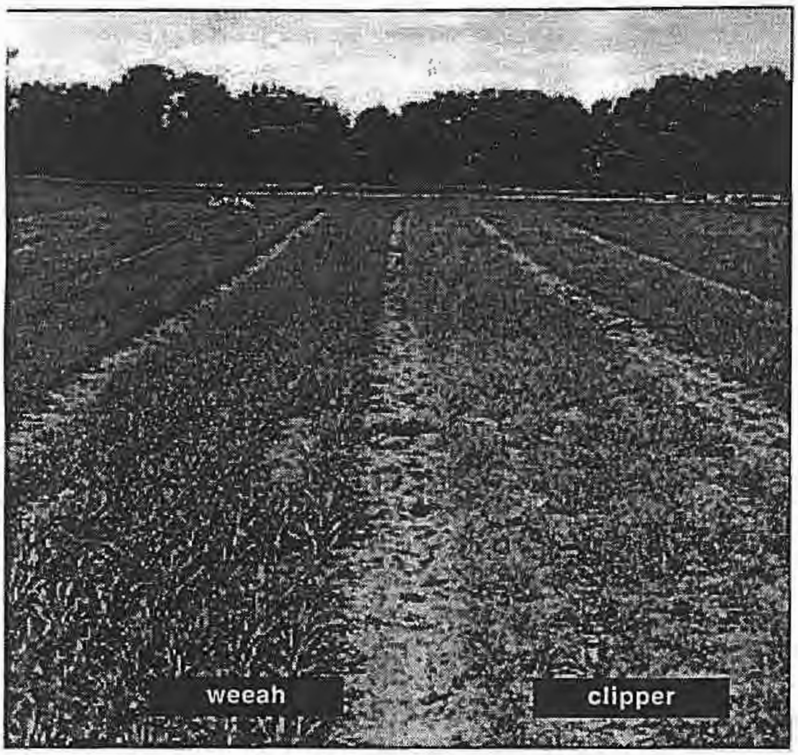
Foliage builds like a layering splash: ground water drily upheld in edge-on, wax-rolled, gall-puckered leaves upon leaves. The shoal life of parrots up there.

(Les Murray (1991), Collected Poems*)*

A superb stand of flooded gums (Eucalyptus grandis) near Coffs Harbour, northern New South Wales, 'each tall because of each' (Les Murray (1991), *Collected Poems*) *(Original photograph by Ken Eldridge, supplied by Peter Burgess, CSIRO Forestry and Forest Products)*

Chapter outline

16 *Nutrients: a sparse resource*



There is a need to optimize the productivity of infertile and problem soils in order to meet increasing world-wide demand for agricultural and forestry products *and we now* recognise the increasingly important role of selection and breeding of plants specifically for such soils. Plant breeding solutions will complement agronomic methods to achieve these objectives in a manner which is both economically sound and ecologically responsible

(Randall 1993; italics added)

Figure 16.0 A demonstration of genetic differences between two varieties of barley (*Hordeum vulgare*) in their tolerance to a manganese-deficient soil near Warooka, South Australia. Overall crop response to a foliar spray equivalent to 6 kg manganese per hectare is evident in shoot growth (middle background behind arrow). While unsprayed plots in the foreground are less productive, the cultivar Weeah (left side) tolerates this low-manganese soil better than Clipper (right side)
(Original photograph courtesy R.J. Hannam, South Australian Department of Agriculture, 1982)

Chapter outline

17 *Salt: an environmental stress*

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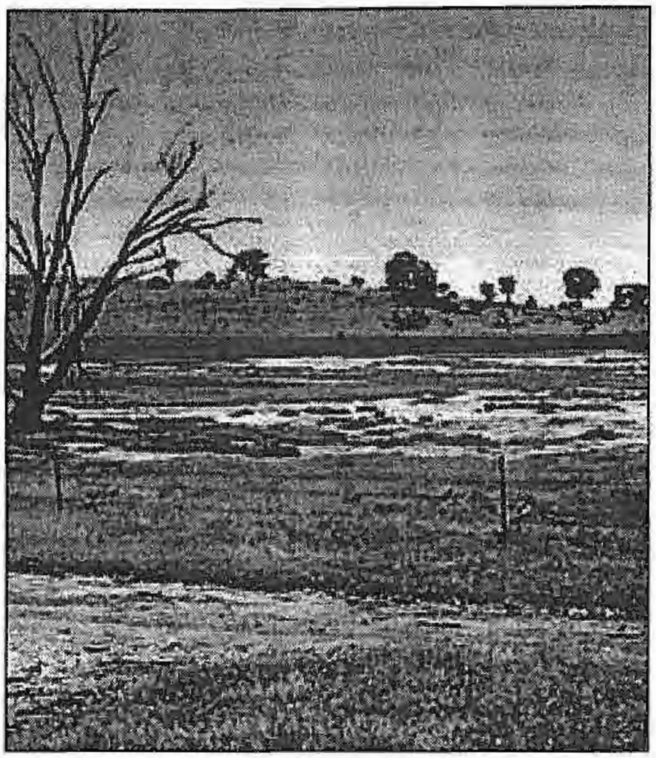

Salinity, like drought, remains as one of the world's oldest and most serious environmental problems. Mistakes made by the Sumerians in the Tigris and Euphrates basin of Mesopotamia over 4000 yeas ago are being repeated today...

(McWilliam 1986)

Secondary salinisation near Ouyen, Victoria, showing a lower slope discharge zone for saline groundwater. Established eucalypts have died, and salt is encroaching upslope into grazing land. Local hydrologic balance was disturbed by land clearing which increased groundwater accession and led to a subsequent rise in water tables
(Original photograph courtesy P.E. Kriedemann)

Chapter outline

18 *Waterlogging and submergence: surviving poor aeration*

A permanent body of water in Kakadu National Park, Northern Territory, showing a range of species thriving in a flooded environment. Submerged tubers of *Nymphaea violacea* produce long underwater stems that support a floating leaf, while spectacular flowers are supported on pedoles projecting from the water surface, as seen on the book cover. Woody species that also exhibit flood tolerance can be seen in the background: these include the dense canopy of a freshwater mangrove (*Barringtonia acutangula*), a single tree (*Lophostemon grandiflorum* ssp. *riparius*) growing in the open water and stands of river red gum (*Eucalyptus camaldulensis*) growing along the waterlogged banks *(Photograph courtesy of S. Jacobs)*

After Colonel Byrd discovered and named The Great Dismal Swamp in seventeenth century America, his disenchantment was recorded in the Westover Manuscripts thus:

> ...the foul damps ascend without ceasing, corrupt the air and render it unfit for respiration...Never was Rum, that cordial of Life, found more necessary than in this Dirty place.
>
> *Colonel William Byrd III (1929) 'Histories of the Dividing Line Betwixt Virginia and North Carolina' North Carolina Historical Commission, Raleigh*

Chapter outline

19 *Fire: an ecosystem sculptor*

...and he looked, and behold, the bush burned with fire and the bush was not consumed...

(Moses in the Book of Exodus)

Fires often consume the large fuel loads produced by cane grass at the end of each dry season in the Kakadu National Park of northern Australia. Here a savanna woodland burns vigorously, leaving the sclerophyllous eucalypts blackened but alive and able to regrow in the following season (see Colour Plate xx)
(Photograph courtesy of Michael Douglas)

Chapter outline

20 *Herbicide resistance: a case of rapid evolution*

Amid young flowers and tender grass
Thy endless infancy shall pass;
And, singing down thy narrow glen,
Shalt mock the fading race of men.

William Cullen Bryant, The Rivulet, 1794–1878

Herbicide-resistant *Lolium rigidum* infesting railway lines in Western Australia. Following 10 years of use of atrazine and amitrole to control weeds, a monoculture of *L. rigidum* resistant to these two herbicides has evolved alongside the tracks (see Colour Plate xx)

Chapter outline