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C. R. ADAMS · K. M. BAMFORD · M. P. EARLY

PRINCIPLES OF HORTICULTURE

FIFTH EDITION

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Fifth edition

C.R. Adams, K.M. Bamford and M.P. Early

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Butterworth-Heinemann is an imprint of Elsevier

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Butterworth-Heinemann is an imprint of Elsevier
Linacre House, Jordan Hill, Oxford OX2 8DP, UK
30 Corporate Drive, Suit 400, Burlington, MA 01803, USA

First published 1984
Reprinted 1985, 1987, 1988, 1990, 1991, 1992
Second edition 1993
Third edition 1998
Reprinted 1999
Fourth edition 2004
Fifth edition 2008

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloguing in Publication Data
A catalogue record for this book is available from the Library of Congress

ISBN: 978-0-7506-8694-5

For information on all Butterworth-Heinemann publications
visit our web site at http://www.elsevierdirect.com

Typeset by Charon Tec Ltd., A Macmillan Company
(www.macmillansolutions.com)

Printed and bound in Slovenia

08 09 10 11 12 10 9 8 7 6 5 4 3 2 1

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Preface

By studying the principles of horticulture, one is able to learn how and why plants grow and develop. In this way, horticulturists are better able to understand the responses of the plant to various conditions, and therefore to perform their function more efficiently. They are able to *manipulate* the plant so that they achieve their own particular requirements of maximum yield and/or quality at the correct time. The text therefore introduces **the plant** in its own right, and explains how a correct naming method is vital for distinguishing one plant from another. The internal structure of the plant is studied in relation to the functions performed in order that we can understand why the plant takes it particular form. The environment of a plant contains many variable factors, all of which have their effects, and some of which can dramatically modify growth and development. It is therefore important to distinguish the effects of these factors in order to have precise control of growth. The environment which surrounds the parts of the plant above the ground includes factors such as light, day-length, temperature, carbon dioxide and oxygen, and all of these must ideally be provided in the correct proportions to achieve the type of growth and development required. The growing medium is the means of providing nutrients, water, air and usually anchorage for the plants.

In the wild, a plant will interact with other plants, often to different species and other organisms to create a balanced community. Ecology is the study of this balance. In growing plants for our own ends we have created a new type of community which creates problems – problems of competition for the environmental factors between one plant and another of the same species, between the crop plant and a weed, or between the plant and a pest or disease organism. These latter two competitive aspects create the need for **crop protection**.

It is only by identification of these competitive organisms (weeds, pests and diseases) that the horticulturist may select the correct method of control. With the larger pests there is little problem of recognition, but the smaller insects, mites, nematodes, fungi and bacteria are invisible to the naked eye and, in this situation, the grower must rely on the **symptoms** produced (type of damage). For this reason, the pests are covered under major headings of the organism, whereas the diseases are described under symptoms.

Symptoms (other than those caused by an organism) such as frost damage, herbicide damage and mineral deficiencies may be confused with pest or disease damage, and reference is made in the text to this problem. Weeds are broadly identified as perennial or annual problems. References at the end of each chapter encourage students to expand their knowledge of symptoms. In an understanding of crop protection, the **structure** and **life cycle** of the organism must be emphasized in order that specific measures, e.g. chemical control, may be used at the correct time and place to avoid complications such as phytotoxicity, resistant pest production or death of beneficial organisms. For this reason, each weed, pest and disease is described in such a way that **control** measures follow logically from an understanding of its biology. More detailed explanations of **specific** types of control, such as biological control, are contained in a separate chapter where concepts such as economic damage are discussed.

This book is not intended to be a reference source of weeds, pests and diseases; its aim is to show the *range* of these organisms in horticulture. References are given to texts which cover symptoms and life cycle stages of a wider range of organisms. Latin names of species are included in order that confusion about the varied common names may be avoided.

Growing media include soils and soil substitutes such as composts, aggregate culture and nutrient film technique. Usually the plant's water and mineral requirements are taken up from the growing medium by roots. Active roots need a supply of oxygen, and therefore the root environment must be managed to include aeration as well as to supply water and minerals. The growing medium must also provide anchorage and stability, to avoid soils that 'blow', trees that uproot in shallow soils or tall pot plants that topple in lightweight composts.

The components of the soil are described to enable satisfactory root environments to be produced and maintained where practicable. Soil conditions are modified by cultivations, irrigation, drainage and liming, while fertilizers are used to adjust the nutrient status to achieve the type of growth required.

The use of soil substitutes, and the management of plants grown in pots, troughs, peat bags and other containers where there is a restricted rooting zone, are also discussed in the final chapter.

The importance of the plant's aerial environment is given due consideration as a background to growing all plants notably their **microclimate**, its measurement and methods of modifying it. This is put in context by the inclusion of a full discussion of the **climate**, the underlying factors that drive the weather systems and the nature of local climates in the British Isles.

There has been an expansion of the **genetics** section to accommodate the need for more details especially with regard to genetic modification (GM) to reflect the interest in this topic in the industry. The changes in the classification system have been accommodated and the plant divisions revised without losing the familiar names of plant groups, such as monocotyledon, in the text. Concerns about **biodiversity** and the interest in plant conservation are addressed along with more detail on ecology and companion planting. More examples of plant adaptions have been provided and more emphasis has been given to the practical application of plant form in the leisure use of plants. The use of pesticides has been revised in the light of continued regulations about their use. More details have been included on the use of inert growing media such as **rockwool**.

Essential definitions have been picked out in tinted boxes alongside appropriate points in the text. Further details of some of the science associated with the principles of growing have been included for those who require more backgound; these topics have been identified by boxing off and tinting in grey.

The fifth edition is in full colour and has been reorganized to align closely with the syllabus of the very popular **RHS Certificate of Horticulture**. To this end, the chapters have been linked directly to the learning outcomes of the modules that cover The Plant, Horticultural Plant Health Problems, the Root Environment and Plant Nutrition. Introductions to Outdoor Food Production, Protected Cultivation, Garden Planning, Horticultural Plant Selection, Establishment and Maintenance have been expanded and a new chapter on Plant Propagation has been added. The expansion of these areas has made the essential relationship between scientific principles and horticultural practice more comprehensive with the essential extensive to help relate topics across the text.

This edition of the book continues to support not only the RHS Certificate of Horticulture and other Level Two qualifications, such as the National Certificates in Horticulture, but also provides an introduction to Level Three qualifications including the RHS Advanced Certificate and Diploma in Horticulture, Advanced National Certificates in Horticulture, National Diplomas in Horticulture and the associated Technical Certificates. The book continues to be an instructive source of information for keen gardeners, especially those studying Certificate in Gardening modules and wish to learn more of the underlying principles. Each chapter is fully supported with 'Further Reading' and self-assessment ('Check your Learning') sections.

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Katherine M Bamford

Micheal P Early

Answers to 'Check Your Learning' on free website

A selection of answers to the 'Check Your Learning' sections found at the end of each chapter is available as a free download at http:/elsevierdirect.com/companions/9780750686945.

Acknowledgements

We are indebted to the following people without whom the new edition would not have been possible:

The dahlia featured on the cover is 'Western Spanish Dancer' and is with the kind permission of Aylett Nurseries Ltd.

Nick Blakemore provided the microscope photographs used on the cover and through the plant section of the new edition.

Thanks are also due to the following individuals, firms and organizations that provided photographs and tables:

Access Irrigation Limited

Agricultural Lime Producers' Association

Alison Cox

Cooper Pegler for sprayer

Dr C.C. Doncaster, Rothamsted Experimental Station

Dr P.R. Ellis, National Vegetable Research Station

Dr P. Evans, Rothamsted Experimental Station

Dr D. Govier, Rothamsted Experimental Station

Dr M. Hollings, Glasshouse Crops Research Institute

Dr M.S. Ledieu, Glasshouse Crops Research Institute

Dr E. Thomas, Rothamsted Experimental Station

Kenwick Farmhouse Nursery, Louth

KRN Houseplants

Micropropagation Services (EM) Ltd.for tissue culture photographs

Shell Chemicals

Syngenta Bioline for biological control

Soil Survey of England and Wales

Two figures illustrating weed biology and chemical weed control are reproduced after modification with permission of Drs H.A. Roberts, R.J. Chancellor and J.M. Thurston. Those illustrating the carbon and nitrogen cycles are adapted from diagrams devised by Dr E.G. Coker who also provided the photograph of the apple tree root system that he had excavated to expose the root system.

Contributions to the fifth edition were made by Chris Bird, Sparsholt College; Drs S.R. Dowbiggin and Jane Brooke, Capel Manor College; Anna Dourado; Colin Stirling, HortiCS; with essential technician support from David Carmichael and Terry Laverack.

Chapter 1 Horticulture in context

Summary

This chapter includes the following topics:

- **The nature of horticulture**
- **Manipulating plants**
- **Outdoor food production**
- **Protected culture**
- **Service horticulture**
- **Organic growing**

Figure 1.1 Horticultural produce

The nature of horticulture

Horticulture may be described as the practice of growing plants in a relatively intensive manner. This contrasts with agriculture, which, in most Western European countries, relies on a high level of machinery use over an extensive area of land, consequently involving few people in the production process. The boundary between the two is far from clear, especially when considering large-scale **outdoor production**. When vegetables, fruit and flowers are grown on a smaller scale, especially in gardens or market gardens, the difference is clearer cut and is characterized by a large labour input and the grower's use of technical manipulation of plant material. **Protected culture** is the more extreme form of this where the plants are grown under protective materials or in glasshouses.

There is a fundamental difference between production horticulture and service horticulture which is the development and upkeep of gardens and landscape for their amenity, cultural and recreational values. Increasingly horticulture can be seen to be involved with social well-being and welfare through the impact of plants for human physical and mental health. It encompasses environmental protection and conservation through large- and small-scale landscape design and management. The horticulturists involved will be engaged in plant selection, establishment and maintenance; many will be involved in aspects of garden planning such as surveying and design.

There may be some dispute about whether **countryside management** belongs within horticulture, dealing as it does with the upkeep and ecology of large semi-wild habitats. In a different way, the use of alternative materials to turf as seen on all-weather sports surfaces tests what is meant by the term horticulture.

This book concerns itself with the principles underlying the growing of plants in the following sectors of horticulture:

- **Outdoor production** of vegetables, fruit and/or flowers (see p5).
- **Protected cropping**, which enables plant material to be supplied outside its normal season and to ensure high quality, e.g. chrysanthemums, all the year round, tomatoes to a high specification over an extended season, and cucumbers from an area where the climate is not otherwise suitable. Plant propagation, providing seedlings and cuttings, serves outdoor growing as well as the glasshouse industry. Protected culture using low or walk-in polythene covered tunnels is increasingly important in the production of vegetables, salads, bedding plants and flowers.
- **Nursery stock** is concerned with the production of soil- or container-grown shrubs and trees. Young stock of fruit may also be established by this sector for sale to fruit growers: **soft fruit** (strawberries, etc.), **cane fruit** (raspberries, etc.) and **top fruit** (apples, pears, etc.).
- **Landscaping**, **garden construction** and maintenance that involve the skills of construction together with the development of planted

areas (**soft landscaping**). Closely associated with this sector is **grounds maintenance**, the maintenance of trees and woodlands (**arboriculture** and **tree surgery**), specialist features within the garden such as walls and patios (**hard landscaping**) and the use of water (**aquatic gardening**).

- **Interior landscaping** is the provision of semi-permanent plant arrangements inside conservatories, offices and many public buildings, and involves the skills of careful plant selection and maintenance.
- **Turf culture** includes decorative lawns and sports surfaces for football, cricket, golf, etc.
- **Professional gardening** covers the growing of plants in gardens including both public and private gardens and may reflect many aspects of the areas of horticulture described. It often embraces both the decorative and productive aspects of horticulture.
- **Garden centres** provide plants for sale to the public, which involves handling plants, maintaining them and providing horticultural advice. A few have some production on site, but stock is usually bought in.

The plant

There is a feature common to all the above aspects of horticulture; the grower or gardener benefits from knowing about the factors that may increase or decrease the plant's growth and development. The main aim of this book is to provide an understanding of how these factors contribute to the ideal performance of the plant in particular circumstances. In most cases this will mean optimum growth, e.g. lettuce, where a fast turnover of the crop with once over harvesting that grades out well is required. However, the aim may equally be restricted growth, as in the production of dwarf chrysanthemum pot plants. The main factors to be considered are summarized in Figure 1.2, which shows where in this book each aspect is discussed.

In all growing it is essential to have a clear idea of what is required so that all factors can be addressed to achieve the aim. This is what makes **market research** so essential in commercial horticulture; once it is known what is required in the market place then the choice of crop, cultivar, fertilizer regime, etc., can be made to produce it accurately.

It must be stressed that the incorrect functioning of any one factor may result in undesirable plant performance. It should also be understood that factors such as the soil conditions, which affect the underground parts of the plant, are just as important as those such as light, which affect the aerial parts. The nature of soil is dealt with in Chapter 17. Increasingly, plants are grown in alternatives to soil such as peat, bark, composted waste and inert materials which are reviewed in Chapter 22.

To manage plants effectively it is important to have a clear idea of what a **healthy plant** is like at all stages of its life. The appearance of abnormalities can then be identified at the earliest opportunity and

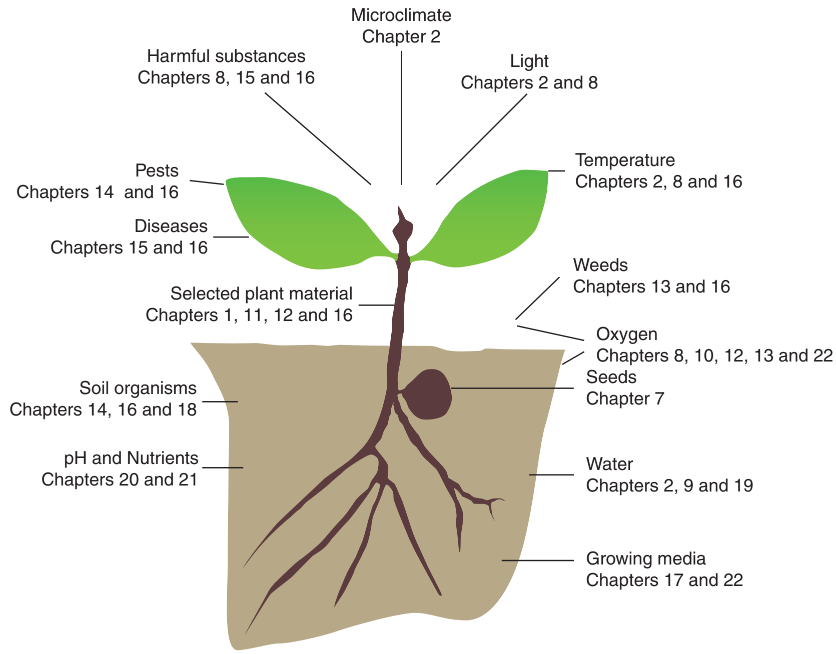

Figure 1.2 The requirements of the plant for healthy growth and development

appropriate action taken. This is straightforward for most plants, but it is essential to be aware of those which have peculiarities such as those whose healthy leaves are not normally green (variegated, purple, etc., see p82), dwarf forms, or those with contorted stems e.g. *Salix babylonica* var. *pekinensis* 'tortuosa'. The unhealthiness of plants is usually caused by pests (see Chapter 14) or disease (see Chapter 15). It should be noted that **physiological disorders** account for many of the symptoms of unhealthy growth which includes nutrient deficiencies or imbalance (see p127). Toxics in the growing medium (such as uncomposted bark, see p388) or excess of a nutrient (see p370) can present problems. Damage may also be attributable to environmental conditions such as frost, high and low temperatures, high wind (especially if laden with salt), a lack or excess of light (see p113) or water (see p122). Further details are given in Chapter 15.

Weather plays an important part in horticulture generally. It is not surprising that those involved in growing plants have such a keen interest in weather forecasting because of the direct effect of temperature, water and light on the growth of plants. Many growers will also wish to know whether the conditions are suitable for working in. Climate is dealt with in Chapter 2, which also pays particular attention to the microclimate (the environment the plant actually experiences).

A single plant growing in isolation with no competition is as unusual in horticulture as it is in nature. However, specimen plants such as leeks, marrows and potatoes, lovingly reared by enthusiasts looking for prizes in local shows, grow to enormous sizes when freed from competition. In landscaping, specimen plants are placed away from the influence of others, so that they not only stand out and act as a focal point, but also can attain perfection of form. A pot plant such as a fuchsia is isolated in its container, but the influence of other plants, and the consequent effect on its growth, depend on spacing. Generally, plants are to be found in groups, or communities (see Chapter 3).

Outdoor food production

Outdoor production of vegetables or fruit, whether on a commercial or garden scale, depends on many factors such as cultivation, propagation, timing, spacing, crop protection, harvesting and storage, but success is difficult unless the right site is selected in the first place.

Selecting a site

It is important that the plants have access to **light** to ensure good growth (see photosynthesis p113). This has a major effect on growth rate (see p110), but early harvesting of many crops is particularly desirable. This means there are advantages in growing on open sites with no overhanging trees and a southern rather than northern **aspect** (see p35).

A **free draining** soil is essential for most types of production (see drainage p343). This is not only because the plants grow better, but many of the cultural activities such as sowing, weeding and harvesting are easier to carry out at the right time (see soil consistency p342). **Earliness** and **timeliness** (p343) is also favoured by growing in light, well-drained soils which warm up quicker in the spring (see p29). Lighter soils are also easier to cultivate (see p307). For many crops, such as salads, where frequent cultivation is required the lighter soils are advantageous, but some crops such as cabbages benefit from the nature of heavier soils. In general, heavier soils are used to grow crops that do not need to be cultivated each year, such as soft fruit and top fruit in orchards, or are used for main crop production when the heavier soils are sufficiently dry to cultivate without structural damage. All horticultural soils should be well-drained unless deliberately growing 'boggy' plants.

Many tender crops, such as runner beans, tomatoes, sweet corn and the blossom of top fruit, are vulnerable to frost damage. This means the site should not be in a frost pocket (see p36). Slopes can be helpful in allowing cold air to drain off the growing area, but too steep slopes can become subject to **soil erosion** by water flow (see p298). Lighter soils, and seed, can be blown away on exposed sites (see p318).

Shelter is essential to diffuse the wind and reduce its detrimental effects. It plays an important part in extending the growing season. This can take the form of windbreaks, either natural ones such as trees or hedges or artificial ones such as webbing. Solid barriers like walls are not as effective as materials that diffuse the wind (see p37). Complete shelter is provided in the form of floating mulches, cloches, polytunnels and greenhouses (see protected culture p12).

Extending the season

Many fruits and vegetables are now regarded as commodity crops by the supermarkets and required year round. It is therefore necessary for British growers to extend the season of harvesting, within the bounds of our climate, to accommodate the market. Traditionally walled gardens provided a means to supply the 'big house' with out of season produce, but commercially this is now achieved with a range of techniques including various forms of protected cropping (see p12).

Cultural operations

Soil pH (acidity and alkalinity) levels are checked to ensure that the soil or substrate is suitable for the crop intended. If too low the appropriate amount of lime is added (see p361) or if too high sulphur can be used to acidify the soil (see p364).

Cultivations required in outdoor production depend on the plants, the site and the weather. Usually the soil is turned over, by digging or ploughing, to loosen it and to bury weeds and incorporate organic matter, then it is worked into a suitable tilth (with rakes or harrows) for seeds or to receive transplants (see p156). In many situations cultivation is supplemented or replaced by the use of rotavators (see p314). If there are layers in the soil that restrict water and root growth (see pans p312) these can be broken up with subsoilers (see p315).

Bed systems are used to avoid the problems associated with soil compaction by traffic (feet or machinery). On a garden scale, these are constructed so that all the growing area can be reached from a path so there is no need to step on it. These can be laid out in many ways, but should be no more than 1.2 metres across with the paths between minimized whilst allowing access for all activities through the growing season.

'No-dig' methods are particularly associated with organic growing (see p21). These include addition of large quantities of bulky organic matter applied to the surface to be incorporated by earthworms. This ensures the soil remains open (see p330) for good root growth as well as, usually, adding nutrients (see p376).

Freedom from weeds is fundamental to preparing land for the establishment of plants of all kinds. Whilst traditional methods involve turning over soil to bury the weeds several methods that use much less energy have become more common (see p314). Once planted the crop then has to be kept free of weeds by cultural methods or by using weed killers (see Chapter 16).

Propagation methods used for outdoor cropping include the use of seeds (p116), cuttings (p175) or grafting (p176).

Nutrient requirements are determined and are added in the form of fertilizers (see p373). They are usually applied as base dressings, top dressings, fertigation or a combination of methods (see p374).

Pest and disease control can be achieved by cultural, biological or chemical means (see Chapter 16) according to the production method adopted. This is helped by having knowledge and understanding of the causal organisms that affect the crop (Chapters 14 and 15).

Vegetable production

The choice of **cultivar** is an important decision that has to be made before growing starts. There are many possibilities for each crop, but a major consideration is the need for uniformity. Where this is important, e.g. for 'once over harvesting' or uniform size, then F1 hybrids are normally used even though they are more expensive (see p144). Required harvesting dates affect not only sowing dates but the selection of appropriate early, mid-season or late cultivars. Other factors for choice include size, shape, taste, cooking qualities, etc. Examples of carrot types to choose from are given in Table 1.1.

Table 1.1 Types of carrot shapes

Type	Features	Examples
Amsterdam	Small stumpy cylindrical roots	Amsterdam Forcing-3, Sweetheart
Autumn King	Large, late-maturing	Autumn King, 2 Vita Longa
Berlicum	Cylindrical, stumpy and late crop.	Camberly, Ingot
Chantenay	Stumpy and slightly tapered, for summer	Red Cored Supreme, Babycan
Nantes	Broader and longer	Nantes Express, Navarre, Newmarket
Paris Market	Small round or square roots, early harvest	Early French Frame, Little Finger

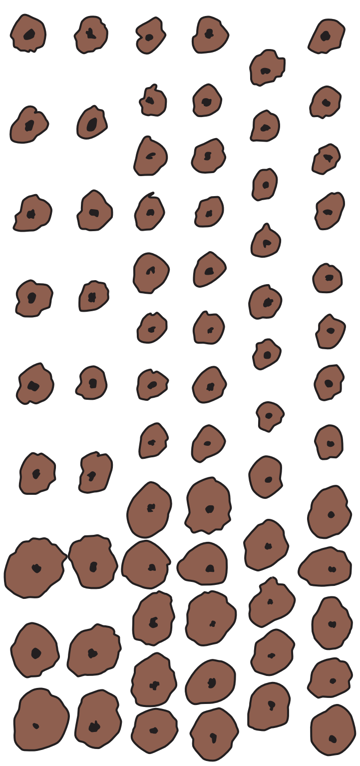

Figure 1.3 Spacing of plants in rows; offset rows to the right and mature plants to the bottom

Most vegetables are grown in rows. This helps with many of the activities such as thinning and weed control (see p267). Seeds are often sown more thickly than is ideal for the full development of the plant; this ensures there are no gaps in the row and extra seedlings are removed before plant growth is affected. The final **plant density** depends on the crop concerned, but it is often adjusted to achieve specific market requirements, e.g. small carrots for canning require closer spacing than carrots grown for bunching. The arrangement of plants is also an important consideration in **spacing**; equidistant planting can be achieved by offsetting the rows (see Figure 1.3).

Seeds are often sown into a separate seedbed or into modular trays until they are big enough to be planted out, i.e. transplanted, into their final position. This enables the main cropped areas to be used with a minimum of wasted space. It is also a means of extending the season and speeding up plant growth by the use of greater protection and, where worthwhile, with extra heat. Larger plants are better able to overcome initial pest or disease attack in the field and also the risk of drying out.

Intercropping (the growing of one crop in between another) is uncommon in this country but worldwide is a commonly used technique for the following reasons:

- to encourage a quick growing plant in the space between slower ones in order to make best use of the space available;
- to enable one plant species to benefit from the presence of the others which provide extra nutrients e.g. legumes (see p366);
- to reduce pest and disease attacks (see also companion planting p54).

Successional cropping

Continuity of supply can be achieved by several means, most usually by the following:

- selecting cultivars with different development times (early to late cultivars);
- by using the same cultivar but planting on different dates.

These options can be combined to spread out the harvest and which can be achieved with some accuracy with knowledge of each cultivar and the use of accumulated temperature units (ATUs see p32).

Aftercare

After the crop is established, there are many activities to be undertaken according to the crop, the production method and the intended market. These operations include:

- feeding (see fertilizer, p373)
- weed control (see Chapter 13)
- irrigation (see p346)
- mulching (see p335)
- earthing up e.g. potatoes and leeks (see p46)
- pest and disease control. This is essential to ensure both the required yield and quality of produce. Examples of the important pests and diseases of vegetables are given in Chapters 14 and 15 and a survey of methods of control can be found in Chapter 16.

Harvesting

The stage of harvesting is critical depending upon the purpose of the crop. Recognizing the correct stage to sever a plant from its roots will affect its shelf life, storage or suitability for a particular market. Some vegetables which are harvested at a very immature stage are called 'baby' or 'mini'.

The method of harvesting will vary; wholesale packaging requires more protective leaf left on than a pre-packed product. Grading may take place at harvesting, e.g. lettuce, or in a packing shed after storage, e.g. onions.

Storage

An understanding of the physiology of the vegetable or plant material being stored is necessary to achieve the best possible results. Root vegetables are normally biennial and naturally prepared to be overwintered, whether in a store or outside (see p119). Annual vegetables are actively respiring at the time of picking (see p118), but with the correct temperature and humidity conditions the useful life can be extended considerably. Great care must be taken with all produce to be stored as any bruising or physical damage can become progressive in the store. Dormant vegetables can be cold stored, but care must be taken to prevent drying out. For this reason different types of store are used depending on the crop; ambient air cooling is used for most hard vegetables and refrigeration for perishable crops gives a fast pull-down of temperature and field heat (see p119).

Fruit production

Crops in the British Isles can be summarized as follows:

- **top (tree) fruit**; which in turn can be sub-divided into **pip fruit**, mainly apples and pears, and **stone fruit** (plums, cherries and peaches).
- **soft fruit** which in turn can be sub-divided into **bush fruit** (black, white and red currants; gooseberries, blueberries), **cane fruit** (raspberries, blackberries, loganberries and other hybrids; see p69) and **strawberries**.

There are many differences between vegetable and fruit growing, most of which are related to how long the crop is in the ground before replanting. Whereas most vegetables are in the soil for less than a year, fruit is in for much longer; typically strawberries last for two to three years, raspberries for eight to ten years and top fruit for some 15 to 20 years or more. Fruit plants should not be replanted in the same place (see p278).

The particular **site** requirements are as follows:

- **freedom from frost** is a major consideration (see p31) as most fruit species are vulnerable to low temperatures which damage blossom and reduce pollination (p134). Cold can also damage young tender growth which leads to less efficient leaves (p115) and russeting of fruit.
- **deep**, **well-drained loams** are ideal for most types of fruit growing. Unlike vegetable production, heavier soils are acceptable because the soil is not cultivated on a regular basis.
- **soil pH** should be adjusted before these long-term crops are established; most benefit from slightly acid soils (pH 6 to 6.5), but allowance should be made for the normal drop in pH over time (see p358). Blueberries and other Ericaceous fruits are the exception, requiring a pH of 4.5 to 5.5.

There are many production methods and the choice is mainly related to the space available, aftercare (such as pest and disease control) and the method of harvesting; taking fruits from large trees presents difficulties and making it easy for the public in 'pick your own' (PYO) situations is essential. Several methods lend themselves to smaller gardens, growing against walls or as hedges. These considerations greatly influence the selection of cultivar and rootstocks.

Top fruit can be grown in a natural or 'unrestricted' way in which case the size of the tree depends on the cultivar and whether it is grown as a standard, half standard or bush. Restricted forms include cordons, espalier, fan and columns (see Figure 1.4). **Rootstocks** play an important part in determining the size of top fruit trees, e.g. by grafting a cultivar with good fruiting qualities on to the roots of one with suitable dwarfing characteristics (see p177). Excess vigour, which can lead to vegetative growth (leafiness) at the expense of fruit, may be reduced by restricting nutrient and water uptake by growing in grass (see competition p46), ringing the bark (see p95) or, more rarely, root pruning. Soft and cane fruits are usually grown on their own unrestricted roots.

Figure 1.4 Fruit tree forms

Training and pruning plays an important part of the husbandry of fruit growing. The shape of trees and bushes is established in the early years ('formative pruning'). Suitable frameworks and wiring systems are set up for many of the growing systems (see Figure 1.4) and the new growth has to be tied in at appropriate times. Pruning plays a major part in maximizing flowering and fruiting, as does the bending down of branches (see p158). The shape created and maintained has a significant effect on pest and disease control; the aim is usually to have an open centre which reduces humidity around the foliage (see p159) and lets the sunlight into the centre of the tree to give a good fruit colour. Pruning is also undertaken to remove weak and diseased growth (see p159).

Fertilization of flowers is required before fruits are formed (see p137). In order for this to be successful **pollination** needs to take place (see p134).

Most top fruit is not self fertile. Therefore, another plant is needed to supply pollen and insects are required to carry it. Since successful pollination will only take place when both plants are in flower the choice of cultivars becomes limited; later flowering cultivars do not pollinate early flowering ones. Apple cultivars are placed in seven groups to help make this choice whereby selection is made from the same group (ideally) or an adjoining one. However, choice is further limited because some cultivars are incompatible with each other (p146). In particular, triploid cultivars, such as Bramley's Seedling, are unable to pollinate any other (see p146). Similar considerations apply to pears, but some plums, cherries and peaches are self fertile.

Propagation of top fruit is by grafting (see p176), raspberries by suckers (see p174), blackberries by tip layering and strawberries by runners.

Pest and disease control methods are discussed in Chapter 16. Note that **Certification Schemes** and **Plant Passports** are particularly important for plants that are propagated by vegetative means where viruses can be a significant problem. This is especially the case where they are grown for many years before renewal (see also p294).

Harvesting fruit for immediate sale or consumption must be undertaken at maturity to present the full flavour of the variety. Techniques involved in handling fruit to prevent bruising and subsequent rotting require an understanding of fruit physiology. Stone fruits, e.g. plums and cherries, are picked directly into the market container being graded at the same time because these fruits often have a very attractive bloom which is lost if handled too often. Soft fruits will not tolerate washing or excessive handling and grading is done at picking. With strawberries the stalk is not left attached, only the calyx, to prevent it sticking into an adjoining fruit and causing a rot. Machine harvesting of raspberries for the processing industry is less important now as most fruit is grown for the dessert market and is often protected during harvest by temporary, polythene covered structures known as 'Spanish Tunnels' or 'Rain Sheds'.

Storage of fruit crops requires considerable skill and technique. Pip fruits, e.g. apples and pears, must be at an exact stage of maturity for satisfactory storage. If storage is to be for a long time, e.g. the following spring, then controlled atmosphere storage is used, where the levels of CO_2 and O_2 are controlled as well as temperature and humidity.

Soft fruit crops are harvested during the summer when the ambient air temperature is high and the fruit will continue to ripen after it has been picked. It is therefore essential to lower the temperature of the fruit quickly, known as removing 'field heat'. Refrigerated storage is used, but excessively low temperatures will cause the fruit to respire even more quickly when removed from store (see p119). This causes punnets (fruit containers) to mist up and the fruit to rot more quickly. The maintenance of the fruit at a cool temperature from grower to consumer is referred to as 'cool chain marketing'.

Protected culture

Protection for plants can be in the form of simple coverings such as floating mulches, cloches or cold frames and more complex structures such as polytunnels or glasshouses.

The advantage of protection by these various methods is that to a greater or lesser extent they **modify weather** conditions, particularly wind, and so keep the environment around the plants warmer. This factor enables plants to be grown over a longer season, which is advantageous where continuity of supply, or earlier or later produce commands a premium. In leisure horticulture, the protection offered enables a wider range of plants to be kept, propagated and displayed.

The changed environment in protected cropping necessitates a careful management approach to watering (p350) and ventilation. Any plants requiring insect pollination have to be catered for (p137). Pests, diseases and weeds can also benefit from the warmer conditions and tropical species assume more importance.

Glasshouses, or conservatories, enable tender plants (see p156) to be grown all year round, especially if a source of **heat** is also available. Half hardy plants can be 'brought on' earlier and similarly plants can be grown from seed and planted out when conditions are suitable after a period of 'hardening off' (p156).

The closed environment makes it possible to maximize crop growth by using supplementary lighting, shade, and raising carbon dioxide levels (see p113).

Day length can be modified by the use of night lighting and blackouts to encourage flowering out of season (see p161). A wider range of biological control is possible within an enclosed zone (see p271). Greenhouses also allow work to continue even when the weather is unsuitable outside.

There are many designs of greenhouses, some of which are illustrated in Figure 1.5. Others are much more ornamental rather than purely functional. They range from the grand, as seen in the Botanic Gardens, to the modest in the smaller garden. Although the structures can be clear glass to the ground, there are many situations where brick is used up to bench level e.g. Alpine Houses. Many older 'vinery' style houses were substantially underground to conserve heat.

Structural materials used for glasshouses depend again on their intended purpose, but most are either aluminium and steel construction or wood (usually Western Red Cedar). Those which are for commercial production tend to be made of aluminium and steel with an emphasis on maximizing light (see p113) by increasing the height of the gutter and using larger panes of glass. Aluminium is lightweight and very suitable as glazing bars for glasshouse roofs, it is also virtually maintenance free, but does transmit heat away more than alternatives such as wood. Where more attractive structures are preferred, wood is often chosen although

Figure 1.5 Glasshouses

such structures are less efficient in light transmission and require more maintenance.

Cladding materials are usually glass or plastic although there are many types of plastic available. Glass has superior light transmission and heat retention. Plastics tend to be cheaper but are less durable. They have poorer light transmission when new and most deteriorate more rapidly than glass. Polycarbonate is often used in garden centres where the danger of glass overhead is considered to be too great in public areas. The biodomes at the Eden Project in Cornwall are made up of hexagonal panels made of thermoplastic ETFE cushions (see Figure 1.6).

Orientation of the glasshouse depends on the intended purpose. For many commercial glasshouses the need for winter light is the most

Figure 1.6 **Geodesic biome domes** at the Eden Project

significant consideration, this is achieved with an east–west orientation. However, the most even light distribution occurs when the house is orientated north–south which may also be the choice if several houses are in a block. For many decorative structures the orientation is subservient to other considerations.

The **siting** should ensure an open position to maximize light, but with shelter from wind. Frost pockets need to be avoided (see p36) and there should be good access which meets the needs of the intended use. Water is needed for irrigation and normally an electricity supply needs to be available.

Light availability is emphasized in the selection of structure, cladding and siting, as this is fundamental to the growth of plants (see photosynthesis p110). **Supplementary lighting** in the greenhouse is advantageous in order to add to incoming light when this is too low (see p114). More rarely, **total lighting** can be used when plants are grown with no natural light such as in growth cabinets for experimental purposes. Low level lighting to adjust day length is used to initiate flowering out of season, e.g. year round chrysanthemums, poinsettia for the Christmas market (see **photoperiodism** p160).

Careful **water management** is essential in the glasshouse where plants are excluded from rainfall. A suitable supply of water, free from toxins and pathogens (see p351), is a major consideration especially with increasing emphasis on water conservation (see p351). For many, water is supplied by hoses or watering cans with spray controlled with the use of a lance or rose. There are many systems which lend themselves to reduced manual input, and on both small and large scale automatic watering is preferred, using one or other of the following:

- overhead spraying
- low level spraying
- seep hose
- trickle or drip lines
- ebb and flow
- capillary matting or sand beds.

Water is not only used to supply plant needs directly, but also to help cool greenhouses. '**Damping down**' is the practice of hosing water on to the floor, usually in the morning, so that the evaporation that follows takes heat out of the air (see p37). This increases the humidity in the environment (see p39) which can advantageously create a good environment for plant growth. On the other hand, if done at the wrong time it can encourage some pests and diseases (see p267). Water can also be used to apply nutrients through a dilutor, either as a one-off event or at each watering occasion; this is known as 'fertigation' and enables the grower to provide the exact nutritional requirement for the plant at particular stages of its development.

Heating can be supplied by a variety of methods including paraffin, electricity, methane (mains gas), propane (bottled gas) and, less commonly now, solid fuel. Some commercial growers are installing biomass boilers and some are in a position to use waste heat from other processes. Fuel costs and environmental considerations have put increasing emphasis on reducing the need for heat (choice of plants, use of thermal screens, etc.) and reducing heat losses with **insulation** materials such as bubble wrap (with consequent reduction in light transmission).

Ventilation is essential in order to help control temperature and humidity (see p39). Air is effectively circulated by having hinged panes set in the roof and the sides (these are often louvre panes). The movement of air is often further enhanced by the use of fans.

Shading is used to reduce the incoming radiation (see p113). Although much emphasis is put on ensuring good light transmission, particularly for winter production, the high radiation levels in summer can lead to temperatures which are too high even with efficient ventilation. Traditionally, shading was achieved by applying a lime wash. This has been superseded by modern materials which are easier to remove and some even become less opaque when wet to maintain good light levels when it is raining. Most modern production units have mechanized blinds which can also help retain heat overnight. Many ornamental houses will have attractive alternatives such as external shades in natural materials.

Growing media options in protected culture are very extensive, but the choice depends on whether the plants are grown in soil, in containers on the ground or in containers on benching. **Border soils** have been used over the years, but they have many disadvantages, especially with regard to pest and disease problems and the expense of controlling this (see soil sterilization p265). A range of composts is available for those who choose to grow in containers (see p390). However, a significant proportion of commercial glasshouse production uses one of the hydroponics systems (see p394).

Pest and disease control has special considerations because the improved conditions for plants can also lead to major pest and disease outbreaks which develop quickly. If the atmosphere becomes wet, too humid or too dry even more problems can be expected. Furthermore this environment supports organisms not commonly found outdoors such as two-spotted red spider mites (see p224). Besides a range of cultural and chemical methods, the enclosed space makes it possible to use a wider range of biological controls than is possible outside (see p275).

Automatic systems to control temperature, ventilation and lighting have developed over the years to reduce the manual input (and the unsociable hours) required to manage conditions through the growing season. Some of the most exciting developments have occurred as computerized **systems** have been introduced to integrate the control of light, temperature and humidity. In order to control the conditions indoors the systems are usually linked to weather stations (see p39) to provide the required information about the current wind strength and direction, rain and light levels (see Figure 1.7). The use of the computer has made it possible for the whole environment of the glasshouse and the ancillary equipment to be fully integrated and controlled to provide the optimum growing conditions in the most efficient manner. It has also enabled more sophisticated growing regimes to be introduced.

Figure 1.7 Glasshouse weather station

Polytunnels provide a cheaper means of providing an enclosed protected area. They are usually constructed of steel hoops set in the ground and clad with polythene, but in some cases, such as for nursery stock, a net cover is more appropriate (see Figure 1.8). They are not usually considered to be attractive enough for consideration outside commercial production although they are often seen in garden centres.

Figure 1.8 Net tunnel

Walk-in tunnels offer many of the features of a greenhouse, but there are considerable drawbacks besides looks; they tend to have limited ventilation and, despite use of ultra violet inhibitors, the cladding is short lived (3–6 years). Nevertheless there have been steady improvements in design and there are many hybrids available between the basic polytunnel and the true traditional greenhouse, utilizing polycarbonate either as double or triple glazing.

Low tunnels (with wire hoops 30 to 50 cm high) are commonly used to protect rows of vegetables. These are put in place after sowing or planting; access and ventilation is gained thereafter by pulling up the sides.

Cold frames are mainly used to raise plants from seed and to harden off plants from the greenhouse ready to be planted outdoors. The simple 'light' (a pane of glass or plastic in a frame) is hinged on the base of wood or brick and propped up to provide ventilation and exposure to outdoor temperatures. The degree to which plants are exposed to the outdoor conditions is steadily increased as the time for planting out approaches. A **frameyard** is a collection of cold frames.

Cloches were originally glass cases put over individual plants for protection (cloche comes from the name of the cover used in old clocks). They are now more usually sheets of glass or plastic clipped together over individual plants, or rows of them can cover a line of vegetables (mostly superseded today by low tunnels in commercial production).

Floating mulches are lightweight coverings laid loosely over a row or bed of plants (see Figure 1.9) and held in place by stones or earth at intervals. They provide some protection against frost, speed up germination and early growth and provide a barrier against some pests.

Figure 1.9 **Fleece**; an example of a floating mulch

They take three main forms:

- **fleece**, which is a light, non-woven material (polypropylene fibre) permeable across its entire surface allowing light, air and water to penetrate freely. Humidity can be a problem as the temperatures rise.
- **perforated plastic film** is a thin gauge plastic film perforated with holes which allow it to stretch as the plants grow. High humidity is less of a problem because of the holes. Films are made with varying concentration of holes which allow for the requirements of different crops. The greater the number of holes the less the harvest date is advanced but the longer the cover can stay on the plants.
- **fine netting** does not offer the same protection from the elements, but does help keep off pest attacks.

Service horticulture

In contrast to the production of plants for food and flowers, those in service horticulture (embracing the many facets of landscaping, professional gardening and turf culture) are engaged in **plant selection**, **establishment** and **maintenance**. This will mainly involve:

- trees and shrubs;
- hedges, windbreaks and shelter belts;
- climbing plants;
- decorative annuals, biennials, perennial plants;
- ground cover;
- alpines;
- ornamental grasses and turf for lawns or sports surfaces.

Many will be involved in aspects of garden planning such as surveying and design.

Site requirements

For many aspects of this part of horticulture these will be similar to that for the production of plants, but it is much more common to find that the choice of plants is made to fit in with the site characteristics, i.e. 'go with the flow'. This is because the site (the garden, the park, the recreational area) already exists and it is often too expensive to change except on a small scale, e.g. for acid loving plants Rhododendron and Ericaceous species (see p364). The characteristics of the site need to be determined when planning their use and (as for outdoor production) this will include climate, topography, aspect, soil(s), drainage, shade, access, etc. However, there will often be more consideration given to view lines, incorporating existing features of value and accommodating utilities such as sheds, storage, maintenance and composting areas.

Design

Substantial plant knowledge is needed to help fulfil the principles of design which encompass:

- **unity** (or harmony); this is ensuring that there are strong links between the components, i.e. the individual parts of the design relating to each other. This encompasses all aspects such as continuity of materials, style or ideas (e.g. 'Japanese', 'chic' or 'rural');
- **simplicity**; to bring a sense of serenity, avoiding clutter by limiting the number of different materials used and repeating plants, colours and materials around the garden;
- **repetition** of shapes, materials, patches of colour to ensure unity, but also in order to introduce rhythm by the spacing and regularity of the repetition (see Figure 1.10);
- **focal points** are features of the garden that draw the eye, such as statues, furniture and individual plants, only one of which should be

Figure 1.10 **Show garden** illustrating unity, simplicity and repetition

noticeable at a time. These are used to create a series of set pieces for viewing and to move the viewer through the garden;
- **scale**; plantings, materials, features, patio and path sizes should be in proportion with each other, e.g. only small trees are likely to look right in small gardens;
- **balance** can be achieved most easily by developing a symmetrical garden, but success with other approaches is possible by considering less formal ways of balancing visual components, e.g. groups of evergreens with deciduous trees; ponds with lawns; several small plants with a single shrub; open area with planted areas;
- **interest**; much of the interest is related to the selection and grouping of plants based on their form, colours and textures.

Decisions need to be made with regard to the overall **style** to be achieved. The need for unity suggests that mixing styles is to be avoided or handled with care. This is particularly true for the choice between formal and informal approaches to the garden or landscape.

Propagation

Nursery stock growers specialize in propagating plants which are sold on to other parts of the industry. Other parts of the industry may also propagate their own plants. Plants can be grown from seed (see p166), from division, layering, cuttings, micro-propagation, grafting or budding (see vegetative propagation p172).

Sources of plants

The source depends on the type and quantity, but is usually from specialist nurseries, garden centres or mail order, including the Internet. Plants are supplied in the following ways:

- **Bare rooted plants** are taken from open ground in the dormant period (p115). Whilst cheaper, these are only available for a limited period and need to be planted out in the autumn or spring when conditions are suitable; in practice this is mainly October and March. Roots should be kept moist until planted and covered with wet sacking while waiting. Plants received well before the time for permanent planting out should be 'heeled in' (i.e. temporary planting in a trench to cover the roots).

- **Root balled plants** are grown in open ground, but removed with soil, and the rootball is secured until used by sacking (hessian). This natural material does not need to be removed at planting and will break down in the soil. This reduces the problems associated with transplanting larger plants.
- **Containerized** plants are also grown in open ground, but transferred to containers. Care needs to be taken to ensure that the root system has established before planting out unless treated as a bare-rooted stock.
- **Container-grown** plants, in contrast, are grown in containers from the time they are young plants (rather than transferred to containers from open ground). This makes it possible to plant any time of the year when conditions are suitable. Most plants supplied in garden centres are available in this form.

It is essential that care is taken when buying plants. Besides ensuring that the best form of the plants are being purchased and correctly labelled, the plants must be healthy and 'well grown'; the plants should be compact and bushy (see etiolated p153), free from pest or disease and with appropriately coloured leaves (no signs of mineral deficiency; see p127). The roots of container plants should be examined to ensure that they are visible and white rather than brown. The contents of the container should not be rootbound and the growing medium not too wet or dry.

Establishment

The site needs to be prepared to receive the plant at the right time of the year. The soil should be cultivated to produce the appropriate structure and tilth (see p313) and base dressings of fertilizers applied. Plants should not go into the ground when it is dry, waterlogged or frozen. After sowing or planting out, care has to be taken particularly with regard to watering and weed control, also with protection from pests and diseases.

Maintenance activity is ongoing (as anyone who looks after a garden will know). There are many things to do almost every month of the year to keep the planting in good order, including:

- mowing turf
- irrigation/watering
- feeding
- hedge cutting, clipping topiary
- pruning trees and shrubs
- weeds, pest and disease control
- staking

- dead heading
- dividing perennials.

Interior plant care

Interior spaces in offices, shops, schools, etc., can be decorated and benefit from an enhanced atmosphere using mobile containers. Often carried out on contract, this work requires all the care of protected cropping with particular attention being paid to watering (often spaces are centrally heated) and lighting (plants are often pushed into an otherwise little-used dark corner). The problems of transport and associated variation in environmental conditions must also be considered.

Organic growing

Organic, or **ecological**, **growers** view their activities as an integrated whole and try to establish a sustainable way forward by conserving non-renewable resources and eliminating reliance on external inputs. Where their growing depends directly, or indirectly (e.g. the use of straw or farmyard manure), on the use of animals due consideration is given to their welfare and at all times the impact of their activities on the wider environment is given careful consideration.

The soil is managed with as little disturbance as possible to the balance of organisms present. Organic growers maintain **soil fertility** by the incorporation of animal manures (see p330), composted material (see p333), green manure or grass–clover leys (p332). The intention is to ensure plants receive a steady, balanced release of nutrients through their roots; 'feed the soil, not the plant'. Besides the release of nutrients by decomposition (see p324), the stimulated earthworm activity incorporates organic matter deep down the soil profile, improving soil structure which can eliminate the need for cultivation (see earthworms, p321).

The main cause of species imbalance is considered to be the use of many **pesticides** and **quick-release fertilizers**. Control of pests and diseases is primarily achieved by a combination of resistant cultivars (p290) and 'safe' pesticides derived from plant extracts (p282), by careful rotation of plant species (p267) and by the use of naturally occurring predators and parasites (p271). Weeds are controlled by using a range of cultural methods including mechanical and heat-producing weed control equipment (p264). The balanced nutrition of the crop is thought to induce greater resistance to pests and diseases (p60). The European Union Regulations (1991) on the 'organic production of agricultural products' specify the substances that may be used as 'plant-protection products (see Table 16.4), detergents, fertilizers, or soil conditioners' (see Table 21.3).

Those intending to sell produce with an organic label need to comply with the standards originally set by the International Federation of

Organic Agricultural Movement (IFOAM). These standards set out the principles and practices of organic systems that, within the economic constraints and technology of a particular time, promote:

- the use of management practices which sustain soil health and fertility;
- the production of high levels of nutritious food;
- minimal dependence on non-renewable forms of energy and burning of fossil food;
- the lowest practical levels of environmental pollution;
- enhancement of the landscape and wild life habitat;
- high standards of animal welfare and contentment.

Certification is organized nationally with a symbol available to those who meet and continue to meet the requirements. In the UK, the Soil Association is licensed for this purpose.

Check your learning

1. State what is meant by nursery stock production.
2. Explain why market research is advisable before starting to grow a crop.
3. Explain what is meant by a healthy plant.
4. Explain why most crops are grown in rows.
5. State the different methods of growing plants earlier in the year.
6. State the advantages a wooden structure for a glasshouse in a garden situation.
7. Explain what is meant by 'hardening off' plants and why it is necessary.
8. Explain how organic growers can maintain the fertility of their soils.

Further reading

Armitage, A.M. (1994). *Ornamental Bedding Plants*. CABI.
Baker, H. (1992). *RHS Fruit*. Mitchell Beazley.
Baker, H. (1998). *The Fruit Garden Displayed*. 9th edn. Cassell.
Beckett, K.A. (1999). *RHS Growing Under Glass*. Mitchell Beazley.
Beytes, C. (ed.) (2003). *Ball Redbook: Greenhouses and Equipment.* Vol. 1. 17th edn. Ball Publishing.
Brickell, C. (ed.) (2006). *RHS Encyclopedia of Plants and Flowers*. Dorling Kindersley.
Brickell, C. (ed.) (2003). *RHS A–Z Encyclopedia of Garden Plants.* 2 vols. 3rd edn. Dorling Kindersley.
Brookes, J. (2001). *Garden Design*. Dorling Kindersley.
Brookes, J. (2002). *Garden Masterclass*. Dorling Kindersley.
Brown, S. (2005). *Sports Turf and Amenity Grassland Management*. Crowood Press.
Caplan, B. (1992). *Complete Manual of Organic Gardening*. Headline Publishing.
Eames, A. (1994). *Commercial Bedding Plant Production*. Grower Books.
Edmonds, J. (2000). *Container Plant Manual*. Grower Books.
Fedor, J. (2001). *Organic Gardening for the 21st Century*. Frances Lincoln.

Hamrick, D. (ed.) (2003). *Ball Redbook: Crop Production.* Vol. 2. 17th edn. Ball Publishing.
Hessayon, D.G. (1993). *The Garden Expert.* Expert Publications.
Lamb, K. *et al.* (1995). *Nursery Stock Manual*. Revised edn. Grower Books.
Lampkin, N. (1990). *Organic Farming*. Farming Press.
Larcom, J. (1994). *The Vegetable Garden Displayed*. Revised edn. BT Batsford.
Larcom, J. (2002). *Grow Your Own Vegetables*. Frances Lincoln.
Mannion, A.M. and Bowlby, S.R. (eds) (1992). *Environmental Issues in the 1990s*. John Wiley & Sons.
Pears, P. and Strickland, S. (1999). *Organic Gardening*. RHS. Mitchell Beazley.
Pollock, M. (ed.) (2002). *Fruit and Vegetable Gardening*. MacMillan.
Power, P. (2007). *How to Start Your Own Gardening Business: An Insider Guide to Setting Yourself Up as a Professional Gardener*. 2nd edn. How to Books.
Staines, R. (1992). *Market Gardening*. Fulcrum Publishing.
Swithenbank, A. (2006). *The Greenhouse Gardener*. Frances Lincoln.
Thomas, H. and Wooster, S. (2008). *The Complete Planting Design Course: Plans and Styles for Every Garden*. Mitchell Beazley.
Toogood, A. (2003). *Flowers*. Harper Collins.
Williams, R. (1995). *The Garden Designer*. Frances Lincoln.
Wilson, A. (ed.) (2007). *Garden Plans*. Mitchell Beazley.

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Chapter 2 Climate and microclimate

Summary

This chapter includes the following topics:

- **The sun's energy**
- **Effect of latitude**
- **Weather systems**
- **Weather and climate**
- **Climate of British Isles**
- **Growing seasons**
- **World climate**
- **Local climate**
- **Microclimate**
- **Weather instruments**

Figure 2.1 **Agrometerological station** showing rain gauge (left), Stevenson's screen (centre) and anemometer (right).

The Sun's energy

The energy that drives our weather systems comes from the sun in the form of solar radiation. The sun radiates waves of **electro-magnetic energy** and high-energy particles into space. This type of energy can pass through a vacuum and through gases. The **Earth intercepts the radiation energy** and, as these energy waves pass through the atmosphere, they are absorbed, scattered and reflected by gases, air molecules, small particles and cloud masses (see Figure 2.2).

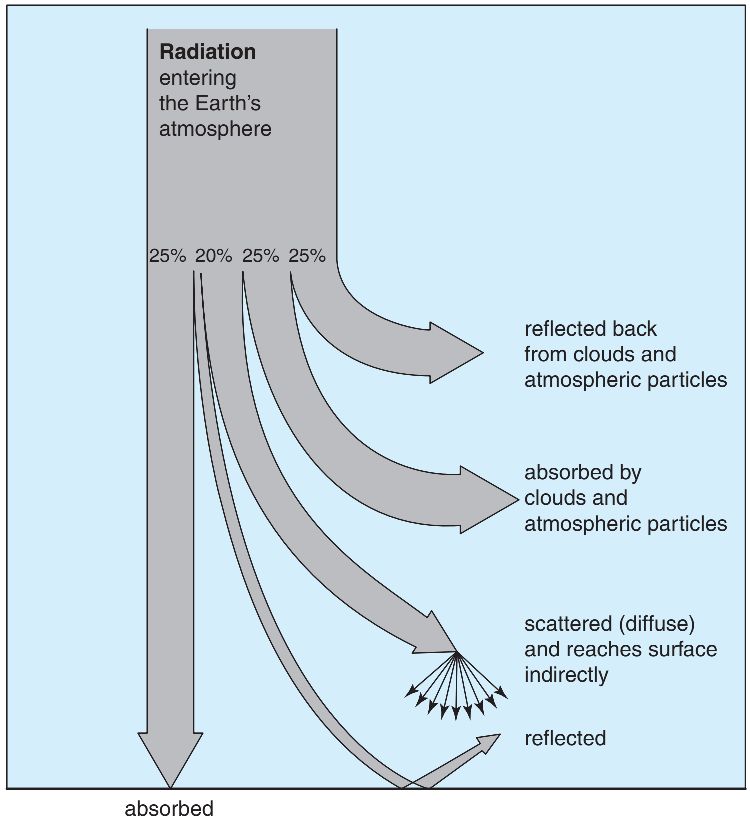

Figure 2.2 **Radiation energy** reaching the Earth's surface showing the proportions that are reflected back and absorbed as it passes through the atmosphere and that which reaches plants indirectly. About 5 per cent of the radiation strikes the Earth's surface but is reflected back (this is considerably more if the surface is light coloured, e.g. snow, and as the angle of incidence is increased).

About a quarter of the total radiation entering the atmosphere reaches the Earth's surface directly. Another 18 per cent arrives indirectly after being scattered (diffused). The surface is warmed as the molecules of rock, soil, and water at the surface become excited by the incoming radiation; the energy in the electro-magnetic waves is converted to heat energy as the surface material absorbs the radiation. A reasonable estimate of energy can be calculated from the relationship between radiation and sunshine levels. The amounts received in the British Isles are shown in Figure 2.3 where the differences between winter and summer are illustrated.

However, the nature of the surface has a significant effect on the proportion of the incoming radiation that is absorbed. The sea can

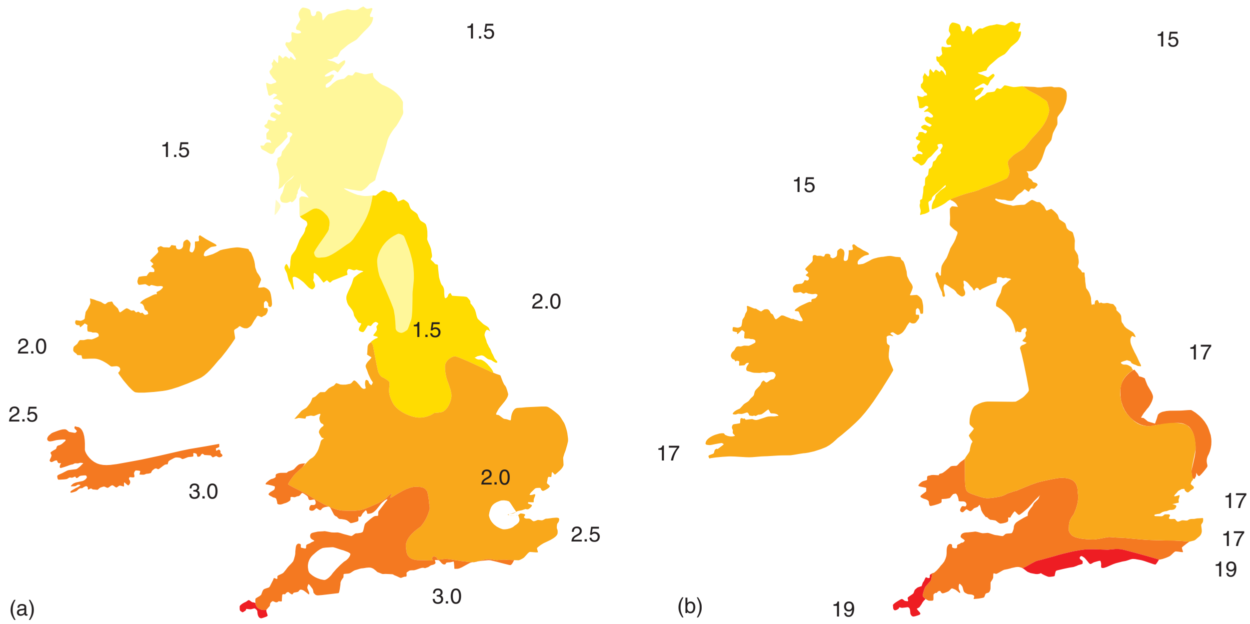

Figure 2.3 **Radiation received in the British Isles**; mean daily radiation given in megajoules per metre square. (a) January (b) July.

absorb over 90 per cent of radiation when the sun is overhead, whereas for land it is generally between 60 and 90 per cent. Across the Earth darker areas tend to absorb more energy than lighter ones; dark soils warm up more quickly than light ones; afforested areas more than lighter, bare areas with grass are between these values. Where the surface is white (ice or snow) nearly all the radiation is reflected.

Effect of latitude

Over the Earth's surface some areas become warmed more than others because of the differences in the quantity of radiation absorbed. Most energy is received around the Equator where the sun is directly overhead and the radiation hits the surface at a right angle. In higher latitudes such as the British Isles more of the radiation is lost as it travels further through the atmosphere. Furthermore, the energy waves strikes the ground at an acute angle, leading to a high proportion being reflected before affecting the molecules at the surface (see Figure 2.4).

As a consequence of the above, more energy is received than lost over the span of a year in the region either side of the Equator between the Tropic of Capricorn and Tropic of Cancer. In contrast, to the north and south of these areas more energy radiates out into space, which would lead to all parts of this region becoming very cold. However, air and water (making up the Earth's atmosphere and oceans) are able to redistribute the heat.

Movement of heat and weather systems

Heat energy moves from warmer areas (i.e. those at a higher temperature) into cooler areas (i.e. those at a lower temperature) and there are three types of energy movement involved. **Radiation** energy moves efficiently

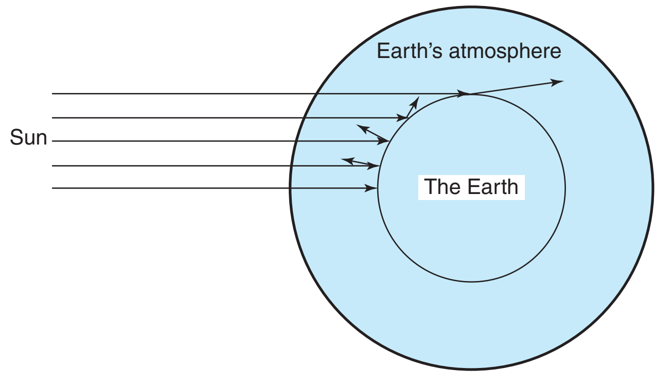

Figure 2.4 **Effect of angle of incidence** on heating at the Earth's surface. A higher proportion of the incoming radiation is reflected as the angle of incidence increases. Note also that a higher proportion of the incoming radiation is absorbed or reflected back as it travels longer through the atmosphere in the higher latitudes.

through air (or a vacuum), but not through water or solids. Heat is transferred from the Earth's surface to the lower layers by **conduction**. As soil surfaces warm up in the spring, temperatures in the lower layers lag behind, but this is reversed in the autumn as the surface cools and heat is conducted upwards from the warmer lower layers. At about one metre down the soil temperature tends to be the same all the year round (about 10°C in lowland Britain).

Heat generated at the Earth's surface is also available for redistribution into the atmosphere. However, air is a poor conductor of heat (which explains its usefulness in materials used for insulation such as polystyrene foam, glass fibre and wool). It means that, initially, only the air immediately in contact with the warmed surface gains energy. Although the warming of the air layers above would occur only very slowly by conduction, it is the process of **convection** that warms the atmosphere above. As fluids are warmed they expand, take up more room and become lighter. Warmed air at the surface becomes less dense than that above, so air begins to circulate with the lighter air rising, and the cooler denser air falling to take its place; just as with a convector heater warming up a room. This circulation of air is referred to as **wind**.

In contrast, the water in seas and lakes is warmed at the surface making it less dense which tends to keep it near the surface. The lower layers gain heat very slowly by conduction and generally depend on gaining heat from the surface by turbulence. Large-scale water **currents** are created by the effect of tides and the winds blowing over them.

On a global scale, the differences in temperature at the Earth's surface lead to our major **weather systems**. Convection currents occur across the world in response to the position of the hotter and colder areas and the influence of the Earth's spin (the Coriolis Effect). These global air movements, known as the trade winds, set in motion the sea currents, follow the same path but are modified as they are deflected by the continental land masses (see Figure 2.5).

Weather and climate

Weather is the manifestation of the state of the atmosphere. Plant growth and horticultural operations are affected by weather; the influence of rain and sunshine are very familiar, but other factors such as frost, wind, and humidity have important effects. It is not surprising that growers usually have a keen interest in the weather and often seek to modify its effect on their plants. Whilst most people depend on public weather forecasting, some growers are prepared to pay for extra information and others believe in making their own forecasts, especially if their locality tends

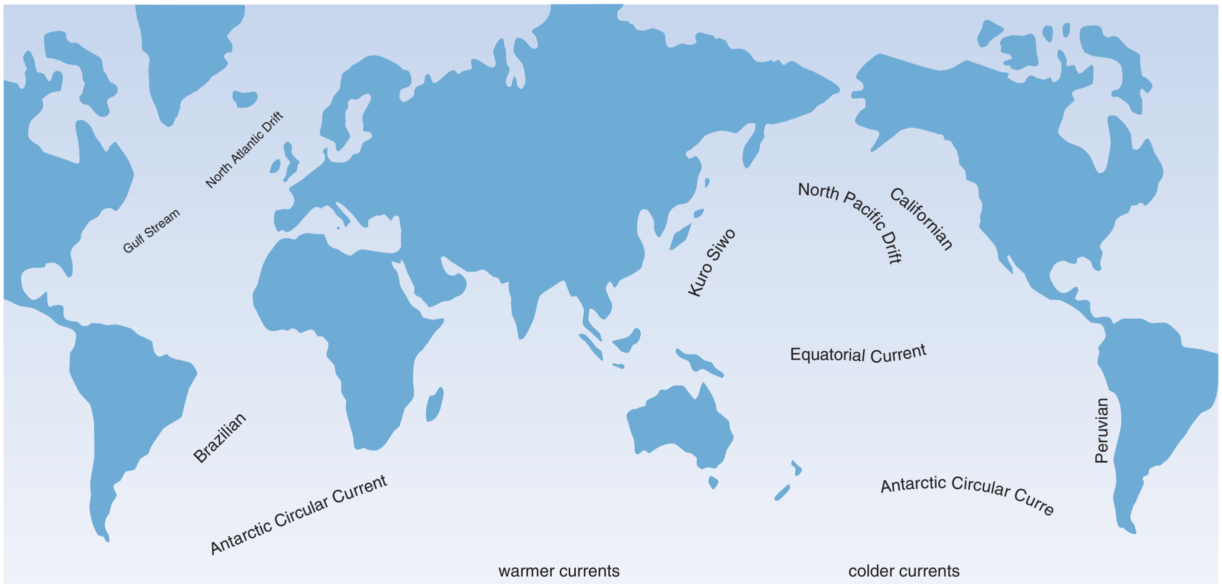

Figure 2.5 **Global sea and wind movements.** Warmer and colder water currents set in motion by the wind circulation around the world.

to have different weather from the rest of the forecast area. Weather forecasting is well covered in the literature and only its component parts are considered here.

Climate can be thought of as a description of the weather experienced by an area over a long period of time. More accurately, it is the long-term state of the atmosphere. Usually the descriptions apply to large areas dominated by atmosphere systems (global, countrywide or regional), but local climate reflects the influence of the topography (hills and valleys), altitude and large bodies of water (lakes and seas).

Climate of the British Isles

The British Isles has a **maritime** climate, characterized by mild winters and relatively cool summers, which is a consequence of its proximity to the sea. This is because water has a much larger **heat capacity** than materials making up the land. As a consequence, it takes more heat energy to raise the temperature of water one degree, and there is more heat energy to give up when the water cools by one degree, when compared with rock and soil. Consequently bodies of water warm up and cool down more slowly than adjoining land. The nearby sea thus prevents coastal areas becoming as cold in the winter as inland areas and also helps maintain temperatures well into the autumn.

In contrast, inland areas on the great landmasses at the same latitude have a more extreme climate, with very cold winters and hot summers; the features of a **continental climate**. Whereas most of the British Isles lowland is normally above freezing for most of the winter, average mid-winter temperatures for Moscow and Hudson Bay (both continental climate situations) are nearer −15°C.

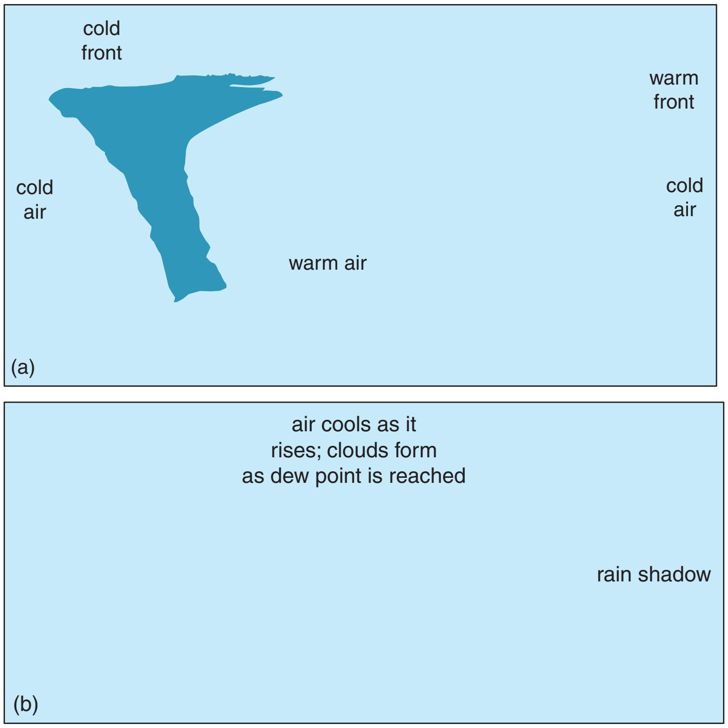

Figure 2.6 **Cloud formation and rainfall** caused by (a) fronts and (b) higher ground (orographic rain). Note: warm air caused to rise over cold air or higher ground forms cloud when the air reaches the dew point of the air mass.

The **North Atlantic Drift**, the ocean current flowing from the Gulf of Mexico towards Norway, dominates the climate of the British Isles (see Figure 2.5). The effect of the warm water, and the prevailing southwesterly winds blowing over it, is particularly influential in the winter. It creates mild conditions compared with places in similar latitudes, such as Labrador and the Russian coast well to the north of Vladivostok, which are frozen in the winter.

The mixing of this warm moist air stream and the cold air masses over the rest of the Atlantic leads to the formation of a succession of **depressions**. These regularly pass over the British Isles bringing the characteristic unsettled weather; with clouds and rain where cold air meets the moist warm air in the slowly swirling air mass. Furthermore, the moist air is also cooled as it is forced to rise over the hills to the west of the islands giving rise to **orographic rain**. In both instances clouds form when the dew point is reached (see p41). This leads to much higher rainfall levels in the west and north compared with the south and east of the British Isles. In contrast, a **rain shadow** is created on the opposite side of the hills because, once the air has lost water vapour and falls to lower warmer levels, there is less likelihood of the dew point being reached again (see Figure 2.6). Depressions are also associated with windier weather.

The sequence of depressions (low-pressure areas) is displaced from time to time by the development of **high-pressure areas** (anti-cyclones). These usually bring periods of settled drier weather. In the summer these are associated with hotter weather with air drawn in from the hot European land mass or North Africa. In the winter, clear cold weather occurs as air is drawn in from the very cold, dry continental landmass. In the spring, these anti-cyclones often lead to radiation **frosts**, which are damaging to young plants and top fruit blossom.

The growing season

The outdoor growing season is considered to be the time when temperatures are high enough for plant growth. Temperate plants usually start growing when the daily mean temperatures are above 6°C. Spring in the southwest of the British Isles usually begins in March, but there is nearly a two-month difference between its start in this area and the northeast (see Figure 2.7).

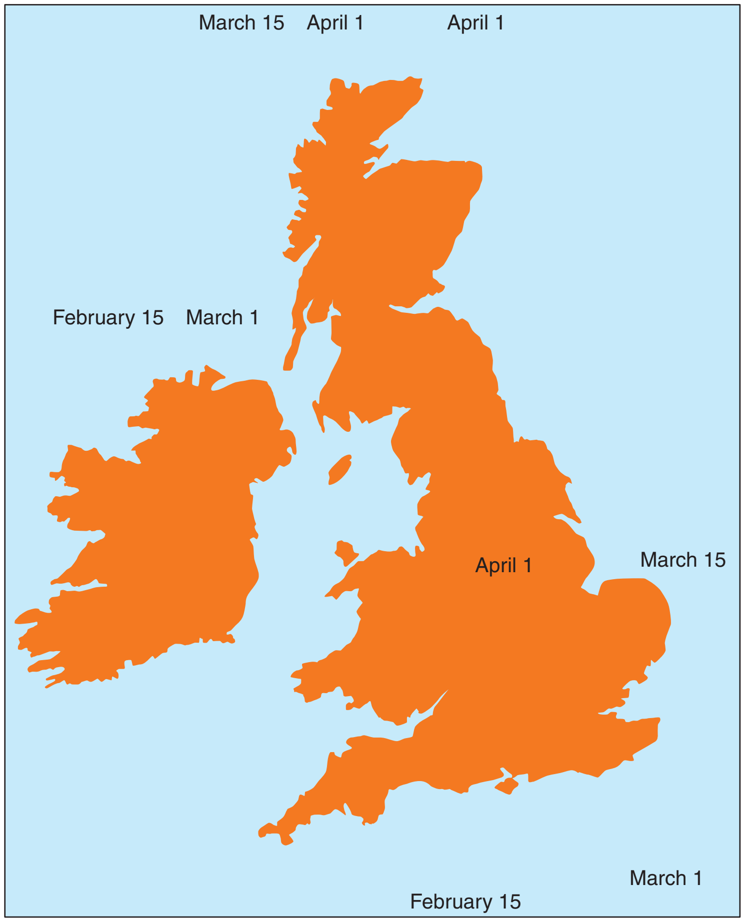

Figure 2.7 **Beginning of Spring** in the British Isles (average dates when soil reaches 6°C).

In contrast, as temperatures drop below 6°C the growing season draws to a close. This occurs in the autumn, but in the southwest of England and the west of Ireland this does not occur until December, and on the coast in those areas there can be 365 growing days per year. Within the general picture there are variations of growth periods related to altitude, aspect, frost pockets, proximity of heat stores, shelter and shade: the so-called local climates and microclimates (see p37). However, for most of mainland UK, the potential growing season spans between eight and nine months. Examples are given in Table 2.1.

Although this length of growing period will be a straightforward guide to grass growing days and the corresponding need for mowing, many other plants will stop growing as they complete their life cycle well before low temperatures affect them. Furthermore, there are plants whose growing season is defined differently. For example, most plants introduced from tropical or sub-tropical areas do not start growing until a mean daily temperature of 10°C is experienced. More significantly, they are restricted by their intolerance to cold so for many their outdoor season runs from the **last frost** of spring to the **first frost** of autumn.

Proximity to the sea not only increases the length of the growing season, but also reduces its intensity, i.e. the extent to which temperatures

Table 2.1 **Length of growing season** in the British Isles

Area	Length of growing season in days*	Time of year	
		start	finish
S-W Ireland	320	Feb 15	Jan 7
Cornwall	320	Feb 15	Jan 7
Isle of Wight	300	March 1	Jan 1
Anglesey	275	March 1	Dec 15
South Wales	270	March 15	Dec 15
East Lancs	270	March 15	Dec 1
East Kent	265	March 15	Nov 28
N. Ireland	265	March 15	Nov 28
Lincolnshire	255	March 21	Nov 25
Warwickshire	250	March 21	Nov 22
West Scotland	250	March 21	Nov 20
East Scotland	240	March 28	Nov 15
N-E Scotland	235	April 1	Nov 10

*Length of season is given for lower land in the area; reduce by 15 days for each 100 m rise into the hills (approximately 5 days per 100 feet).

exceed the minimum for growth. Although inland areas have a shorter season they become much warmer more quickly before cooling down more rapidly in the autumn. The differences in intensity can be expressed in terms of accumulated temperature units.

Accumulated temperature units (ATUs) are an attempt to relate plant growth and development to temperature and to the duration of each temperature. There is an assumption that the rate of plant growth and development increases with temperature. This is successful over the normal range of temperatures that affect most crops. On the basis that most temperate plants begin to grow at temperatures above 6°C the simplest method accredits each day with the number of degrees above the base line of 6°C and accumulates them (note that negative values are not included). A second method calculates ATUs from weather records on a monthly rather than daily basis. Examples are given in Table 2.2.

Methods such as these can be used to predict likely harvest dates from different sowing dates. Growers may also use such information to calculate the sowing date required to achieve a desired harvest date. In the production of crops for the freezing industry, it has been possible to smooth out the supply to the factory by this method. For example, a steady supply of peas over six weeks can be organized by using the local weather statistics to calculate when a range of early to late varieties of peas (i.e. with different harvest ATUs) should be sown.

More accurate methods, such as the **Ontario Units**, use day and night temperatures in the calculation. These have been used to study the growth

Table 2.2 Examples of Accumulated Temperature Units (ATUs) calculated on (a) a daily basis and (b) monthly basis

a) Accumulated Temperature Units (ATUs) calculated on a daily basis with a base line of 6°C				
Date March	**Average temp. (°C)**		**Temperature units in day-degrees**	**ATUs in day-degrees**
1	6	(6 − 6 = 0)	1 × 0 = 0	0
2	7	(7 − 6 = 1)	1 × 1 = 1	0 + 1 = **1**
3	7	(7 − 6 = 1)	1 × 1 = 1	1 + 1 = **2**
4	5	(5 − 6 = '0')	1 × (0) = 0	2 + 0 = **2**
5	8	(8 − 6 = 2)	1 × 2 = 2	2 + 2 = **4**
6	7	(7 − 1 = 1)	1 × 1 = 1	4 + 1 = **5**
7	8	(8 − 6 = 2)	1 × 2 = 2	5 + 2 = **7**
b) Accumulated Temperature Units (ATUs) calculated on a monthly basis				
Month	**Average temperature**		**Temperature units in day degrees**	**ATUs in day-degrees**
February	5	(5 − 6 = '0')	28 × 0 = 0	0
March	7	(7 − 6 = 1)	31 × 1 = 31	31
April	8	(8 − 6 = 2)	30 × 2 = 60	91
May	11	(11 − 6 = 5)	31 × 5 = 155	246
June	13	(13 − 6 = 7)	30 × 7 = 210	456
July	14	(14 − 6 = 8)	31 × 8 = 248	704

This method provides a basis for comparing the growing potential of different areas (see Table 2.3 and Figure 2.7).

Table 2.3 Accumulated Heat Units for different places in Europe

	Accumulated Heat Units (AHUs)		
Location	**May to June**	**July to Sept**	**Total**
Edinburgh	300	700	1000
Glasgow	250	650	900
Belfast	300	700	1000
Manchester	425	875	1300
Norwich	430	950	1380
Birmingham	450	900	1350
Amsterdam	480	980	1460
Swansea	450	900	1350
London	470	950	1420
Littlehampton	450	950	1400
Channel Isles	480	970	1450
Paris	550	1100	1650
Bordeaux	600	1200	1800
Marseilles	800	1500	2300

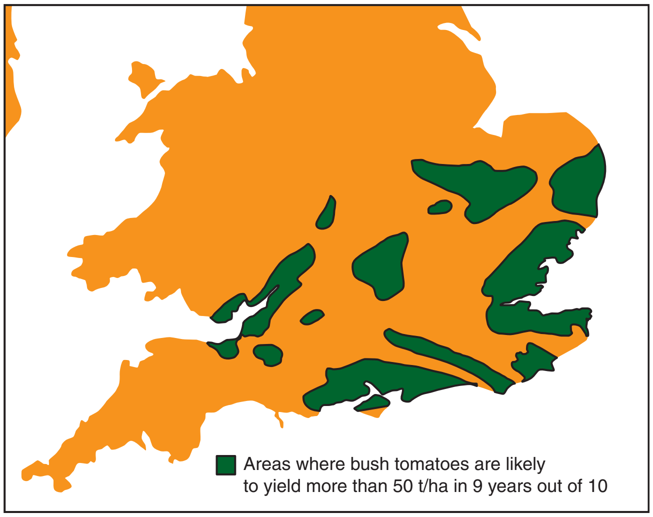

Figure 2.8 **Use of Ontario Units** to determine the likely success of bush tomato crops.

of tropical crops such as sunflowers, tomatoes and sweet corn grown in a temperate area. Using this approach the extent to which bush tomatoes could be grown in Southern England for an expected yield of 50 tonnes per hectare in nine years out of ten could be mapped (see Figure 2.8).

The accumulated heat unit concept can also be used to estimate greenhouse heating requirements by measuring the extent to which the outside temperature falls below a base or control temperature, called 'degrees of cold'. In January, a greenhouse maintained at 18°C at Littlehampton on the coast in Sussex accumulates, on average, 420 cold-degrees compared with 430 for the same structure inland at Kew, near London. For a hectare of glass this difference of 10 cold-degrees C is the equivalent of burning an extra 5000 litres of oil. This provides a useful means of assessing possible horticultural sites when other data such as solar heating and wind speed are all brought together. Other methods based on this concept enable growers to calculate when different varieties of rhubarb will start growing and the energy requirements for chill stores and refrigeration units.

World climates

In addition to **maritime** and **continental** climates already mentioned there are many others, including the **Mediterranean** climate (as found in southern parts of Europe, California, South Africa, Australia and central Chile) that is typified by hot dry summers and mild winters. The characteristics of a range of the world climate types are given in Table 2.4. Plants native to these other areas can present a challenge for those wishing to grow them in the British Isles. To some extent plants are tolerant, but care must be taken when dealing with the plant's degree of hardiness (its

Table 2.4 A summary of some of the **world climates**

	Temperature			Rainfall	
Climatic region	Range	Winter	Summer	Distribution	Total
Temperate					
maritime	narrow	mild	warm	even	moderate
continental	wide	very cold	very warm	summer max	moderate
Mediterranean	moderate	mild	hot	winter max	moderate
Sub-tropical	moderate	mild*	hot	summer max	high
Tropical maritime	narrow	warm**	hot	even	moderate
Equatorial	narrow	hot**	hot	even	high

*frosts uncommon.

**no frosts.

ability to withstand all the features in the climate to which it is exposed). Plant species that originated in **sub-tropical** areas (such as south-east China and USA) tend to be vulnerable to frosts and those from **tropical** and **equatorial** regions are most commonly associated with growing under complete protection such as in conservatories and hothouses.

Local climate

Most people will be aware that even their regional weather forecast does not do justice to the whole of the area. The local climate reflects the influence of the topography (hills and valleys), altitude and lakes and seas that modifies the general influence of the atmospheric conditions.

Coastal areas

These are subject to the moderating influence of the body of water (see p29). Water has a large heat capacity compared with other materials and this modifies the temperature of the surroundings.

Altitude

The climate of the area is affected by altitude; there is a fall in temperature with increase in height above sea level of nearly 1°C for each 100 m. The frequency of snow is an obvious manifestation of the effect. In the southwest of England there are typically only 5 days of snow falling at sea level each year whereas there are 8 days at 300 m. At higher altitudes the effect is more dramatic; in Scotland there are nearer 35 days per year at sea level, 38 days at 300 m, but 60 days at 600 m.

The colder conditions at higher altitudes have a direct effect on the growing season. On the southwest coast of England there are nearly 365 growing days per year, but this decreases by 9 days for each 30 m above sea level. In northern England and Scotland there are only about 250 growing days which are reduced by 5 days per 30 m rise, i.e. to just 200 days at 300 m (1000 feet) above sea level in northern England.

Topography

The presence of slopes modifies climate by its aspect and its effect on air drainage. **Aspect** is the combination of the slope and the direction that it faces. North-facing slopes offer plants less sunlight than a south-facing one. This is dramatically illustrated when observing the snow on opposite sides of an east– west valley (or roofs in a street), when the north facing sides are left white long after the snow has melted on the other side (see Figure 2.9); much

Figure 2.9 **Effect of aspect**; note the difference between the north-facing slope (right) with snow still lying after it has melted on the south-facing slope (left).

more radiation is intercepted by the surface on the south facing slope. Closer examination reveals considerable differences in the growth of the plants in these situations and it is quite likely that different species grow better in one situation compared with the other. Plants on such slopes experience not only different levels of light and heat, but also different water regimes; south-facing slopes can be less favourable for some plants because they are too dry.

Air drainage

Cold air tends to fall, because it is denser than warm air, and collects at the bottom of slopes such as in valleys. **Frost pockets** occur where cold air collects; plants in such areas are more likely to experience frosts than those on similar land around them. This is why orchards, where blossom is vulnerable to frost damage, are established on the slopes away from the valley floor. Cold air can also collect in hollows on the way down slopes. It can also develop as a result of barriers, such as walls and solid fences, placed across the slope (see Figure 2.10).

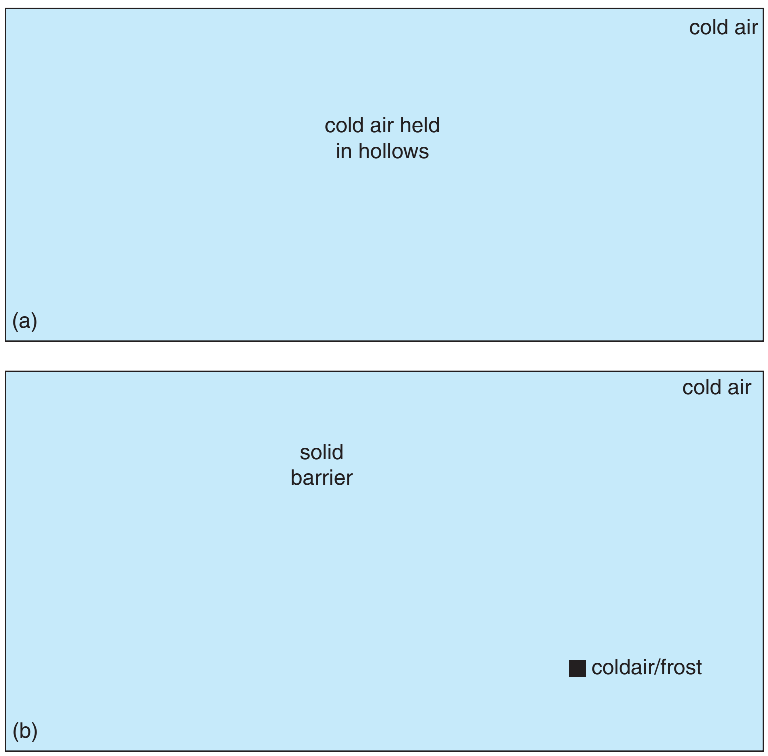

Figure 2.10 **The creation of frost pockets**: (a) natural hollows on the sides of valleys. (b) effect of solid barriers preventing the drainage of cold air.

Permeable barriers, such as trees making up shelterbelts, are less of a problem as the cold air is able to leak through. Frost susceptible plants grown where there is good **air drainage** may well experience a considerably longer growing season. Gardens on slopes can be modified to advantage by having a low-permeable hedge above (a woodland is even better) and a very permeable one on the lower boundary.

Microclimate

The features of the immediate surroundings of the plant can further modify the local climate to create the precise conditions experienced by the plant. This is known as its **microclimate**. The significant factors that affect plants include proximity to a body of water or other heat stores, shelter or exposure, shade, altitude, aspect and air drainage. The modifications for improvement, such as barriers reducing the effect of wind, or making worse, such as barriers causing frost pockets, can be natural or artificial. The microclimate can vary over very small distances. Gardeners will be familiar with the differences across their garden from the cool, shady areas to the hot, sunny positions and the implications this has in terms of the choice of plants and their management.

Growers improve the microclimate of plants when they establish windbreaks, darken the soil, wrap tender plants in straw, etc. More elaborate attempts involve the use of fleece, cold frames, cloches, polytunnels, glasshouses and conservatories. Automatically controlled, fully equipped greenhouses with irrigation, heating, ventilation fans, supplementary lighting and carbon dioxide are extreme examples of an attempt to create the ideal microclimate for plants.

Heat stores are materials such as water and brickwork, which collect heat energy and then release it to the immediate environment that would otherwise experience more severe drops in temperature. Gardeners can make good use of brick walls to extend the growing season and to grow plants that would otherwise be vulnerable to low temperatures. Water can also be used to prevent frost damage when sprayed on to fruit trees. It protects the blossom because of its **latent heat**; the energy that has to be removed from the water at 0°C to turn it to ice. This effect is considerable, and until the water on the surface has frozen, the plant tissues below are protected from freezing.

Shelter that reduces the effect of wind comes in many different forms. Plants that are grown in groups, or stands, experience different conditions from those that stand alone. As well as the self-sheltering from the effect of wind, the grouped plants also tend to retain a moister atmosphere, which can be an advantage but can also create conditions conducive to pest and disease attack. Walls, fences, hedges and the introduction of shelterbelts also moderate winds, but there are some important differences in the effect they have. The reduction in flow downwind depends on the height of the barrier although there is a smaller but significant effect on the windward side (see Figure 2.11).

The diagram also shows how turbulence can be created in the lee of the barrier, which can lead to plants being damaged by down forces. Solid materials such as brick and wooden fences create the most turbulence. In contrast, hedges and meshes filter the wind; the best effect comes from those with equal gap to solid presented to the wind. However, the introduction of a shelterbelt can bring problems if it holds back cold air to create a frost pocket (see p36).

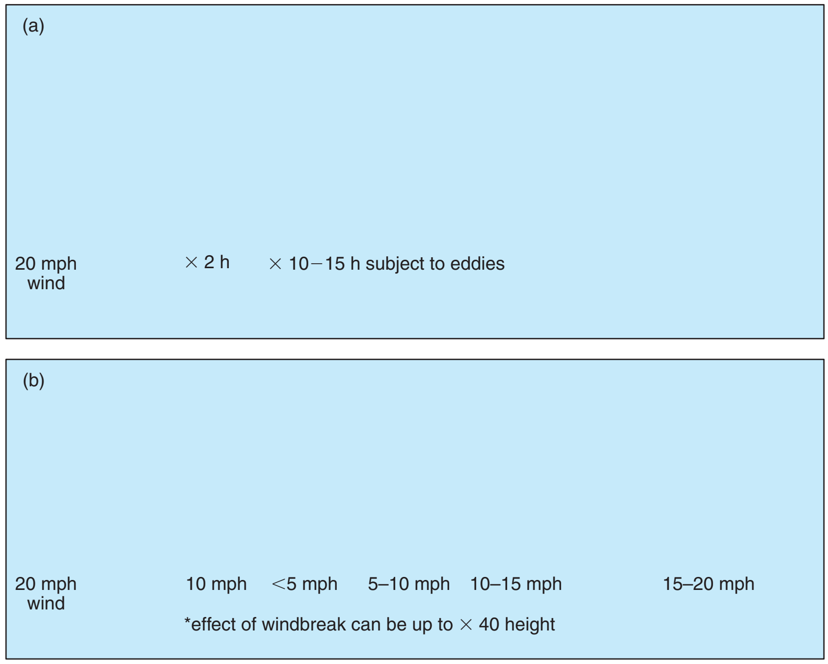

Figure 2.11 **The effect of windbreaks**: (a) solid barriers tend to create eddies to windward and, more extensively, to leeward, (b) a permeable barrier tends to filter the air and reduce its speed without setting up eddies.

Shade reduces the radiation that the plant and its surroundings receive. This tends to produce a cooler, moister environment in which some species thrive (see ecology p48). This should be taken into account when selecting plants for different positions outside in gardens. The grower will deliberately introduce shading on propagation units or on greenhouses in summer to prevent plants being exposed to high temperatures and to reduce water losses.

Plant selection

The horticulturist is always confronted with choices; plants can be selected to fit the microclimate or attempts can be made to change the microclimate to suit the plant that is desired.

Forecasting

Not only is there an interest in weather forecasting in order to plan operations such as cultivations, planting, frost protection, etc., but also for predicting pest and disease attacks, many of which are linked to factors such as temperature and humidity. Examples of outbreaks and methods of predicting them, such as **critical periods** that are used to predict potato blight.

Measurement

A range of instruments in an agro-meteorological weather station are used to measure precipitation, temperature, wind and humidity. The measurements are normally made at 09.00 Greenwich Mean Time (GMT) each day. Most of the instruments are housed in a characteristic Stevenson's Screen although there are usually other instruments on the designated ground or mounted on poles nearby (see Figure 2.1).

Temperature

The normal method of measuring the **air temperature** uses a vertically mounted mercury-in-glass thermometer that is able to read to the nearest 0.1°C. In order to obtain an accurate result, thermometers used must be protected from direct radiation i.e. the readings must be made 'in the shade'.

In meteorological stations, they are held in the **Stevenson's Screen** (see Figures 2.1 and 2.12), which is designed to ensure that accurate results are obtained at a standard distance from the ground. The screen's most obvious feature is the slatted sides, which ensure that the sun does not shine directly on to the instruments (see radiation p26) whilst allowing the free flow of air around the instruments. The whole screen is painted white to reflect radiation that, along with its insulated top and base, keeps the conditions inside similar to that of the surrounding air. In controlled environments such as glasshouses the environment is monitored by instruments held in an **aspirated screen**, which draws air across the instruments to give a more accurate indication of the surrounding conditions (see p116).

The dry bulb thermometer is paired with a wet bulb thermometer that has, around its bulb, a muslin bag kept wet with distilled water. In combination, they are used to determine the **humidity** (see below). Robust mercury-in-glass thermometers set in sleeves are also used to determine soil temperatures; temperatures both at the soil surface and at 300 mm depth are usually recorded in agro-meteorological stations. The highest and lowest temperatures over the day (and night) are recorded on the **Max-Min (maximum and minimum) thermometers** (see Figure 2.12) mounted horizontally on the floor of the screen. The maximum thermometer is a mercury-in-glass design, but with a constriction in the narrow tube near the bulb that contains the mercury. This allows the mercury to expand as it warms up, but when temperatures fall the mercury cannot pass back into the bulb and so the highest temperature achieved can be read off ('today's high'). Shaking the contents back into the bulb resets it. The minimum thermometer contains alcohol. This expands as it warms but as it contracts to the lowest temperature ('tonight's low') a thin marker is pulled down by the retreating liquid. Because it is lightly sprung, the marker

Figure 2.12 **Stevenson's Screen** showing Max-Min Thermometer (horizontal) and Wet and Dry Thermometer (vertical).

is left behind whenever the temperature rises. Using a magnet, or tilting, to bring the marker back to the surface of the liquid in the tube, can reset the thermometer. In addition to the screen reading, there are other lowest-temperature thermometers placed at ground level giving 'over bare soil' and 'grass' temperatures (see Figure 2.1).

Precipitation

The term precipitation covers all the ways in which water reaches the ground as rain, snow and hail. It is usually measured with a **rain gauge** (see Figure 2.13).

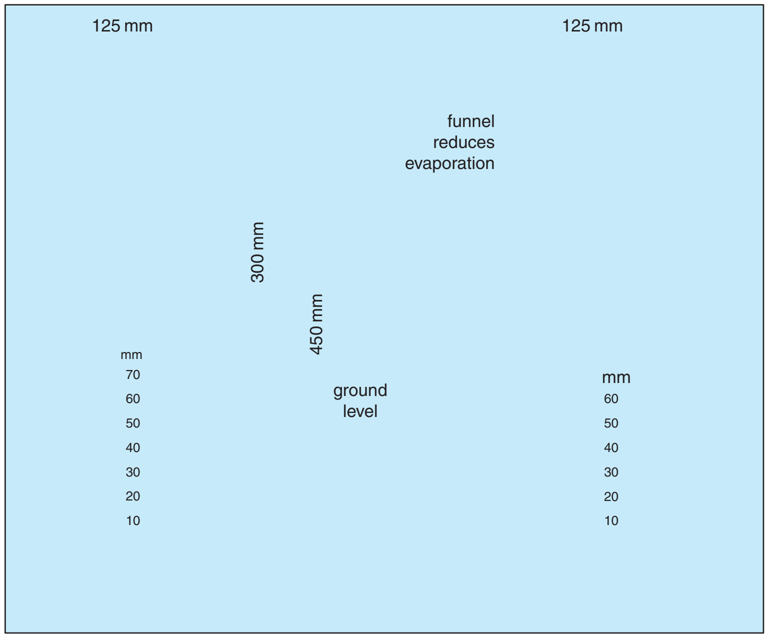

Figure 2.13 **Rain gauges**. A simple rain gauge consists of a straight-sided can in which the depth of water accumulated each day can be measured with a dipstick. An improved design incorporates a funnel, to reduce evaporation, and a calibrated collection bottle. A rain gauge should be set firmly in the soil away from overhanging trees etc. and the rim should be 300 mm above ground to prevent water flowing or bouncing in from surrounding ground.

Simple rain gauges are based on straight-sided cans set in the ground with a dipstick used to determine the depth of water collected. Accurate readings to provide daily totals are achieved with a design that maximizes collection, but minimizes evaporation losses by intercepting the precipitation water in a funnel. This leads to a tapered measuring glass calibrated to 0.1 mm. These gauges are positioned away from anything that affects the local airflow e.g. buildings, trees and shrubs. They are set in the ground but with the rim above it to prevent water running in from the surroundings.

Recording rain gauges are available which also give more details of the pattern of rainfall within twenty-four hour periods. The 'tipping bucket' type has two open containers on a see-saw mechanism so arranged that as one bucket is filled, it tips and this is recorded on a continuous chart; meanwhile the other bucket is moved into position to continue collection.

Humidity

Humidity is the amount of water vapour held in the atmosphere. In everyday language it is something described as 'close' (warm and sticky), 'dry' (little water in the air), 'damp' (cool and moist) and 'buoyant' (comfortable atmosphere). It is usually expressed more accurately in terms of relative humidity (see below).

The **whirling hygrometer** (psychrometer) is the most accurate portable instrument used for taking air measurements (see Figure 2.14). The wet and dry bulb thermometers are mounted such that they can be rotated around a shaft held in the hand, rather like a football rattle. Whilst the dry bulb gives the actual temperature of the surroundings, the wet bulb temperature is depressed by the evaporation of the water on its surface (the same cooling effect you feel when you have a wet skin). The drier the air, the greater the cooling effect, i.e. a greater wet bulb depression.

The relative humidity is calculated using hygrometric tables after the full depression of the wet bulb temperature has been found (see example below).

Hygrometers made out of hair, which lengthens as the humidity increases, are also used to indicate humidity levels. These can be connected to a pen that traces the changes on a revolving drum carrying a hygrogram chart. Other hygrometers are based on the moisture absorbing properties of different materials including the low technology 'bunch of seaweed'.

Figure 2.14 **Whirling hygrometer with calculator.**

Relative Humidity

The quantity of water vapour held in the air depends on temperature, as shown below:

0°C	3 g of water per kilogram of air
10°C	7 g
20°C	14 g
30°C	26 g

The maximum figure for each temperature is known as its saturation point or **dew point**, and if such air is cooled further, then water vapour condenses into liquid water. One kilogram of saturated air at 20°C would give up 7 g of water as its temperature fell to 10°C. Indoors this is seen as 'condensation' on the coolest surfaces in the vicinity. Outdoors it happens when warm air mixes with cold air. Droplets of water form as clouds, fog and mist; dew forms on cool surfaces near the ground. If the air is holding less than the maximum amount of water it has **drying capacity** i.e. it can take up water from its surroundings.

One of the most commonly used measurements of humidity is relative humidity (RH) which is the ratio, expressed as a percentage, of the actual quantity of water vapour contained in a sample of air to the amount it could contain if saturated at the dry bulb temperature. This is usually estimated by using the wet and dry bulb temperatures in conjunction with hygrometric tables.

1. If the absolute humidity for air at 20°C (on the dry bulb) is found to be 14 g/kg this compares with the maximum of 14 g that can be held when such air is saturated. Therefore, the RH is 100 per cent.
2. It can be seen that RH falls to 25 per cent when the wet bulb depression shows only 3.5 g of water are present. This means that its drying capacity has increased (it can now take up 10.5 g of water before it becomes saturated).
3. An example of working out the relative humidity from wet and dry bulb measurements is given below in Tables 2.5 and 2.6. In example 4, when the dry bulb reading is 20°C and the depression of the wet bulb is 2.5°C then the relative humidity is 78 per cent.

Table 2.5 Calculation of relative humidity from wet and dry bulb measurements

Example	1	2	3	4	5
Dry bulb reading °C (A)	25	25	25	20	10
Wet bulb reading 26°C	21	19.5	18	22.5	6.5
Depression of wet bulb °C (B)	4	5.5	7	2.5	2.5
Relative humidity (%)*	70	60	50	78	71

*found from tables supplied with the hygrometer by reading along to the dry bulb reading row (A) then find where the column intersects the depression of the wet bulb figure (B) as shown in Table 2.6 below.

Table 2.6 Determination of relative humidity from the wet bulb depression

Depression of wet bulb	Dry bulb reading (in °C)															
from Table 2.5																
in °C	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0.5	94	94	94	95	95	95	95	95	95	95	96	96	96	96	96	96
1.0	88	88	89	89	90	90	90	90	91	91	91	91	92	92	92	92
1.5	82	83	83	84	84	85	85	86	86	86	87	87	88	88	88	88
2.0	76	77	78	79	79	80	81	82	82	83	83	83	83	84	84	84
2.5	71	72	73	74	74	75	76	77	77	78	78	79	80	80	80	81
3.0	65	66	68	69	70	71	71	72	72	74	74	75	76	76	77	77
3.5	60	61	62	64	65	66	67	68	69	70	70	71	72	72	73	74
4.0	54	56	57	59	60	61	63	64	65	65	66	67	68	69	69	69

Note: Example 4 from Table 2.5 illustrated in grey to show intersection of the dry bulb temperature of 20°C with the depression of the wet bulb by 2.5°C.

Wind

Wind speed is measured with an **anemometer**, which is made up of three hemispherical cups on a vertical shaft ideally set 10 metres above the ground (see Figures 1.7 and 2.1). The wind puts a greater pressure on the inside of the concave surface than on the convex one so that the shaft is spun round; the rotation is displayed on a dial usually calibrated in knots (nautical miles per hour) or metres per second. An older and still much used visual method is the **Beaufort Scale**; originally based on observations made at sea, it is used to indicate the wind forces at sea or on land (see Table 2.7).

Wind direction is indicated with a wind vane, which is often combined with an anemometer. Decorative wind vanes are a familiar sight, but the standard meteorological design comprises a pointer with a streamlined vertical plate on one end mounted so that it can rotate freely. The arrow shape points into the wind and the movements over a minute or so are averaged. The direction the wind is **coming from** is recorded as the number of degrees read clockwise from true north, i.e. a westerly wind

Table 2.7 The Beaufort Scale

Force	Description for use on land	Equivalent wind speed	
		m/sec	approx miles/hour
0	**Calm**; smoke rises vertically	0	0–1
1	**Light air**; wind direction seen by smoke drift rather than by wind vanes	2	1–3
2	**Light breeze**; wind felt on face, vane moves, leaves rustle	5	4–7
3	**Gentle breeze**; light flags lift, leaves and small twigs move	9	8–12
4	**Moderate breeze**; small branches move, dust and loose paper move	13	13–18
5	**Fresh breeze**; small leafy trees sway, crested wavelets on lakes	19	19–24
6	**Strong breeze**; large branches sway, umbrellas difficult to use	24	25–31
7	**Near gale**; whole trees move, difficult to walk against	30	32–38
8	**Gale**; small twigs break off, impedes all walking	37	39–46
9	**Strong gale**; slight structural damage	44	47–55
10	**Storm**; trees uprooted, considerable structural damage	52	55–63

is given as 270, south-easterly as 135 and a northerly one as 360 (000 is used for recording no wind).

Light

The units used when measuring the intensity of all wavelengths are watts per square metre (W/sq m) whereas lux (lumens/sq m) are used when only light in the photosynthetic range is being measured. More usually in horticulture, the **light integral** is used. The light sensors used for this measure the light received over a period of time and expressed as gram calories per square centimetre (gcals/sq m) or megajoules per square metre (MJ/sq m). These are used to calculate the irrigation need of plants in protected culture.

The usual method of measuring **sunlight** at a meteorological station is the Campbell-Stokes Sunshine Recorder (Figure 2.15), a glass sphere that focuses the sun's rays on to a sensitive card; the burnt trail indicates the periods of bright sunshine (see p26). Another approach is to use a solarimeter, which converts the incoming solar radiation to heat and then to electrical energy that can be displayed on a dial.

Automation

Increasingly instrumentation is automated and, in protected culture, linked to computers programmed to maintain the desired environment by adjusting the ventilation and boiler settings. To achieve this, the computer is informed by external instruments measuring wind speed, air temperature and humidity, and internally by those measuring CO_2 levels, ventilation settings, heating pipe temperature, air temperature and humidity.

Figure 2.15 Campbell-Stokes Sunshine Recorder

Check your learning

1. State the methods by which heat energy moves.
2. Explain why the British Isles is said to have a maritime climate.
3. Calculate, using the information in Table 2.2, the date of the second sowing of a variety of peas to be harvested in June, 2 days after the first sown on March 1.
4. Explain what is meant by a microclimate.
5. Determine the relative humidity of a site which has been tested with a whirling hygrometer and the dry bulb reading is 15°C and the wet bulb reading is 13°C.

Further reading

Bakker, J.C. (1995). *Greenhouse Climate Control – an Integrated Approach*. Wageningen Press.

Barry, R. *et al.* (1992). *Atmosphere, Weather and Climate*. 6th edn. Routledge.

Kamp, P.G.H. and Timmerman, G.J. (1996). *Computerised Environmental Control in Greenhouses*. IPC Plant.

Reynolds, R. (2000). *Guide to Weather*. Philips.

Taylor, J. (1996). *Weather in the Garden*. John Murray.

Chapter 3 Environment and ecology

Summary

This chapter includes the following topics:

- **The role of plants within plant communities**
- **Ecosystems**
- **Environmental factors**
- **Conservation**

Figure 3.1 A limestone valley

Plant communities

Plant communities can be viewed from the natural wild habitat to the more ordered situation in horticulture. Neighbouring plants can have a significant effect on each other, since there is competition for factors such as root space, nutrient supply and light. In the natural wild habitat, competition is usually between different species. In subsistence horticulture in the tropics, different crops are often inter-planted (see also companion planting, p54). In Western Europe, crops are usually planted as single species communities.

Single species communities

When a plant community is made up of one species it is referred to as a **monoculture**. Most fields of vegetables such as carrots have a single species in them. On a football field there may be only ryegrass (*Lolium*) with all plants a few millimetres apart. Each plant species, whether growing in the wild or in the garden, may be considered in terms of its own characteristic spacing distance (or plant density). For example, in a decorative border, the bedding plant *Alyssum* will be planted at 15 cm intervals while the larger *Pelargonium* will require 45 cm between plants. For decorative effect, larger plants are normally placed towards the back of the border and at a wider spacing.

In a field of potatoes, the plant spacing will be closer within the row (40 cm) than between the rows (70 cm) so that suitable soil ridges can be produced to encourage tuber production, and machinery can pass unhindered along the row. In nursery stock production, small trees are often planted in a square formation with a spacing ideal for the plant species, e.g. the conifer *Chamaecyparis* at 1.5 metres. The recent trend in producing commercial top fruit, e.g. apples, is towards small trees (using dwarf rootstocks) in order to produce manageable plants with easily harvested fruit. This has resulted in spacing reduced from 6 to 4 metres.

Too much competition for soil space by the roots of adjacent plants, or for light by their leaves, would quickly lead to reduced growth. Three ways of overcoming this problem may be seen in the horticulturist's activities of transplanting seedlings from trays into pots, increasing the spacing of pot plants in greenhouses, and hoeing out a proportion of young vegetable seedlings from a densely sown row. An interesting horticultural practice, which reduces root competition, is the **deep-bed** system, in which a one metre

Figure 3.2 Regular spacing in pot plants depth of well-structured and fertilized soil enables deep root penetration. However, growers often deliberately grow plants closer to restrict growth in order to produce the correct size and the desired uniformity, as in the growing of carrots for the processing companies.

Whilst spacing is a vital aspect of plant growth, it should be realized that the grower might need to adjust the physical environment in one of many other specific ways in order to favour a chosen plant species. This may involve the selection of the correct light intensity; a rose, for example, whether in the garden, greenhouse or conservatory, will respond best to high light levels, whereas a fern will grow better in low light.

Another factor may be the artificial alteration of day length, as in the use of 'black-outs' and cyclic lighting in the commercial production of chrysanthemums to induce flowering. Correct soil acidity (pH) is a vital aspect of good growing; heathers prefer high acidity, whilst saxifrages grow more actively in non-acid (alkaline) soils. Soil texture, e.g. on golf greens, may need to be adjusted to a loamy sand type at the time of green preparation in order to reduce compaction and maintain drainage.

Each species of plant has particular requirements, and it requires the skill of the horticulturist to bring all these together. In greenhouse production, sophisticated control equipment may monitor air and root-medium conditions every few minutes, in order to provide the ideal day and night requirements.

This aspect of single species communities emphasizes the great contrast between production horticulture and the mixed plantings in ornamental horticulture. This inter-species competition is even more marked in the natural habitat of a broad-leaved temperate woodland habitat and reaches its greatest diversity in tropical lowland forests where as many as 200 tree species may be found in one hectare.

Plant species as plant communities

The subject of ecology deals with the inter-relationship of plant (and animal) species and their environment. Below are described some of the ecological concepts which most commonly apply to the natural environment, where human interference is minimal. It will be seen, however, that such concepts also have relevance to horticulture in spite of its more controlled environment.

Firstly, the structure, physiology and life cycle properties of a plant species should be seen as closely related to its position within a habitat, giving it a competitive advantage. Small short-lived ephemerals such as groundsel (*Senecio*) with its rapid seed production and low dormancy are able to achieve a speedy colonization of bare ground. The spreading perennial, bramble (*Rubus*) has thorns that ease its climbing habit over other plant species and a tolerance of low light conditions that assumes greater importance as tree species grow above it. Woody species such as oak (*Quercus*) quickly create a well-developed root system that supplies the water and minerals for their dominance of the habitat.

Aquatic species such as pondweed (*Potamogeton* spp) often have air spaces in their roots to aid oxygen and carbon dioxide diffusion.

Ecology terms

For a marsh willow-herb (*Epilobium palustre*), its only habitat is in slightly acidic ponds. In contrast, a species such as a blackberry (*Rubus fruticosus*) may be found in more than one habitat, e.g. heath land, woodland and in hedges. The common rat (*Rattus norvegicus*), often associated with humans, is also seen in various habitats (e.g. farms, sewers, hedgerows and food stores).

Habitat

The area or environment where an organism or community normally lives or occurs.

Within the term 'habitat', distinction can be drawn between closed plant communities and open plant communities.

A **closed plant community** is one that receives only minimal contact with outside organisms (and also materials). A small isolated island community in the middle of a large lake would be one example.

These two terms can only be used in a relative way because the radiation from the sun, the gases in the atmosphere, and migrant species prevent a true closed system being established within the natural environment.

A couple of general points may be added about the vegetation of the British Isles. The British Isles at present has about 1700 plant species. Fossil and pollen evidence suggests that before the Ice Age there was a much larger number of plant species, possibly comparable to the 4000 species now seen in Italy (a country with a similar land area to that of Britain). In Neolithic times, when humans began occupying this area, most of Britain was covered by mixed oak forest. Since that time progressive clearing of most of the land has occurred, especially below the altitude limits for cattle (450 m) and for crops (250 m).

Plant associations

In natural habitats, it is seen that a number of plant species (and associated animals) are grouped together, and that away from this habitat they are not commonly found. Two habitat examples can be given. In south-east Britain, in a low rainfall, chalk grassland habitat there will often be greater knapweed (*Centaurea scabiosa*), salad burnet (*Poterium sanguisorba*) and bee orchid (*Ophrys apifera*). In the very different high rainfall, acid bogs of northern Britain, cotton grass (*Eriophorum vaginatum*), bog myrtle (*Myrtus gale*) and sundew (*Drosera anglica*) are commonly found together. Other habitat species such as bluebell (in dense broadleaved woodland), bilberry (in dry acid moor), mossy saxifrage (in wet north-facing cliffs), broom (in dry acid soils) and water violet (in wet calcareous soils) can be mentioned. It should be noted that successful weeds such as chickweed are not habitat-restricted (see Chapter 13) in this way.

An **open plant community** is one that receives continuous exposure to other organisms (and materials) from outside. A marine shoreline community would be one example.

Niche

The role of a species within its habitat.

'Semi natural vegetation' is vegetation not planted by humans, but influenced by human actions such as grazing, logging and other types of disruption of the plant communities. The vegetation described as 'semi natural' has been able to recover to such an extent that wild species composition and ecological processes are similar to those found in an undisturbed state.

For a *Sphagnum* moss, its niche would be as a dominant species within an acid bog. The term 'niche' carries with it an idea of the specialization that a species may exhibit within a community of other plants and animals. A niche involves, for plants, such factors as temperature, light intensity, humidity, pH, nutrient levels, etc. For animals such as pests and their predators, there are also factors such as preferred food and chosen time of activity determining the niche. The niche of an aphid is as a remover of phloem sugars from its host plant.

A **dominant species** is a species within a given habitat that exerts its influence on other species to the greatest extent and is usually the largest species member. In mixed oak woodland, the oak is the dominant plant species.

The term is sometimes hard to apply in an exact way, since each species shows a certain tolerance of the factors mentioned above, but it is useful in emphasizing specialization within a habitat. The biologist, Gause, showed that no two species can exist together if they occupy the same niche. One species will, sooner or later, start to dominate.

For the horticulturalist, the important concept here is that for each species planted in the ground, there is an ideal combination of factors to be considered if the plant is to grow well. Although this concept is an important one, it cannot be taken to an extreme. Most plants tolerate a range of conditions, but the closer the grower gets to the ideal, the more likely they are to establish a healthy plant.

Biome

A major regional or global community of organisms, such as a grassland or desert, characterized by the dominant forms of plant life and the prevailing climate.

This term refers to a wider grouping of organisms than that of a habitat. As with the term habitat, the term 'biome' is biological in emphasis, concentrating on the species present. This is in contrast to the broader ecosystem concept described below. Commonly recognized biomes would be 'temperate woodland', 'tropical rainforest', 'desert', 'alpine' and 'steppe'. About 35 types of biome are recognized worldwide, the classification being based largely on climate, on whether they are land- or water-based, on geology and soil, and on altitude above sea level. Each example of a biome will have within it many habitats. Different biomes may be characterized by markedly different potential for annual growth. For example, a square metre of temperate forest biome may produce ten times the growth of an alpine biome.

Ecosystems

This term brings emphasis to both the community of living organisms and to their non-living environment. Examples of an ecosystem are a wood, a meadow, a chalk hillside, a shoreline and a pond. Implicit within this term (unlike the terms habitat, niche, and biome) is the idea of a whole integrated system, involving both the living (**biotic**) plant and animal species, and the non-living (**abiotic**) units such as soil and climate, all reacting together within the ecosystem.

Ecosystems can be described in terms of their energy flow, showing how much light is stored (or lost) within the system as plant products such as starch (in the plant) or as organic matter (in the soil). Several other systems such as carbon, nitrogen, and sulphur cycles and water conservation may also be presented as features of the ecosystem in question (see page 324).

Ecosystem

An ecological community, together with its environment, functioning as a unit.

The importance of plants as energy producers

Energy perspectives are relevant to the ecosystem concept mentioned above. The process of photosynthesis enables a plant to retain, as chemical energy, approximately 1 per cent of the sun's radiant energy falling on the particular leaf's surface. As the plant is consumed by primary consumers, approximately 90 per cent of the leaf energy is lost from the biomass (see p54), either by respiration in the primary consumer, by heat radiation from the primary consumer's body or as dead organic matter excreted by the primary consumer. This organic matter, when incorporated in the soil, remains usefully within the ecosystem.

The relative levels of the total biomass as against the total organic matter in an ecosystem are an important feature. This balance can be markedly affected by physical factors such as soil type, by climatic factors such as temperature, rainfall, and humidity, and also influenced by the management system operating in that ecosystem. For example, a temperate woodland on 'heavy' soil with 750 mm annual rainfall will maintain a relatively large soil organic matter content, permitting good nutrient retention, good water retention and resisting soil erosion even under extreme weather conditions. For these reasons, the ecosystem is seen to be relatively stable. On the other hand, a tropical forest on a sandy soil with 3000 mm rainfall will have a much smaller soil organic matter reserve, with most of its carbon compounds being used in the living plants and animal tissues. As a consequence, nutrient and moisture retention and resistance to soil erosion are usually low; serious habitat loss can result when wind damage or human interference occurs. For temperate horticulturists, the main lesson to keep in mind is that high levels of soil organic matter are usually highly desirable, especially in sandy soils that readily lose organic matter.

Figure 3.3 Mature woodland

Succession

Communities of plants and animals change with time. Within the same habitat, the species composition will change, as will the number of individuals within each species. This process of change is known as 'succession'. Two types of succession are recognized.

- **Primary** succession is seen in a situation of uncolonized rock or exposed subsoil. Sand dunes, disused quarries and landslide locations are examples. Primary succession runs in parallel with the development of soils (see p300) or peat (see p328). It can be seen that plant and animal species from outside the new habitat will be the ones involved in colonization.

The term '**sere**' is often used instead of 'succession' when referring to a particular habitat. **Lithosere** refers to a succession beginning with uncolonized rock, **psammosere** to one beginning with sand (often in the form of sand dunes).

- **Secondary** succession is seen where a bare habitat is formed after vegetation has been burnt, or chopped down, or covered over with flood silt deposit. In this situation, there will often be plant seeds and animals which survive under the barren surface, which are able to begin colonization again by bringing topsoil, or at least some of its associated beneficial bacteria and other micro-organisms, to the surface. This kind of succession is the more common type in the British Isles. A **hydrosere** refers to succession occurring in a fresh water lake.

Influences on succession can come in two ways. '**Allogenic succession**' occurs when the stimulus for species change is an external one. For example, a habitat may have occasional flooding (or visits from grazing animals) which influence species change. In contrast, '**autogenic succession**' occurs when the stimulus for change is an internal one. For example, a gradual change in pH (or increased levels of organic matter) may lead to the species change.

Stages in succession

Referring now to secondary succession, there is commonly observed a characteristic sequence of plant types as a succession proceeds. The first species to establish are aptly called the '**pioneer** community'. In felled woodland, these may well be mosses, lichens, ferns and fungi. In contrast, a drained pond will probably have *Sphagnum* moss, reeds and rushes, which are adapted to the wetter habitat.

The second succession stage will see plants such as grasses, foxgloves and willow herb taking over in the ex-woodland area. Grasses and sedges are the most common examples seen in the drained pond. Such early colonizing species are sometimes referred to as **opportunistic**. They often show similar characteristics to horticultural weeds (see p184), having an extended seed germination period, rapid plant establishment, short time to maturity, and considerable seed production. They quickly cover over the previously bare ground.

The third succession stage involves larger plants, which, over a period of about five years, gradually reduce the opportunists' dominance. Honeysuckle, elder and bramble are often species that appear in ex-woodland, whilst willows and alder occupy a similar position in the drained pond. The term '**competitive**' is applied to such species.

A **climax association** is the community of plant species (and animals) present in a habitat at the end of the succession process.

The fourth stage introduces tree species that have the potential to achieve considerable heights. It may well happen that both the ex-woodland and the drained pond situation have the same tree species such as birch, oak and beech. These are described as **climax** species, and will dominate the habitat for a long time, so long as it remains undisturbed by natural or human forces. Within the climax community there often remain some specimens of the preceding succession stages, but they are now held in check by the ever-larger trees.

This short discussion of succession has emphasized the plant members of the community. As succession progresses along the four stages described, there is usually an increase in **biodiversity** (an increase in numbers of plant species). It should also be borne in mind that for every plant species there will be several animal species dependent on it for food, and thus succession brings biodiversity in the plant, animal, fungal and bacterial realms. Not only is there an increase in species numbers in climax associations, but the food webs described below are also more complex, including important rotting organisms such as fungi which break down ageing and fallen trees.

Food chains

Charles Darwin is said to have told a story about a village with a large number of old ladies. This village produced higher yields of hay than the nearby villages. Darwin reasoned that the old ladies kept more cats than other people and that these cats caught more field mice which were important predators of wild bees. Since these bees were essential for the pollination of red clover (and clover improved the yield of hay), Darwin concluded that food chains were the answer to the superior hay yield. He was also highlighting the fact that inter-relationships between plants and animals can be quite complicated.

At any one time in a habitat, there will be a combination of animals associated with the plant community. A first example is a commercial crop, the strawberry, where the situation is relatively simple. The strawberry is the main source of energy for the other organisms, and is referred to, along with any weeds present, as the **primary producer** in that habitat. Any pest (e.g. aphid) or disease (e.g. mildew) feeding on the strawberries is termed a **primary consumer** , whilst a ladybird eating the aphid is called a **secondary consumer**. A habitat may include also tertiary and even quaternary consumers.

Food chains and webs

Any combination of species such as the above is referred to as a **food chain** and each stage within a food chain is called a **trophic level**. In the strawberry, this could be represented as:

strawberry → aphids → ladybird

In the soil, the following food chain might occur:

Primula root → vine weevil → predatory beetle

In the pond habitat, a food chain could be:

green algae → *Daphnia* crustacean → minnow fish.

Within any production horticulture crop, there will be comparable food chains to the ones described above. It is normally observed that in a monoculture such as strawberry, there will be a relatively short period of time (up to 5 years) for a complex food chain to develop (involving several species within each trophic level). However, in a long-term stable habitat, such as oak wood land or a mature garden growing perennials, there will be many plant species (primary producers), allowing many food chains to occur simultaneously. Furthermore, primary consumer species, e.g. caterpillars and pigeons, may be eating from several different plant types, whilst secondary consumers such as predatory beetles and tits will be devouring a range of primary consumers on several plant species. In this way, a more complex, interconnected community is developed, called a **food web** (see Figure 3.4).

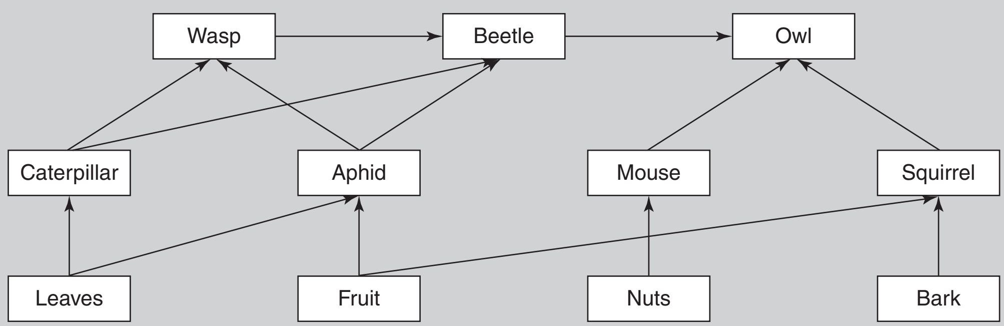

Figure 3.4 **Food web** in a woodland habitat

Decomposers

At this point, the whole group of organisms involved in the recycling of dead organic matter (called decomposers or detritovores) should be mentioned in relation to the food-web concept. The organic matter (see also Chapter 18) derived from dead plants and animals of all kinds is digested by a succession of species: large animals by crows, large trees by bracket fungi, small insects by ants, roots and fallen leaves by earthworms, mammal and bird faeces by dung beetles, etc. Subsequently, progressively smaller organic particles are consumed by millipedes, springtails, mites, nematodes, fungi and bacteria, to eventually create the organic molecules of humus that are so vital a source of nutrients, and a means of soil stability in most plant growth situations. It can thus be seen that although decomposers do not normally link directly to the food web they are often eaten by secondary consumers. They also are extremely important in supplying inorganic nutrients to the primary producer plant community.

Biomass

At any one time in a habitat, the amounts of living plant and animal tissue (**biomass**) can be measured or estimated. In production horticulture, it is clearly desirable to have as close to 100 per cent of this biomass in the form of the primary producer (crop), with as little primary consumer (pest or disease) as possible present. On the other hand, in a natural woodland habitat, the primary producer would represent approximately 85 per cent of the biomass, the primary consumer 3 per cent, the secondary consumer 0.1 per cent and the decomposers 12 per cent. This weight relationship between different trophic levels in a habitat (particularly the first three) is often summarized in graphical form as the 'pyramid of species'.

Countryside management utilizes these succession and food-web principles when attempting to strike a balance between the production of species diversity and the maintenance of an acceptably orderly managed area.

Succession to the climax stage is often quite rapid, occurring within 20 years from the occurrence of the bare habitat. Once established, a climax community of plants and animals in a natural habitat will usually remain quite stable for many years.

Garden considerations

When contemplating the distribution of our favourite species in the garden (ranging from tiny annuals to large trees), a thought may be given to their position in the succession process back in the natural habitat of their country of origin (see also p73). Some will be species commonly seen to colonize bare habitats. Most garden species will fall into the middle stages of succession. A few, whether they are trees, climbers, or low-light-requirement annuals or perennials, will be species of the climax succession. The garden contains plant species which compete in their native habitat. The artificial inter-planting of such species from different parts of the world (the situation found in almost all gardens), may give rise to unexpected results as this competition continues year after year. Such experiences are part of the joys, and the heartaches of gardening.

Companion planting

An increasingly common practice in some areas of horticulture (usually in small-scale situations) is the deliberate establishment of two or more plant species in close proximity, with the intention of deriving some cultural benefit from their association. Such a situation may seem at first sight to encourage competition rather than mutual benefit. Supporters of companion planting reply that plant and animal species in the natural world show more evidence of mutual cooperation than of competition.

Some experimental results have given support to the practice, but most evidence remains anecdotal. It should be stated, however, that whilst most commercial horticulturalists producers in Western Europe grow blocks of a single species, in many other parts of the world two or three different species are inter-planted as a regular practice.

Biological mechanisms are quoted in support of companion planting:

- **Nitrogen fixation**. Legumes such as beans convert atmospheric nitrogen to useful plant nitrogenous substances (see p366) by means of *Rhizobium* bacteria in their root nodules. Beans inter-planted with maize are claimed to improve maize growth by increasing its nitrogen uptake.
- **Pest suppression**. Some plant species are claimed to deter pests and diseases. Onions, sage, and rosemary release chemicals that mask the carrot crop's odour, thus deterring the most serious pest (carrot fly) from infesting the carrot crop. African marigolds (*Tagetes*) deter glasshouse whitefly and soil-borne nematodes by means of the chemical thiophene. Wormwood (*Artemisia*) releases methyl jasmonate as vapour that reduces caterpillar feeding, and stimulates plants to resist diseases such as rusts. Chives and garlic reduce aphid attacks.
- **Beneficial habitats**. Some plant species present a useful refuge for beneficial insects (see p271) such as ladybirds, lacewings and hoverflies. In this way, companion planting may preserve a sufficient level of these predators and parasites to effectively counter pest infestations. The following examples may be given: Carrots attract lacewings; yarrow (*Achillea*), ladybirds; goldenrod (*Solidago*), small parasitic wasps; poached-egg plant (*Limnanthes*), hoverflies. In addition, some plant species can be considered as traps for important pests. Aphids are attracted to nasturtiums, flea beetles to radishes, thus keeping the pests away from a plant such as cabbage.
- **Spacial aspects**. A pest or disease specific to a plant species will spread more slowly if the distance between individual plants is increased. Companion planting achieves this goal. For example, potatoes inter-planted with cabbages will be less likely to suffer from potato blight disease. The cabbages similarly would be less likely to be attacked by cabbage aphid.

Environmental factors and plant growth

Environmental stresses

Having dealt with the processes occurring in the natural habitat and in horticulture, it remains to mention some of the factors working against a diverse habitat. The main stresses to ecosystems in Britain and other parts of Western Europe are acidity, excess nutrients, high water tables and heavy metals.

Research suggests that in the last 25 years in Holland, for example, there has been a 25 per cent decrease in woodland species attributable to the increased acidity in the air. The same survey indicated species losses of 50 per cent, 6 per cent and 5 per cent in lakes due to excess nutrients, high water table and air acidity respectively.

Plants are resilient organisms, but stresses imposed on habitats such as those near large towns, those in the wind-path of polluted air, those watered by rivers receiving industrial effluent, and agricultural fertilizers and pesticides are likely to lose indigenous species. The rapid increase in annual temperatures attributed to 'the greenhouse effect' is likely to change wild plant communities in as important a way as the environmental stresses mentioned above.

The effects of specific abiotic factors (pollutants) on plants

Acidity. Continuing increase in soil acidity reduces vital mycorrhizal activity, causes leaching of nutrients such as magnesium and calcium, and leaves phosphate in an insoluble form. In soils formed over limestone and chalk, the effects of acid rain are much less damaging.

Excess nutrient levels in water and soils (especially from fertilizers and farm silage) encourage increase in algae and a corresponding loss of dissolved oxygen. This process (called **eutrophication)** has a serious effect on plant and animal survival. It is seen most strikingly when fish in rivers and lakes are killed in this way.

Figure 3.5 Chimney

Heavy metals may be released into the air or into rivers as by-products of chemical industries and the burning of fossil fuels. Cadmium, lead and mercury are three commonly discharged elements. While plants are more tolerant of these substances than animals, there is a slow increase within the plant cells, and more importantly the levels of chemicals increase dramatically as the plants are eaten and the chemicals move up the food chains (see also DDT p58).

Pesticides. Recent legislation has led to a greater awareness of pesticide effects on the environment. However, herbicide and insecticide leaching through sandy soils into watercourses continues to be a threat if application of the chemicals occurs near watercourses. A herbicide such as MCPA can kill algae, aquatic plants and fish.

A **high water table** can have a marked effect on a habitat if the effect is prolonged. The anaerobic conditions produced often lead to root death in all but the aquatic species present in the plant community.

Monitoring abiotic factors

There is constant monitoring by Government agencies for the factors mentioned above. This is especially so in National Parks, National Nature Reserves (**NNRs)**, and Sites of Special Scientific Interest (**SSSIs)**. Environmental scientists and laboratories have a range of techniques for assessing levels of these factors. Chemical tests for common nutrient substances and for pH can be performed in the field. More sophisticated analysis is required for heavy metals and pesticides. A common five day test for water quality called 'Biological Oxygen Demand' (**BOD)** enables a confident assessment of a water sample's pollution level. An unpolluted sample would register at about 3 mg of oxygen per unit volume per day whereas a sample polluted by fertilizers could be about 50 mg of oxygen per unit volume per day.

Plant modifications to extreme conditions (see also p80)

A survey of plants worldwide shows what impressive structural and physiological modifications they possess to survive in demanding habitats. A few examples of British species are described here.

A **xerophyte** is a plant adapted to living in a dry arid habitat.

A **hydrophyte** is a plant adapted to growing in water.

A **halophyte** is a plant adapted to living in a saline environment.

Marram grass (*Ammophila arenaria*) living on sand dunes controls water-loss by means of leaf lamina which in cross-section is shown to be rolled up. It also possesses extremely long roots (see page 78).

The yellow water lily (*Nupar lutea*) shows the following modifications: leaves with a thin cuticle (but with numerous stomata), large flat leaves and a stem with air sacs.

The coastal habitats provide many examples of species which must conserve water in salty, windy coastal conditions. Glasswort (*Salicornia stricta*) is a succulent with greatly reduced leaves which have a thick cuticle, and its stomata remain closed most of the day. The species is able to extract water from the seawater and is tolerant to internal salt concentrations that would kill most plant species (see plasmolysis, p123). An interesting halophyte is the sugar beet plant which was bred in France from a native coastal species. It is the only crop grown in Europe that receives salt (sodium chloride) as part of its fertilizer requirements.

Conservation

From the content of preceding paragraphs it can be seen that the provision of as extensive a system of varied habitats, each with its complex foodweb, in as many locations as possible, is increasingly being considered desirable in a nation's environment provision. In this way, a wide variety of species numbers (**biodiversity)** is maintained, habitats are more attractive and species of potential use to mankind are preserved. In addition, a society that bequeaths its natural habitats and ecosystems to future generations in an acceptably varied, useful and pleasant condition is contributing to the **sustainable development** of that nation.

The ecological aspects of natural habitats and horticulture have been highlighted in recent years by the **conservation movement**. One aim is to promote the growing of crops and maintain wildlife areas in such a way that the natural diversity of wild species of both plants and animals is maintained alongside crop production, with a minimum input of fertilizers and pesticides. Major public concern has focused on the effects of intensive production (monoculture) and the indiscriminate use by horticulturists and farmers of pesticides and quick-release fertilizers.

An example of wildlife conservation is the conversion of an area of regularly mown and 'weedkilled' grass into a wild flower meadow, providing an attractive display during several months of the year.
The conversion of productive land into a wild flower meadow requires lowered soil fertility (in order to favour wild species establishment and competition), a choice of grass seed species with low opportunistic

properties and a mixture of selected wild flower seed. The maintenance of the wild flower meadow may involve harvesting the area in July, having allowed time for natural flower seed dispersal. After a few years, butterflies and other insects become established as part of the wild flower habitat.

The horticulturist has three notable aspects of conservation to consider. Firstly, there must be no willful abuse of the environment in horticultural practice. Nitrogen fertilizer used to excess has been shown, especially in porous soil areas, to be washed into streams, since the soil has little ability to hold on to this nutrient (see p367). The presence of nitrogen in watercourses encourages abnormal multiplication of micro-organisms (mainly algae). On decaying these remove oxygen sources needed by other stream life, particularly fish (a process called eutrophication).

Secondly, another aspect of good practice increasingly expected of horticulturists is the intelligent use of pesticides. This involves a selection of those materials least toxic to man and beneficial to animals, and particularly excludes those materials that increase in concentration along a food chain. Lessons are still being learned from the widespread use of DDT in the 1950s. Three of DDT's properties should be noted. Firstly, it is long-lived (residual) in the soil. Secondly, it is absorbed in the bodies of most organisms with which it comes into contact, being retained in the fatty storage tissues. Thirdly, it increases in concentration approximately ten times as it passes to the next member of the food chain. As a consequence of its chemical properties, DDT was seen to achieve high concentrations in the bodies of secondary (and tertiary) consumers such as hawks, influencing the reproductive rate and hence causing a rapid decline in their numbers in the 1960s. This experience rang alarm bells for society in general, and DDT was eventually banned in most of Europe. The irresponsible action of allowing pesticide spray to drift onto adjacent crops, woodland or rivers has decreased considerably in recent years. This has in part been due to the Food and Environment Protection Act (FEPA) 1985, which has helped raise the horticulturist's awareness of conservation (see page 289).

A third aspect of conservation to consider is the deliberate selection of trees, features and areas which promote a wider range of appropriate species in a controlled manner. A golf course manager may set aside special areas with wild flowers adjacent to the fairway, preserve wet areas and plant native trees. Planting bush species such as hawthorn, field maple and spindle together in a hedgerow provides variety and supports a mixed population of insects for cultural control of pests. Tit and bat boxes in private gardens, an increasingly common sight, provide attractive homes for species that help in pest control. Continuous hedgerows will provide safe passage for mammals. Strips of grassland maintained around the edges of fields form a habitat for small mammal species as food for predatory birds such as owls. Gardeners can select plants for the deliberate encouragement of desirable species (nettles and *Buddleia* for butterflies; Rugosa roses and *Cotoneaster* for winter feeding of seed-eating birds; poached-egg plants for hoverflies).

It is emphasized that the development and maintenance of conservation areas requires continuous management and consistent effort to maintain the desired balance of species and required appearance of the area. As with gardens and orchards, any lapse in attention will result in invasion by unwanted weeds and trees. In a wider sense, the conservation movement is addressing itself to the loss of certain habitats and the consequent disappearance of endangered species such as orchids from their native areas. Horticulturists are involved indirectly because some of the peat used in growing media is taken from lowland bogs much valued for their rich variety of vegetation. Considerable efforts have been made to find alternatives to peat in horticulture (see p387) and protect the wetland habits of the British Isles.

Conservationists also draw attention to the thoughtless neglect and eradication of wild-ancestor strains of present-day crops; the gene-bank on which future plant breeders can draw for further improvement of plant species. There is also concern about the extinction of plants, especially those on the margins of deserts that are particularly vulnerable if global warming leads to reduced water supplies. In situ conservation mainly applies to wild species related to crop plants and involves the creation of natural reserves to protect habitats such as wild apple orchards and there is particular interest in preserving species with different ecological adaptions. Ex situ conservation includes whole plant collections in botanic gardens, arboreta, pineta and gene-banks where seeds, vegetative material and tissue cultures are maintained. The botanic gardens are coordinated by the Botanic Gardens Conservation International (BGCI), which is based at Kew Gardens, London, and are primarily concerned with the conservation of wild species.

Figure 3.6 **Pyracanthas** have good winter food for birds

Large national collections include the National Fruit Collection at Brogdale, Kent (administered by Wye College) and the Horticultural Research International at Wellesbourne, Birmingham, holds vegetables. The Henry Doubleday Heritage Seed Scheme conserves old varieties of vegetables which were once commercially available but which have been dropped from the National List (and so become illegal to sell). They encourage the exchange of seed. The National Council for the Conservation of Plants and Gardens (NCCPG) was set up by the Royal Horticultural Society at Wisley in 1978 and is an excellent example of professionals and amateurs working together to conserve stocks of extinction threatened garden plants, to ensure the availability of a wider range of plants and to stimulate scientific, taxonomic, horticultural, historical and artistic studies of garden plants. There are over 600 collections of ornamental plants encompassing 400 genera and some 5000 plants. A third of these are maintained in private gardens, but many are held in publicly funded institutions such as colleges, e.g. *Sarcococca* at Capel Manor College in North London, *Escallonia* at the Duchy College in Cornwall, *Penstemon* and *Philadelphus* at Pershore College and *Papaver orientale* at the Scottish Agricultural College, Auchincruive. Rare plants are identified and classified as ‘pink sheet’ plants.

Organic growing

The organic movement broadly believes that crops and ornamental plants should be produced with as little disturbance as possible to the balance of microscopic and larger organisms present in the soil and also in the above-soil zone. This stance can be seen as closely allied to the conservation position, but with the difference that the emphasis here is on the balance of micro-organisms. Organic growers maintain soil fertility by the incorporation of animal manures, or green manure crops such as grass–clover leys. The claim is made that crops receive a steady, balanced release of nutrients through their roots in a soil where earthworm activity recycles organic matter deep down; the resulting deep root penetration allows an effective uptake of water and nutrient reserves.

The use of most pesticides and quick-release fertilizers is said to be the main cause of species imbalance, and formal approval for licensed organic production may require soil to have been free from these two groups of chemicals for at least two years. Control of pests and diseases is achieved by a combination of resistant cultivars and 'safe' pesticides derived from plant extracts, by careful rotation of plant species, and by the use of naturally occurring predators and parasites. Weeds are controlled by mechanical and heat-producing weed controlling equipment, and by the use of mulches. The balanced nutrition of the crop is said to induce greater resistance to pests and diseases, and the taste of organically grown food is claimed to be superior to that of conventionally grown produce.

The organic production of food and non-edible crops at present represents about 5 per cent of the European market. The European Community Regulations (1991) on the 'organic production of agricultural products' specify the substances that may be used as 'plant-protection products, detergents, fertilizers, or soil conditioners' (see pps293 and 375). Conventional horticulture is, thus, still by far the major method of production and this is reflected in this book. However, it should be realized that much of the subsistence cropping and animal production in the Third World could be considered 'organic'.

Check your learning

1. Define the term 'ecosystem'.
2. Define the term 'semi-natural vegetation'.
3. Explain the importance of plants as energy producers within ecosystems.
4. Describe the stages in a named succession, giving plant species examples.
5. Describe the effects of three named pollutants on plant growth and development.
6. Describe three adaptations found in plants living in an extreme environment.

Further reading

Allaby, M. (1994). *Concise Oxford Dictionary of Botany*. Oxford University Press.
Ayres, A. (1990). *Gardening Without Chemicals*. Which/Hodder & Stoughton.
Baines, C. and Smart, J. (1991). *A Guide to Habitat Creation*. Packard Publishing.
Brown, L.V. (2008). *Applied Principles of Horticultural Science*. 3rd edn., Butterworth-Heinemann.
Caplan, B. (1992). *Complete Manual of Organic Gardening*. Headline Publishing.
Carson, R. (1962). *Silent Spring*. Hamish Hamilton.
Carr, S. and Bell, M. (1991). *Practical Conservation*. Open University/ Nature Conservation Council.
Dowdeswell, W.H. (1984). *Ecology Principles and Practice*. Heinemann Educational Books.
Innis, D.Q. (1997). *Intercropping and the Scientific Basis of Traditional Agriculture*. Intermediate Technology Publications.
Lampkin, N. (1990). *Organic Farming*. Farming Press.
Lisansky, S.G., Robinson, A.P., and Coombs, J. (1991). *Green Growers Guide*. CPL Scientific Ltd.
Mannion, A.M. and Bowlby, S.R. (eds) (1992). *Environmental Issues in the 1990s*. John Wiley & Sons.
Preston, C.D., Pearman, D.A., and Dines, T.D. (2002). *New Atlas of the British and Irish Flora*. Oxford University Press.
Tait, J. *et al.* (1998). *Practical Conservation*. Open University.

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Chapter 4 Classification and naming

Summary

This chapter includes the following topics:

- **The major divisions of the plant kingdom**
- **Gymnosperms and angiosperms**
- **Monocotyledons and dicotyledons**
- **Nomenclature, the naming of plants**
- **Plant families**
- **Plant genera, species, subspecies**
- **Plant varieties and cultivars**

with additional information on the following:

- **Principles of classification**
- **Hybrids**
- **Identifying plants**
- **Geographical origins of plants**
- **Fungi**
- **Animals**
- **Bacteria**
- **Algae and lichens**
- **Viruses**

Figure 4.1 **A range of divisions of the plant kingdom**, including moss, fern, fungi, seed producing plants (pine needles) in natural habitat

The classification of plants

Any classification system involves the grouping of organisms or objects using characteristics common to members within the group. A classification can be as simple as dividing things by colour or size. Fundamental to most systems and making the effort worthwhile is that the classification meets a purpose; has a use. This is generally to make life simpler such as to find books in a library; they can be classified in different, but helpful ways, e.g. by subject or date or particular use.

Terms that are used in classification are:

- **taxonomy**, which deals with the principles on which a classification is based;
- **systematics** identifies the groups to be used in the classification;
- **nomenclature** deals with naming.

Various systems for organisms have been devised throughout history, but a seventeenth century Swedish botanist, **Linnaeus**, laid the basis for much subsequent work in the classification of plants, animals (and also minerals). The original divisions of the plant kingdom were the main groupings of organisms according to their place in evolutionary history. Simple single-celled organisms from aquatic environments evolved to more complex descendants, multicellular plants with diverse structures, which were able to survive in a terrestrial habitat, and develop sophisticated reproduction mechanisms.

The world of living organisms is currently divided into five kingdoms including:

- Plantae (plants)
- Animalia (animals)
- Fungi
- Bacteria (Prokaryotae)
- Protoctista (all other organisms that are not in the other kingdoms including algae and protozoa).

The organisms constituting the plant kingdom are distinguishable from animals in having sedentary growth, cellulose cell walls and polyploidy (see Chapter 10). They are able to change energy from one form (e.g. light) into organic molecules (autotrophic nutrition; see photosynthesis p110). Animals, amongst other things, have no cell walls and rely on eating ready-made organic molecules (heterotrophic nutrition).

Plant **divisions** (the names ending in -phyta) are further sub-divided into

- **class** (ending -psida);
- **order** (ending -ales);
- **family** (ending -aceae);
- **genus**;
- **species**.

A **species** is a group of individuals with the greatest mutual resemblance, which are able to breed amongst themselves.

Species is the basic unit of classification, and is defined as a group of individuals with the greatest mutual resemblance, which are able to breed amongst themselves. A number of species with basic similarities constitute a genus (plural genera), a number of genera constitute a family, and a number of families make up an order (see example given in Table 4.1). **Subspecies** are a naturally occurring variation within a species where the types are quite different from each other.

Table 4.1 Classification. The lettuce cultivar 'Little Gem' used to illustrate the hierarchy of the classification up to kingdom

Kingdom	**Plantae**	**Plants**
SubKingdom	Tracheobionta	Vascular plants
Superdivision	Spermatophyta	Seed plants
Division	**Magnoliophyta**	**Flowering plants**
Class	**Magnoliopsida**	**Dicotyledons**
Subclass	Asteridae	
Order	**Asterales**	
Family	**Asteraceae**	**Aster family**
Genus	***Lactuca***	**lettuce**
Species	***L. sativa***	**garden lettuce**
Cultivar	***L. sativa* 'Little Gem'**	

In order to produce a universally acceptable system, the International Code of Botanical Nomenclature was formulated, which includes both non-cultivated plants and details specific to cultivated plants.

Kingdom Plantae

Plants

The first major breakdown of the plant kingdom is into divisions (see Table 4.2 below).

Table 4.2 Divisions of the plant kingdom

	Divisions:	**Common name:**
	Bryophyta	Mosses
	Hepatophyta	Liverworts
Vascular plants:		
	Equisetophyta	Horsetails
	Pteridophyta	Ferns
Seed plants:		
	Coniferophyta	Conifers
	Ginkgophyta	Ginkgo
	Magnoliophyta	Flowering plants

Divisions of the plant kingdom

Mosses and liverworts. Over 25 000 plant species which do not have a vascular system (see p92) are included in the divisions Bryophyta and Hepatophyta. They have distinctive vegetative and sexual reproductive structures, the latter producing spores that require damp conditions for survival. Many from both divisions are pioneer plants that play an important part in the early stages of soil formation. The low spreading carpets of vegetation also present a weed problem on the surface of compost in container-grown plants, on capillary benches and around glazing bars on greenhouse roofs.

Moss, Bryophyta

Liverwort, Hepatophyta

Ferns, Pteridophyta

Horsetail, Equisetophyta

Figure 4.2 **Four multicellular plant divisions**, moss, liverwort, fern, horsetail with horticultural significance

Ferns and horsetails in the divisions Pteridophyta and Equisetophyta, have identifiable leaf, stem and root organs, but produce spores rather than seeds from the sexual reproduction process. Many species of ferns, e.g. maidenhair fern (*Adiantum cuniatum*), and some tropical horsetails, are grown for decorative purposes, but the common horsetail (*Equisetum arvense*), and bracken (*Pteris aquilina*) that spread by underground rhizomes are difficult weeds to control.

Seed-producing plants (Super-division – Spermatophyta) contain the most highly evolved and structurally complex plants. There are species adapted to most habitats and extremes of environment. Sexual reproduction produces a seed, which is a small, embryo plant contained within a protective layer.

Angiosperms and gymnosperms

The subdivision into class brings about the gymnospermae, mostly consisting of trees and shrubs, and the angiospermae representing the greatest diversity of plants with adaptations for the majority of habitats. Structurally, the gymnosperms have much simpler xylem vessels than the more complex system in the angiosperms, and flowers are unisexual producing naked seeds. The angiosperms usually have hermaphrodite flowers, which produce complex seeds (see p103), inside a protective fruit.

Conifers (Coniferophyta) are a large division of many hundred species that include the pines (Order – Pinales) and yews (Order – Taxales). Characteristically they produce 'naked' seeds, usually in cones, the female organ. They show some primitive features, and often display structural adaptations to reduce water loss (see Figure 9.2). There are very many important conifers. Some are major sources of wood or wood pulp, but within horticulture many are valued because of their interesting plant habits, foliage shape and colours. The Cupressaceae, for example, includes fast growing species, which can be used as windbreaks, and small, slow growing types very useful for rock gardens. The yews are a highly poisonous group of plants that includes the common yew (*Taxus baccata*) used in ornamental hedges and mazes. The division Ginkgophyta is represented by a single surviving species, the maidenhair tree (*Ginkgo biloba*), which has an unusual slit-leaf shape, and distinctive bright yellow colour in autumn.

Figure 4.3 **Yew (*Taxus baccata*) with berries** – a conifer

Flowering plants (Division – Magnoliophyta) have a flower structure for sexual reproduction producing seeds protected by fruits. This characteristic structure is used as the basis of their classification. There are estimated to be some 25 000 species, occupying a very wide range of habitats. Many in the division are important to horticulture, both as crop plants and weeds. This division is split into two main classes; the Liliopsida formerly the Monocotyledonae and generally known as the **monocotyledons,** and the Magnoliopsida, the **dicotyledons.** The main differences are given in Table 4.3.

(a) Parallel veins
e.g. most monocotyledons

Reticulate (net)veins
e.g. most dicotyledons
(b)

Figure 4.4 **Leaf venation** in
(a) monocotyledon and (b) dicotyledon

Table 4.3 Differences between Monocotyledons and Dicotyledons

Monocotyledons	Dicotyledons
One seed leaf	Two seed leaves
Parallel veined leaves usually alternate and entire (see Figure 4.4)	Net veined leaves
Vascular bundles in stem scattered	Vascular bundles in stem in rings
Flower parts usually in threes, also three seed chambers in fruit	Flower parts usually in fours or fives, also four or five seed chambers in fruit
Except palms, are non-woody	Both woody and herbaceous species
Herbaceous plants	Woody stems showing annual rings

Monocotyledons include some important horticultural families, e.g. Arecaceae, the palms; Musaceae, the bananas; Cyperaceae, the sedges; Juncaceae, the rushes; Poaceae (formerly Graminae), the grasses; Iridaceae, the irises; Liliaceae, the lilies and the Orchidaceae, the orchids.

Dicotyledons has many more families significant to horticulture, including Magnoliaceae, the magnolias; Caprifoliaceae, the honeysuckles; Cactaceae, the cactuses; Malvaceae, the mallows; Ranunculaceae, the buttercups; Theaceae, the teas; Lauraceae, the laurels; Betulaceae, the birches; Fagaceae, the beeches; Solanaceae, the potatoes and tomato; Nymphaeaceae, the water lilies and Crassulaceae, the stonecrops. Four of the biggest and most economically important families in this class have had a change of name. Fabaceae (formerly the Leguminosae), the pea and bean family, have five-petalled asymmetric or zygomorphic (having only one plane of symmetry) flowers, which develop into long pods (legumes) containing starchy seeds. The characteristic upturned umbrella-shaped flower head or **umbel** is found in the Apiaceae (formerly the Umbelliferae), the carrot family, and bears small white five-petalled flowers, which are wind-pollinated. The members of Asteraceae (formerly Compositae) have a characteristic flower head with many small florets making up the composite, regular (or actinomorphic) structure, e.g. chrysanthemum, groundsel. Members of the Brassicaceae (formerly Cruciferae) are characterized by their four-petal flower and contain the *Brassica* genus with a number of important crop plants such as cabbage, cauliflowers, swedes, Brussels sprouts, as well as the wallflower (*Cheiranthus cheiri*). Most of the brassicas have **a biennial** growth habit producing vegetative growth in the first season, and flowers in the second, usually in response to a cold stimulus (see vernalization). A number of weed species are found in this family, including shepherd's purse (*Capsella bursapastoris*), which is an **annual**. Many important genera, e.g. apples (*Malus*), pear (*Pyrus*) and rose (*Rosa*), are found within the Rosaceae family, which generally produces succulent fruit from a flower with five petals and often many male and female organs. Many species within this family display a **perennial** growth habit (see Table 4.4).

Figure 4.5 **Rose flower and hip** – a member of family Rosaceae with five petals, multiple sex organs and a succulent fruit (*see* page 104)

Nomenclature

The naming of cultivated plants

The binomial system

The name given to a plant species is very important. It is the key to identification in the field or garden, and also an international form of identity, which can lead to much information from books and the Internet. The common names which we use for plants, such as potato and lettuce, are, of course, acceptable in English, but are not universally used. A scientific method of naming can also provide more information about a species, such as its relationship with other species.

Linnaeus, working on classification and with the more detailed question of naming, formulated a system that he claimed should identify an individual plant type uniquely, by means of the composed **genus** name followed by the **species** name. For example, the chrysanthemum used for cut flowers is *Chrysanthemum* genus and *morifolium* species; note that the genus name begins with a capital letter, while the species has a small letter. Other examples are *Ilex aquifolium* (holly), *Magnolia stellata* (star-magnolia), *Ribes sangui-neum* (redcurrant).

Subspecies can evolve and display more distinct characteristics than the varieties detailed below, e.g. *Rhododendron arboreum* subsp.

cinnamomeum. The genus and species names must be written in *italics,* or underlined where this is not possible, to indicate that they are internationally accepted terms. However, these two words may not encompass all possible variations, since a species can give rise to a number of naturally occurring **varieties** with distinctive characteristics. In addition, cultivation, selection and breeding have produced variation in species referred to as cultivated varieties or **cultivars**.

A **variety** is a variation within a species which has arisen naturally.

A **cultivar** is similarly a variation within a species which has arisen or has been bred in cultivation.

The two terms, variety and cultivar are exactly equivalent, but the botanical variety name is referred to in Latin, beginning with a small letter, e.g. *Rhododendron arboreum* var *roseum,* while the cultivar is given a name often relating to the plant breeder who produced it, e.g. *Rhododendron arboreum* 'Tony Schilling'. There is no other significant difference in the use of the two terms, and therefore either is acceptable. However, the term cultivar will be used throughout this text. A cultivar name should be written in inverted commas and begin with a capital letter, after the binomial name or, when applicable, the common name. Examples include: *Prunus padus* 'Grandiflora', tomato 'Ailsa Craig', apple 'Bramley's seedling'.

If a cultivar name has more than one acceptable alternative, they are said to be **synonyms** (sometimes written syn.) e.g. *Phlox paniculata* 'Frau Alfred von Mauthner' syn. *P. paniculata* 'Spitfire'.

Hybrids

When **cross-pollination** occurs between two plants, hybridization results, and the offspring usually bear characteristics distinct from either parent. Hybridization can occur between different cultivars within a species, sometimes resulting in a new and distinctive cultivar (see Chapter 10), or between two species, resulting in an **interspecific hybrid**, e.g. *Prunus* × *yedoensis* and *Erica* × *darleyensis.* A much rarer hybridization between two different genera results in an **intergeneric hybrid**, e.g. × *Cupressocyparis leylandii* and × *Fatshedera lizei.* The names of the resulting hybrid types include elements from the names of the parents, connected or preceded by a multiplication sign (×). A chimaera, consisting of tissue from two distinct parents, is indicated by a 'plus' sign, e.g. + *Laburnocystisus adamii,* the result of a graft.

Further classifications of plants

Plants can be grouped into other useful categories. A classification based on their life cycle (ephemerals, annuals, biennials and perennials) has long been used by growers, who also distinguish between the different woody plants such as trees and shrubs. Growers distinguish between those plants that are able to withstand a frost (hardy) and those that cannot (tender); plants can be grouped according to their degree of hardiness. Table 4.4 brings together these useful terms, provides some definitions and gives some plant examples.

Table 4.4 Some commonly used terms that describe the life cycles, size and survival strategies of plants

Life cycles		
Ephemeral	A plant that has several life cycles in a growing season and can increase in numbers rapidly	e.g. groundsel (*Senecio vulgaris*)
Annual	A plant that completes its life cycle within a growing season	e.g. poached-egg flower (*Limnanthes douglasii*)
Biennial	A plant with a life cycle that spans two growing seasons	e.g. foxglove (*Digitalis purpurea*)
Perennial	A plant living through several growing seasons	
Herbaceous perennial	A perennial that loses its stems and foliage at the end of the growing season	e.g. Michaelmas daisy (Aster spp.) and hop (*Humulus lupulus*)
Woody plants		
Woody perennial	A perennial that maintains live woody stem growth at the end of the growing season	e.g. bush fruit, shrubs, trees, climbers (e.g. grape)
Shrub	A woody perennial plant having side branches emerging from near ground level. Up to 5 m tall	e.g. Lilac (*Syringa vulgaris*)
Tree	A large woody perennial unbranched for some distance above ground. Usually more than 5 m	e.g. Horse chestnut (*Aesculus hippocastanum*)
Deciduous	A plant that sheds all its leaves at once	e.g. Mock orange (*Philadelphus delavayi*)
Evergreen	A plant retaining leaves in all seasons	e.g. Aucuba (*Aucuba japonica*)
Hardiness		
Very hardy	A plant able to survive − 18°C	e.g. *Kerria japonica*
Moderately hardy	A plant able to survive − 15°C	e.g. *Camellia japonica*
Semi-hardy	A plant able to survive − 6°C	e.g. *Pittosporum crassifolium*
Tender	A plant not hardy below − 1°C	e.g. Pelargonium cvs

Identifying plants

A **flora** is a text written for the identification of flowering plant species. Some flora use only pictures to classify plants. More detailed texts use a more systematic approach where reference is made to a **key** of features that, by elimination, will lead to the name of a plant. Species are described in terms of their flowers, inflorescences, stems, leaves and fruit. This description will often include details of shape, size and colour of these plant parts.

Flowers. The number and arrangement of flower parts (see Figure 4.6) is the most important feature for classification and is a primary feature in plant identification. It can be described in shorthand using a floral formula or a floral diagram. For example, **the flora formula**, with the interpretation, for Wallflower (*Cheiranthus cheiri*), a member of the Cruciferae family is as follows:

⊕	K4	C4	A2 + 4	$\underline{G(2)}$
symmetrical flower	4 sepals in calyx	4 petals in corolla	6 anthers	2 ovaries joined together

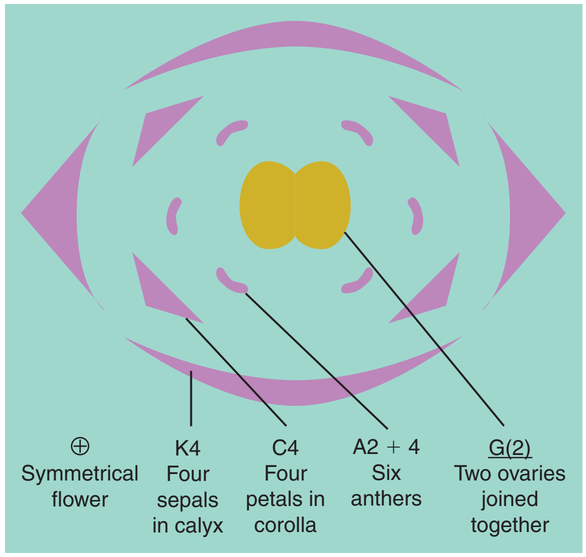

Figure 4.6 **Floral diagram of wallflower**

(a) (b) (c)

Figure 4.7 **Wallflower flower** (a) from above, (b) the side and (c) LS, illustrating the floral diagram above

Other examples of floral formulae include:

Sweet pea (Fabaceae):	·/·	K(5)	C5A(9) + 1	G1
Buttercup (Ranunculaceae):	⊕	K	C5A	G
Dead nettle (Labiatae):	·/·	K(5)	C(5)A4	G(2)
Daisy (Asteraceae):	⊕	K	C(5)A(5)	G(2)

The way that **flowers** are arranged on the plant is also distinctive in different families, e.g. raceme, common in the Fabaceae; corymb and capitulum found in the Asteraceae and umbel, very much associated with Apiaceae (see Chapter 7 for more detail).

Leaf form (see Figure 4.8) is a useful indicator when attempting to identify a plant and descriptions often include specific terms, a few are described below but many more are used in flora.

(a) (b) (c) (d) (e)

(f)

(g)

(h)

Figure 4.8 **Leaf forms**: (a) linear e.g. *Agapanths;* (b) lanceolate e.g. *Viburnum;* (c) oval e.g. *Garrya elliptica;* (d) peltate e.g. nasturtium; (e) hastate e.g. *Zantedeschia;* (f) lobed e.g. Geranium; (g) palmate e.g. lupin; (h) pinnate e.g. rose

- **Simple** leaves have a continuous leaf blade, for example: linear, lanceolate, ovate, obovate, orbicular, oval.
- **Margins** of leaves can be described: entire, sinuous, serrate, and crenate.
- **Leaf vein** arrangement also characterizes the plant: reticulate, parallel, pinnate and palmate.
- **Compound** leaves, such as compound palmate and compound pinnate, have separate leaflets each with an individual base on one leaf stalk (see p117 for leaf structure), but only the axillary bud is at the base of the main leaf stalk.

Most horticulturists yearn for stability in the **naming** of plants. Changes in names confuse many people who do not have access to up-to-date literature. On the other hand, the reasons for change are justifiable. New scientific findings may have shown that a genus or species belongs in a different section of a plant family, and that a new name is the correct way of acknowledging this fact. Alternatively, a plant introduced from abroad, maybe many years ago, may have mistakenly been given the incorrect name, along with all the cultivars derived from it.

Evidence from biochemistry, microscopy and DNA analysis is proving increasingly important in adding to the more conventional plant structural evidence for plant naming. There may be differing views whether a genus or species should be 'split' into smaller units, or several species be 'lumped' into an existing species or genus, or left unchanged. It seems likely that changes in plant names will continue to be a fact of horticultural life.

There has been a massive increase in communication across the world, especially as a result of the Internet. The level of information about plant names has improved. The International Code of Botanical Nomenclature (ICBN) has laid down an international system. Within Britain, the Royal Horticultural Society (RHS) has an advisory panel to help resolve problems in this area. An invaluable reference document 'Index

Kewensis' is maintained by Kew Gardens listing the first publication of the name for each plant species not having specific horticultural importance. Cultivated species are listed in the 'RHS Plant Finder', which also indicates where they can be sourced, is updated annually and can be viewed on the Internet. Further cooperation across Europe has led to the compilation of The International Plant Names Index with associated working parties formed from scientific institutions and the horticultural industry.

Geographical origins of plants

Gardens and horticultural units, from the tropics to more temperate climates, contain an astonishing variety of plant species from the different continents. Below is a brief selection of well-known plants, grown in Britain, illustrating this diversity of origin. It is salutary, when considering these far-flung places, to reflect on the sophisticated cultures, with skills in plant breeding and a passion for horticulture over the centuries that have taken wild plants and transformed them into the wonders that we now see in our gardens.

- **British Isles**; English Oak (*Quercus robur*), *Geranium robertianum*, foxglove, peppermint, *Pinus sylvestris*.
- **Far East** (China and Japan); cherry, cucumber, peach, walnut, *Clematis*, *Forsythia*, hollyhock, *Azalea*, rose.
- **India and South-East Asia**; mustard, radish.
- **Australasia**; *Acacia*, *Helichrysum*, *Hebe*.
- **Africa**; *Phaseolus*, pea, African violet, *Strelitzia*, *Freesia*, *Gladiolus*, *Impatiens*, *Pelargonium*, *Plumbago*.
- **Mediterranean**; asparagus, celery, lettuce, onion, parsnip, rhubarb, carnation, hyacinth, *Antirrhinum*, sweet pea, *Rosemarinus officinalis*.
- **Middle East and Central Asia**; apple, carrot, garlic, grape, leek, pear, spinach.
- **Northern Europe**; cabbage, *Campanula*, Crocus, forget-me-not, foxglove, pansy, *Primula*, rose, wallflower, parsley.
- **North America**; *Aquilegia*, *Ceonothus*, lupin, *Aster*, *Penstemon*, *Phlox*, sunflower.
- **Central and South America**; capsicum, maize, potato, tomato, *Fuchsia*, nasturtium, *Petunia*, *Verbena*.

Figure 4.9 **Oak Tree (*Quercus robur*)** – a native of the British Isles

Non-plant kingdoms

Fungi

Some **fungi** are single celled (such as yeasts) but others are multicellular, such as the moulds and the more familiar mushrooms and toadstools. Most are made up of a **mycelium**, which is a mass of thread-like filaments (**hyphae**). Their cell walls are made of chitin. Their energy and supply of organic molecules are obtained from other organisms (heterotrophic nutrition). They achieve this by secreting digestive enzymes on to their food source and absorbing the soluble products. They obtain their food directly from other living organisms, possibly causing disease (see Chapter 15), or from dead organic matter, so contributing to its breakdown in the soil (see Chapter 18).

Fungi are classified into three divisions:

- **Zygomycota** (mitosporic fungi) have simple asexual and sexual spore forms. Damping off, downy mildew, and potato blight belong to this group.
- **Ascomycota** have chitin cell walls, and show, throughout the group, a wide variety of asexual spore forms. The sexual spores are consistently formed within small sacs (asci), numbers of which may themselves be embedded within flask-shaped structures (perithecia), just visible to the naked eye. Black spot of rose, apple canker, powdery mildew, and Dutch elm disease belong to this group.
- **Basidiomycota** have chitin cell walls, and may produce, within one fungal species (e.g. cereal rust), as many as five different spore forms, involving more than one plant host. The fungi within this group bear sexual spores (basidiospores) from a microscopic club-shaped structure (basidium). Carnation rust, honey fungus, and silver leaf diseases belong to this group.

An artificially derived fourth grouping of fungi is included in the classification of fungi.

Figure 4.10 **Fungi** showing fruiting bodies

- The **Deuteromycota** include species of fungi that only very rarely produce a sexual spore stage. As with plants, the sexual structures of fungi form the most reliable basis for classification. But, here, the main basis for naming is the asexual spore, and mycelium structure. Grey mould (*Botrytis*), *Fusarium* patch of turf, and *Rhizoctonia* rot are placed within this group.

Animals

The **animal** kingdom includes a very large number of species that have a significant influence on horticulture mainly as pests (see Chapter 14) or as contributors to the recycling of organic matter (see Chapter 18).

Some of the most familiar animals are in the phylum **Chordata** that includes mammals, birds, fish, reptiles and amphibians. Mammal pest species include moles (see p200), rabbits (see p198), deer, rats and mice. Bird pest species are numerous including pigeons and bullfinches, but there are very many that are beneficial in that they feed harmful organisms such as tits that eat greenfly. Less familiar are important members of the phylum **Nematoda** (the round worms) that includes a very large number of plant disease causing organisms including Stem and Bulb Eelworm (see p229), Root Knot Eelworm (see p230), Chrysanthemum Eelworm (see p230) and Potato Root Eelworm. Phylum **Arthropoda** are the most numerous animals on earth and include insects, centipedes, millipedes and spiders; many of these are dealt with in the chapter on plant pests (Chapter 14), but it should be noted that there are many that are beneficial e.g. honey bees (see p136) and centipedes, which are carnivorous and many live on insect species that are harmful. Phylum **Annelida** (the segmented worms) includes earthworms, which are generally considered to be useful organisms especially when they are helping to decompose organic matter (see p321) or improving soil structure (see p311), but some species cause problems in fine turf when they produce worm casts. Phylum **Mollusca** is best known for the major pests: slugs and snails (see p203).

Bacteria

Bacteria are single-celled organisms sometimes arranged in chains or groups (colonial). They are autotrophic (can produce their own energy supply and organic molecules); some photosynthesize (see p110), but others are able to make organic molecules using the energy released from chemical reactions usually involving simple inorganic compounds. They have great importance to horticulture by their beneficial activities in the soil (see p321), and as causative organisms of plant diseases (see p251).

Algae and lichens

The **algae**, comprising some 18 000 species, are true plants, since they use chlorophyll to photosynthesize (see Chapter 8). The division Chlorophyta (green algae) contains single-celled organisms that require water for reproduction and can present problems when blocking irrigation lines and clogging water tanks. Marine algal species in Phaeophyta (brown algae) and Rhodophyta (red algae) are multicellular, and have leaf-like structures. They include the seaweeds, which accumulate mineral nutrients, and are therefore a useful source of compound fertilizer as a liquid feed. (The blue-green algae, which can cause problems in water because they produce unsightly blooms but are also toxic, have been renamed cyano-bacteria and placed in Kingdom Prokaryotae.)

Lichens

Classification is complex, since each lichen consists of both fungal and algal parts. Both organisms are mutually beneficial or symbiotic. The significance of lichens to horticulture is not great. Of the 15 000 species, one species is considered a food delicacy in Japan. However, lichens growing on tree bark or walls are very sensitive to atmospheric pollution, particularly to the sulphur dioxide content of the air. Different lichen species can withstand varying levels of sulphur dioxide, and a survey of lichen species can be used to indicate levels of atmospheric pollution in a particular area. Many contribute to the weathering of rock in the initial stages of soil

Figure 4.11 **Lichen** – a combination of fungi and algae development (see p300). Lichens are also used as a natural dye, and can form an important part of the diet of some deer.

Viruses

Viruses are not included in any of the kingdoms. They are visible only under an electron microscope, and do not have a cellular structure but consist of nucleic acid surrounded by an outer protein coat (a capsid). They do not have the cytoplasm, organelles and internal membranes found in the cells of living organisms (see p88). They cannot grow, move or reproduce without access to the cells of a host cell so they are not included in the classification of living things. Viruses survive by invading the cells of other organisms, modifying their behaviour and often causing disease e.g. arabis mosaic, chrysanthemum stunt, cucumber mosaic, leaf mosaic, plum pox, reversion, tomato mosaic and tulip break (see p253).

Check your learning

1. State the major divisions of the plant kingdom important to horticulture.
2. Describe the major differences between gymnosperms and angiosperms
3. Name the features of angiosperms which divide them into monocotyledons and dicotyledons.
4. Explain the reasons for plant nomenclature in horticulture.
5. Define the following terms: family, genus, species, subspecies, ephemeral, biennial, perennial, tender, half-hardy, hardy, herbaceous, woody, evergreen, semi-evergreen, and deciduous.

Further reading

Allaby, M. (1992). *Concise Oxford Dictionary of Botany*. Oxford University Press.
Baines, C. and Smart, J. (1991). *A Guide to Habitat Creation*. Packard Publishing.
Brown, L.V. (2008). *Applied Principles of Horticultural Science*. 3rd edn. Butterworth-Heinemann.
Dowdeswell, W.H. (1984). *Ecology, Principles and Practice*. Heinemann Educational Books.
Heywood, V.H. *et al.* (2007). *Flowering Plant Families of the World*. Firefly Books.
Hillier Gardener's Guide (2005). *Plant Names Explained*. David and Charles.
Ingram, D.S. *et al.* (eds) (2002). *Science and the Garden*. Blackwell Science Ltd.
Lord, T. (updated annually) *The RHS Plant Finder.* Dorling Kindersley.

Chapter 5 External characteristics of the plant

Summary

This chapter includes the following topics:

- **The external appearance or morphology of stem, root, leaf**
- **Their variation, adaptation and use in horticulture**

with additional information on:

- **The leaf form in gardening**
- **Plant size and growth rate**
- **Plant form in design**

Figure 5.1 The external appearance of the plant is often what is valued, e.g. flowers

Plant form

Most plant species at first sight appear very similar since all four organs, the **root**, **stem**, **leaf and flower**, are present in approximately the same form and have the same major functions. The generalized plant form for a dicotyledonous and a monocotyledonous plant can be seen in Figure 5.2.

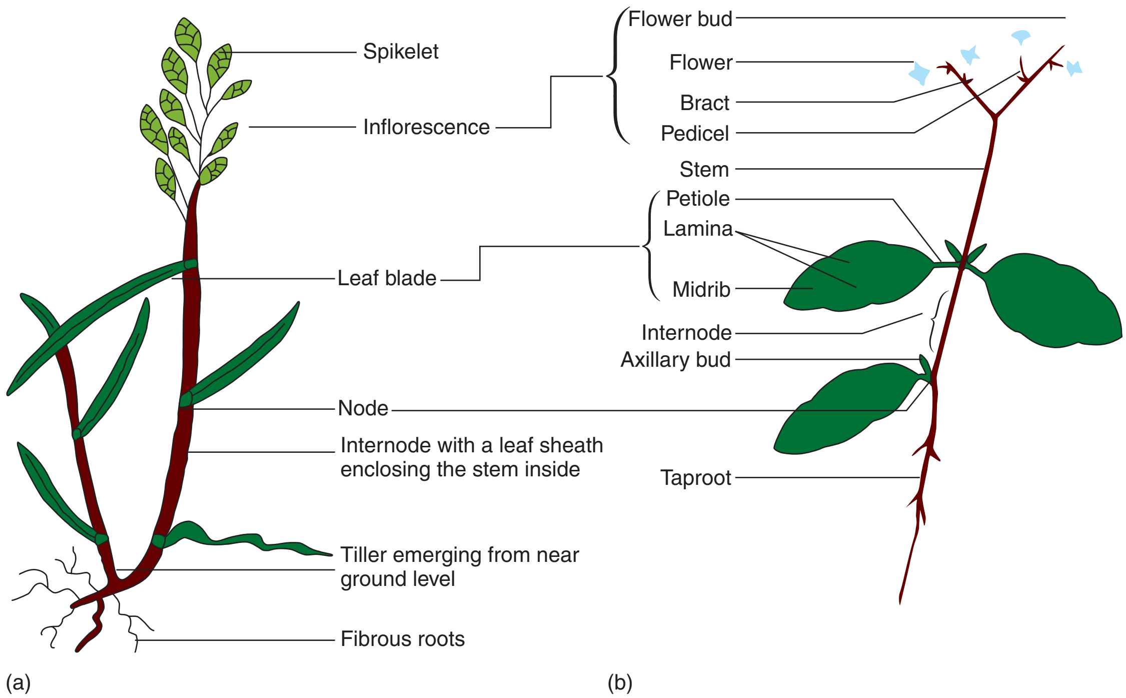

Figure 5.2 **Generalized plant form**: (a) monocotyledon; (b) dicotyledon

The development of the root and the stem from the seed is given in detail in Chapter 10. **Flowers** are the site of sexual reproduction in plants and their external appearance depends principally on the agents of pollination (see Chapters 7 and 10).

Roots

Root morphology (see Figure 5.3). The function of the root system is to take up water and mineral nutrients from the growing medium and to anchor the plant in that medium. Its major function involves making contact with the water in the growing medium. To achieve this it must have as large a surface area as possible. The root surface near to the tip where growth occurs (cell division in the meristem, see p93) is protected by the **root cap**. The root zone behind the root tip has tiny projections called **root hairs** reaching numbers of 200–400 per square millimetre, which greatly increase the surface area in this region (see Figure 5.4). Plants grown in hydroculture, e.g. NFT (p394), produce considerably fewer root hairs. The loss of root hairs during transplanting can check plant growth considerably, and the hairs can be points of entry of diseases such as club root (see Chapter 15). Figure 5.4 shows that the layer with the root hairs, the **epidermis**, is comparable with the epidermis of the stem (see stem structure); it is a single layer of cells which has a protective as well as an absorptive function.

Figure 5.3 **Germinated seed** showing primary and secondary roots growing from lower end of hypocotyl

A **taproot** is a single large root which will have many **lateral roots** growing out from it at intervals.

A **fibrous** root system consists of many roots growing out from the base of the stem.

Two types of root system are produced; a **taproot** is a single large root which usually maintains a direction of growth in response to gravity (see geotropism) with many small lateral roots growing from it, e.g. in chrysanthemums, brassicas, dock. In contrast, a **fibrous root** system consists of many roots growing out from the base of the stem, as in grasses and groundsel (see Figure 5.3).

Primary roots originate from the lower end of the hypocotyl.

Secondary roots are branches of the primary roots.

Adventitious roots grow in unusual places such as on the stem or other organ.

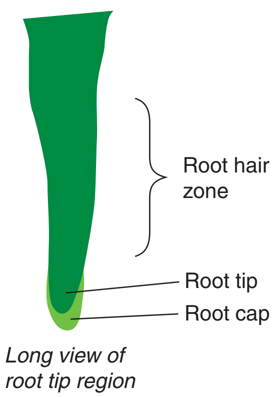

Figure 5.4 **Root tip** showing the tip protected by root cap, and root hair zone

Stems

The **stem's** function is physically to support the leaves and flowers, and to transport water, minerals and food between roots, leaves and flowers (see p91 for stem structure). The leaf joins the stem at the **node** and has in its angle (axil) with the stem an **axillary bud**, which may grow out to produce a lateral shoot. The distance between one node and the next is termed the **internode**. In order to perform these functions, the stem produces tissues (see Chapter 6) specially formed for efficiency. It must also maintain a high water content to maintain turgor (see p122).

Buds

A bud is a condensed stem which is very short and has small folded leaves attached, both enclosing and protecting it. On the outside the leaves are often thicker and dark to resist drying and damage from animals and disease. A meristem is present at the tip of the stem, from which a flower or vegetative growth will emerge. A **terminal bud** is present at the tip of a main stem and will grow out to increase its length. Where leaves join the stem, **axillary buds** may grow into lateral shoots, or may remain dormant.

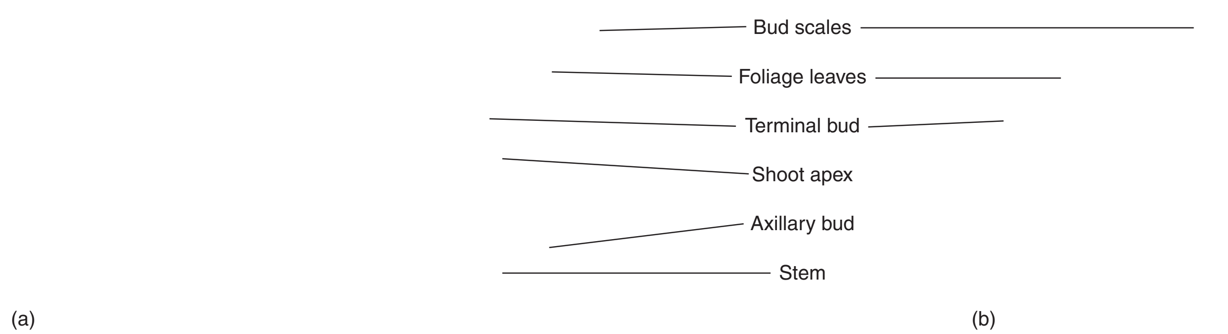

Figure 5.5 **Structure of a bud**: (a) Brussels sprout and (b) magnified image

Leaves

The **leaf**, consisting of the leaf blade (**lamina**) and stalk (**petiole**), carries out photosynthesis, its shape and arrangement on the stem depend on the water and light energy supply in the species' habitat. The arrangement of leaves and examples in different species, along with the major differences between monocotyledons and dicotyledons, is described in Chapter 4. Leaf structure, as an organ of photosynthesis, is described in Chapter 8 (see p117).

Adaptations

The features of typical plants are given, but there are many variations on the basic form of the stem, root and leaves.

Adaptations to plant organs have enabled plants to compete and survive in their habitat. Plants adapted to dry areas (**xerophytes**), such as cacti, have leaves reduced to protective **spines** and stems capable of photosynthesis. **Thorns**, which are modified branches growing from axillary buds, also have a protective function, e.g. hawthorn (*Crataegus*). **Prickles** are specialized outgrowths of the stem epidermis, which not only protect but also assist the plant in scrambling over other vegetation, as in wild roses. Several species possess leaves modified specifically for climbing in the form of **tendrils**, as in many members of the Leguminosae family, and Clematis climb by means of a sensitive, **elongated leaf stalk**, which twists round their support. In runner beans, honeysuckle (*Lonicera*) and *Wisteria*, twining stems wind around other uprights for support. Others are able to climb with the help of adventitious roots such as ivies, and Virginia Creeper (*Parthenocissus*). **Epiphytes** are physically attached to aerial parts of other plants for support; they absorb and sometimes store water in aerial roots, as in some orchids.

To survive an environment with very low nutrient levels, such as the sphagnum peat moor (see p328), some plants have evolved methods of trapping insects and utilizing the soluble products of their decomposed prey. These **insectivorous** plants include the native sundew (*Drosera*) and butterwort (*Pinguicula spp.*), which trap their prey with sticky glands on their leaves. Pitcher plants (*Sarracenia spp.*) have leaves that

(a) (b) (c)

(d) (e) (f)

Figure 5.6 **Variations in structure** of plant parts as adaptations to modes of growth: (a) thorns of *Berberis* and *Pyracantha*; (b) prickles on the stem of rose, *Rosa sericea pteracantha* grown as an ornamental for its large red thorns; (c) tendrils of passion flower; (d) elongated leaf stalks of *Clematis*; (e) adventitious root formed on stems of ivy (*Hedera helix*); (f) twining stems of *Wisteria* form containers which insects are able to enter into, but are prevented from escaping by slippery surfaces or barriers of stiff hairs. The Venus flytrap (*Dionaea muscpula*) has leaves that are hinged so that they can snap shut on their prey when it alights on one of the trigger hairs.

Plants found growing in coastal areas have adaptations that allow them to withstand high salt levels, e.g. salt glands as found in the cord grass (*Spartina spp*.) or *succulent* tissues in 'scurvy grass' (*Cochlearia*), both inhabitants of coastal areas.

Other modifications in plants are dealt with elsewhere. This includes the use of stems and roots as food and water storage organs (see vegetative propagation).

Leaf adaptations

Whilst remaining essentially the organ of photosynthesis and transpiration, the leaf takes on other functions in some species. The most notable of these is the climbing function. Tendrils are slender extensions of the leaf, and are of three types. In *Clematis spp*, the leaf petiole curls round the stems of other plants or garden structures in order to support the climber (see Figure 5.6(d)). In sweet pea (*Lathyrus odoratus*), the plant holds on with tendrils modified from the end-leaflets of the compound leaf. In the monocotyledonous climber, *Smilax china*, the support is provided by modified stipules (found at the base of the petiole). In cleavers (*Galium aparine*), both the leaf and stipules, borne in a whorl, have prickles that allow the weed to sprawl over other plant species.

Buds and bulbs are composed mainly of leaf tissue. In the former, the leaves (called scales) are reduced in size, hard, and brown rather than green. They tightly overlap each other, giving protection to the delicate meristematic tissues inside the bud. In a bulb, the succulent, light-coloured scale leaves contain all the nutrients and moisture necessary for the bulb's emergence. The scales are packed densely together around the terminal bud, minimizing the risk that might be caused by extremes of climate, or by pests such as eelworms or mice. In the houseplant *Bryophyllum daigremontianum*, the succulent leaf bears adventitious buds that are able to develop into young plantlets.

Leaf form

The novice gardener may easily overlook the importance that the shape, texture, venation, colour and size of leaves can contribute to the general appearance of a garden, as they focus more on the floral side of things. Flowers are the most striking feature, but they are often short-lived. It should be emphasized that the dominant theme in most gardens is the foliage and not the flowers (see Figures 5.7 and 5.8). The possibilities for contrast are almost endless when these five leaf aspects are considered.

In Chapter 4 (see p22) the range of leaf forms is described. Consider leaf shape first. The large linear leaves of *Phormium tenax* (New Zealand

(a) (b)

(c) (d) (e)

Figure 5.7 Leaf form: shape, e.g. (a) *Phormium tenax*, (b) *Gunnera manicata*, (c) hostas and ferns; texture, e.g. (d) woolly leaves of silver mint, (e) variegation in ivy (*Hedera helix*) leaf

Flax) are a well-known striking example. In contrast are the large palmate leaves of *Gunnera manicata*. On a smaller scale, the shade-loving *Hostas*, with their lanceolate leaves, mix well with the pinnate-leaved *Dryopteris filix-mas* (Male fern).

Secondly, leaf texture is also important. Most species have quite smooth textured leaves. Notably different are *Verbascum olympicum, Stachys byzantina* (Lamb's tongue) and the alpine *Leontopodium alpinum* (Edelweiss) which all are woolly in texture. Glossy-leaved species such as *Ilex aquifolium* (Holly), and *Pieris japonica* provide a striking appearance.

Figure 5.8 Leaf colours shown by examples *Helleborus*, *Berberis* and *Ajuga*

Thirdly, the plant kingdom exhibits a wide variety of leaf colour tones (see Figure 5.8). The conifer, *Juniperus chinensis* (Chinese juniper), shrubs of the *Ceanothus* genus, and *Helleborus viridus* (Christmas rose) are examples of dark-leaved plants. Notable examples of plants with light-coloured leaves are the tree *Robinia pseudoacacia* (false acacia), the climber *Humulus lupulinus* 'Aureus' (common hop) and the creeping herbaceous perennial, *Lysimachia nummularia* 'Aurea' (Creeping Jenny). Plants with unusually coloured foliage may also be briefly mentioned: the small tree *Prunus* 'Shirofugen' (bronze-red), the sub-shrub *Senecio maritima* (silver-grey) and the shade perennial *Ajuga reptans* 'Atropurpurea' (bronze-purple).

Variegation (the presence of both yellow and green areas on the leaf) gives a novel appearance to the plant (see Figures 5.6 and 10.11). Example species are *Aucuba japonica* (Laurel), *Euonymus fortunei* and

Glechoma hederacea (Ground Ivy). Fourthly, in autumn, the leaves of several tree, shrub and climber species change from green to a striking orange-red colour. *Acer japonicum* (Japanese maple), *Euonymus alatus* (Winged spindle), and *Parthenocissus tri-cuspidata* (Boston ivy) are examples.

Plant size and growth rate

It is important for anyone planning a garden that they recognize the eventual size (both in terms of height and of width) of trees, shrubs and perennials. This vital information is quite often ignored or forgotten at the time of purchase. The impressive *Ginkgo* (Maidenhair tree) really can grow to 30 m in height (at least twice the height of a normal house) and is, therefore, not the plant to put in a small bed. Similarly, *X Cupressocyparis leylandii* (Leyland Cypress), seemingly so useful in rapidly creating a fine hedge, can also grow to 30 m, and reach 5 m in width, to the consternation of even the most friendly of neighbours.

The eventual size of a plant is recorded in plant encyclopaedias, which should be carefully scrutinized for this vital statistic. It may also be wise to contact a specialist nursery which deals with this important aspect on a day-to-day basis, and will give advice to potential buyers. It should be remembered that the eventual size of a tree or shrub may vary considerably in different parts of the country, and may be affected within a garden by factors such as aspect, soil, shade, and wind. Attention should also be given to the rate at which a plant grows; *Taxus* (Yew) or *Magnolia stellata* (Star Magnolia) are two notable examples of slow growing species.

Note that **trees** are large woody plants that have a main stem with branches appearing some distance above ground level. **Shrubs** are smaller, usually less than 3 m in height, but with branches developing at or near ground level to give a bushy appearance to the plant.

Plant form in design

Plant form as individual plants or in groups is the main interest for many in horticulture who use plants in the garden or landscape. Contrasts in plant shapes and sizes can be combined to please the eye of the observer.

The dominant plant within a garden feature is usually a tree or shrub chosen for its **special** striking appearance, or specimen plant. In a large feature, it may be a *Betula pendula* (silver birch) tree growing up to 20 m in height with a graceful form, striking white bark, and golden autumn colour. In a smaller feature, *Euphorbia characias* provides a very special effect with its 1 m high evergreen foliage, and springtime yellow blooms. Such plants can form a focal point in a garden or landscape.

Spaced around these specimen plants, there may be included species providing a visually supportive **background or skeletal** form to the decorative feature. *Garrya elliptica*, a 4 m shrub with elliptical, wavy edged evergreen leaves and mid-winter catkins fits naturally into this category against a larger special plant. At 2.5 m, the evergreen shrub *Choisya ternata* (Mexican Orange Blossom) bearing fragrant white flowers in spring is a popular background species in decorative borders. *Jasminum nudifolium* (winter jasmine) is an example of a climber fulfilling this role. Such framework plants not only provide a suitable background, but also can provide continuity or unity through the garden or landscape and ensure interest all the year round.

Figure 5.9 Flower of *Euphorbia characias ssp wulfenii* can grow to 1 m

Fitting further into the mosaic of plantings are the numerous examples of **decorative** species, exhibiting particular aspects of general structure or of flowering, and often having a deciduous growth. An example is the 0.3 m tall *Cytisus x kewensis* (a broom with a prostrate habit) with its downy arching stems and profuse creamy-white spring flowers. A contrasting example is the 2 m clump-forming grass species, *Cortaderia selloana*, producing narrow leaves and feathery late summer flowering panicles. Climbing species from the *Rosa* and *Clematis* genera also fit into the decorative category. Garden designers are also able to call on a very wide range of leaf forms to create textural or architectural interest in the border.

A host of deciduous **pretty** herbaceous and evergreen perennials are available for filling the decorative feature, fitting around the above-mentioned three categories. *Delphiniums* (up to 2 m), *Lupins* up to 1.5 m), *Asters* (up to 1.5 m), *Sedums* (up to 0.5 m), and *Alchemillas* (up to 0.5 m) are five examples illustrating a range of heights.

Finally, **infill** species either as bulbs (e.g. *Tulipa, Narcissus* or *Lilium*), perennials (e.g. *Saxifraga, Campanula*), or annuals (e.g. *Nicotiana* or *Begonia*), may be placed within the feature, sometimes for a relatively short period whilst other perennials are growing towards full-size. They are also used in colourful bedding displays.

Colour in flowers

The use of different flower colours in the garden has been the subject of much discussion in Britain over the last three hundred years. Many books have been written on the subject, and authorities on the subject will disagree about what combination of plants creates an impressive border. Some combinations are mentioned here, and Figure 5.10 illustrates one example of the harmony created by blue flowers placed next to yellow ones. Other combinations such as blue and white, e.g. *Ceanothus* 'Blue Mound' and *Clematis montana*, yellow and red, e.g. *Euphorbia polychroma* and *Geum rivale*, yellow and white, e.g. *Verbascum nigrum* and *Tanacetum parthenium*, purple and pale yellow, e.g. *Salvia x superba* and *Achillea* 'Lucky Break', red and lavender, e.g. *Rosa gallica* and *Clematis integrifolia*.

Figure 5.10 **Flower border** showing the use of flower colour: light blue flowers of *Brunnera macrophylla* contrast with yellow of *Asphodeline lutea* and dark blue flowered *Anchusa azurea*

Check your learning

1. Define the terms primary root, secondary root, tap root, lateral root, fibrous root, adventitious root.
2. Describe the structure of the root tip.
3. Explain the function of the root cap and root hairs.
4. Describe the position of the different types of buds on the plant.
5. Explain the structure of the stem in relation to its functions.
6. Describe examples of leaf variation in terms of size, form and colour.

Further reading

Bell, A.D. (1991). *Plant Form: an Illustrated Guide to Flowering Plant Morphology*. OUP.

Brickell, C. (ed.) (2003). *A–Z Encyclopaedia of Garden Plants*. 2 vols, Dorling Kindersley.

Clegg, C.J. and Cox, G. (1978). *Anatomy and Activities of Plants*. John Murray.

Hattatt, L. (1999). *Gardening with Colour*. Paragon.

Ingram, D.S. *et al.* (eds) (2002). *Science and the Garden*. Blackwell Science Ltd.

Mauseth, J.P. (1998). *Botany – An Introduction to Plant Biology*. Saunders.

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Chapter 6 Plant cells and tissues

Summary

This chapter includes the following:

- **Plant cells**
- **Cell division**
- **Plant tissues**
- **Stem and root anatomy**
- **Secondary growth**

with additional information on:

- **Meristems**
- **Cell differentiation**

Figure 6.1 **Cabbage, carrot and celery** with examples of plant tissues, showing strengthening, structural and transport tissues

The anatomy of the plant

A **tissue** is a collection of specialized cells carrying out a particular function.

A close examination of the internal structure (anatomy) of the plant with a microscope will reveal how it is made up of different tissues. Each **tissue** is a collection of specialized cells carrying out one function, such as xylem conducting water. An **organ** is made up of a group of tissues carrying out a specific function, such as a leaf producing sugars for the plant. In the following chapter, the anatomy of the stem is illustrated and there is a comparable discussion of leaf structures in Chapter 8.

The cell

Without the use of a microscope, the horticulturist will not be able to see cells, since they are very small (about a twentieth of a millimetre in size). They are very complex and scientific studies continue to discover more of the organization displayed in this fundamental unit.

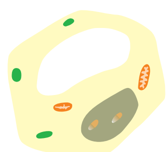


Figure 6.2 An unspecialized plant cell showing the organelles responsible for the life processes

A simple, unspecialized cell of parenchyma (see Figure 6.2) consists of a cellulose cell wall and contents (**protoplasm**) enclosed in a **cell membrane**, which is selective for the passage of materials in and out of the cell. The cellulose in the cell wall is laid down in a mesh pattern, which allows for stretching as the cell expands. Within the mesh framework are many apertures that, in active cells such as parenchyma, allow for strands of cytoplasm (called **plas-modesmata)** connecting between adjacent cells. These strands carry nutrients and hormones between cells, and are able to control the speed at which this movement takes place. When a plant wilts, its cells become smaller, but the plasmodesmata normally retain their links with adjacent cells. In the situation of 'permanent wilting' (see p342) or plasmolysis (see p123), there is a breakage of these strands and the plant is not able to recover.

Suspended in the jelly-like cytoplasm are small structures (organelles) each enclosed within a membrane and having specialized functions within the cell. In all tissues, the cell walls of adjoining cells are held together by calcium pectate (a glue-like substance which is an important setting ingredient in 'jam-making'). Some types of cell (e.g. xylem vessels) do not remain biochemically active, but die in order to achieve their usefulness. Here, the first wall of cellulose becomes thickened by additional cellulose layers and lignin, which is a strong, impervious substance.

The cell is made up of two parts, the nucleus and the cytoplasm. The nucleus coordinates the chemistry of the cell. The long chromosome strands that fill the **nucleus** (see also p138) are made up of the complex chemical deoxyri-bonucleic acid, usually known as DNA. In addition to its ability to produce more of itself for the process of cell division, DNA is also constantly manufacturing smaller but similar RNA (ribonucleic acid) units, which are able to pass through the nucleus membrane and attach themselves to other organelles. In this way, the nucleus is able to transmit instructions for the assembling, or destruction, of important chemicals within the cell.

There are six main types of organelle in the cytoplasm. The first, the **vacuole** is a sac containing dilute sugar, nutrients and waste products. It may occupy the major volume of a cell, and its main functions are storage and maintaining cell shape. The **ribosomes** make proteins from amino acids. Enzymes, which speed up chemical processes, are made of protein. The **Golgi apparatus** is involved in modifying and storing chemicals being made in the cell before they are transported where they are required. **Mitochondria** release energy in a controlled way, by the process of respiration, to be used by the other organelles. The energy is transferred via a chemical called ATP (adenosine triphosphate). The meristem areas of the stem, root and flower have cells with the highest number of mitochondria in order to help the rapid cell division and growth in these areas. **Plastids** such as the chloroplasts are involved in the production of sugar by the process of photosynthesis, and in the short-term storage of condensed sugar (in the form of starch). Lastly, the **endoplasmic reticulum** is a complex mesh of membranes that enables transport of chemicals within the cell, and links with the plasmodesmata at the cell surface. Ribosomes are commonly located on the endoplasmic reticulum. The whole of the living matter of a cell, nucleus and cytoplasm, are collectively called **protoplasm**.

Cell division

When a plant grows the cell number increases in the growing points or apical and lateral meristems of the stems and roots (see p93). The process of **mitosis** involves the division of one cell to produce two new ones.

Mitosis is the process of cell division which results in a replication of cells.

The genetic information in the nucleus is reproduced exactly in the new cells to maintain the plant's characteristics. Each chromosome in the parent cell produces a duplicate of itself, thus producing sufficient material for the two new daughter cells (see Figure 6.3). A delicate, spindle-shaped structure ensures the separation of chromosomes, one complete set into each of the new cells. A dividing cell wall forms across the old cell to complete the division.

Tissues of the stem

Dicotyledonous stem

The internal structure of a dicotyledonous stem, as viewed in cross-section, is shown in Figure 6.4. Three terms, epidermis, cortex and pith are used to broadly describe the distribution of tissues across the stem. The **epidermis** is present as an outer protective layer of the stem, leaves and roots. It consists of a single layer of cells; a small proportion of them are modified to allow gases to pass through an otherwise impermeable layer (see stomata). The second general term, **cortex**, describes the zone of tissues found inside the epidermis and reaching inwards to the inner edge of the vascular bundles. A third term, **pith**,

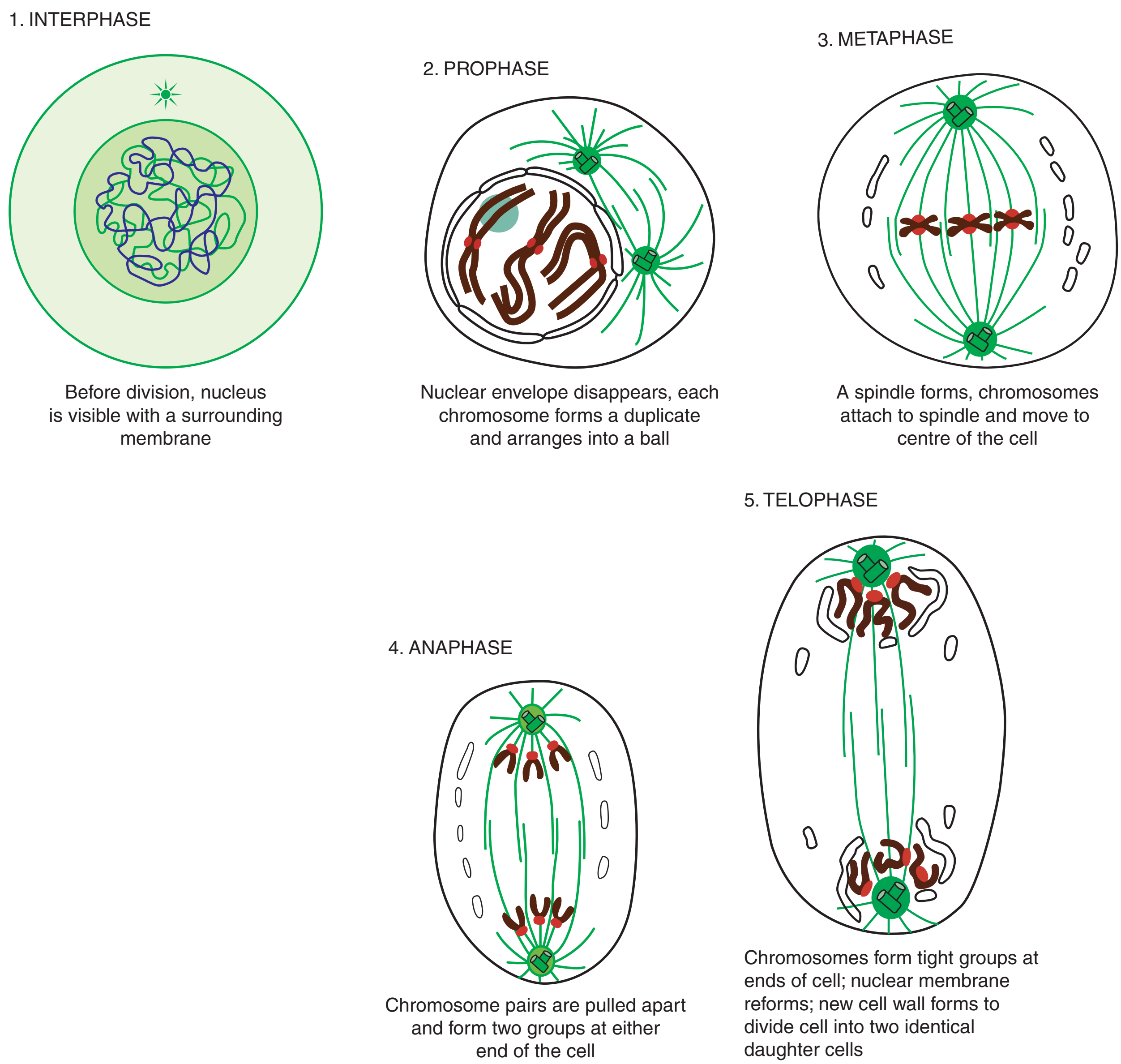


Figure 6.3 Diagram to show the process of mitosis (cell division)

refers to the central zone of the stem, which is mainly made up of parenchyma cells.

Collenchyma and **sclerenchyma cells** are usually found to the inside of the epidermis and are responsible for **support** in the young plant. Both tissues have cells with specially thickened walls. When a cell is first formed it has a wall composed mainly of **cellulose** fibres. In collenchyma cells the amount of cellulose is increased to provide extra strength, but otherwise the cells remain relatively unspecialized. In sclerenchyma cells, the thickness of the wall is increased by the addition of a substance called **lignin**, which is tough and causes the living contents of the cell to disappear. These cells, which are long and tapering and interlock for additional strength, consist only of cell walls.

The cortex of the stem contains a number of tissues. Many are made up of unspecialized cells such as **parenchyma**. In these tissues, the cells are thin walled and maintained in an approximately spherical shape by osmotic pressure (see p122). The mass of parenchyma cells (surrounding the other tissues) combine to maintain plant shape. Lack

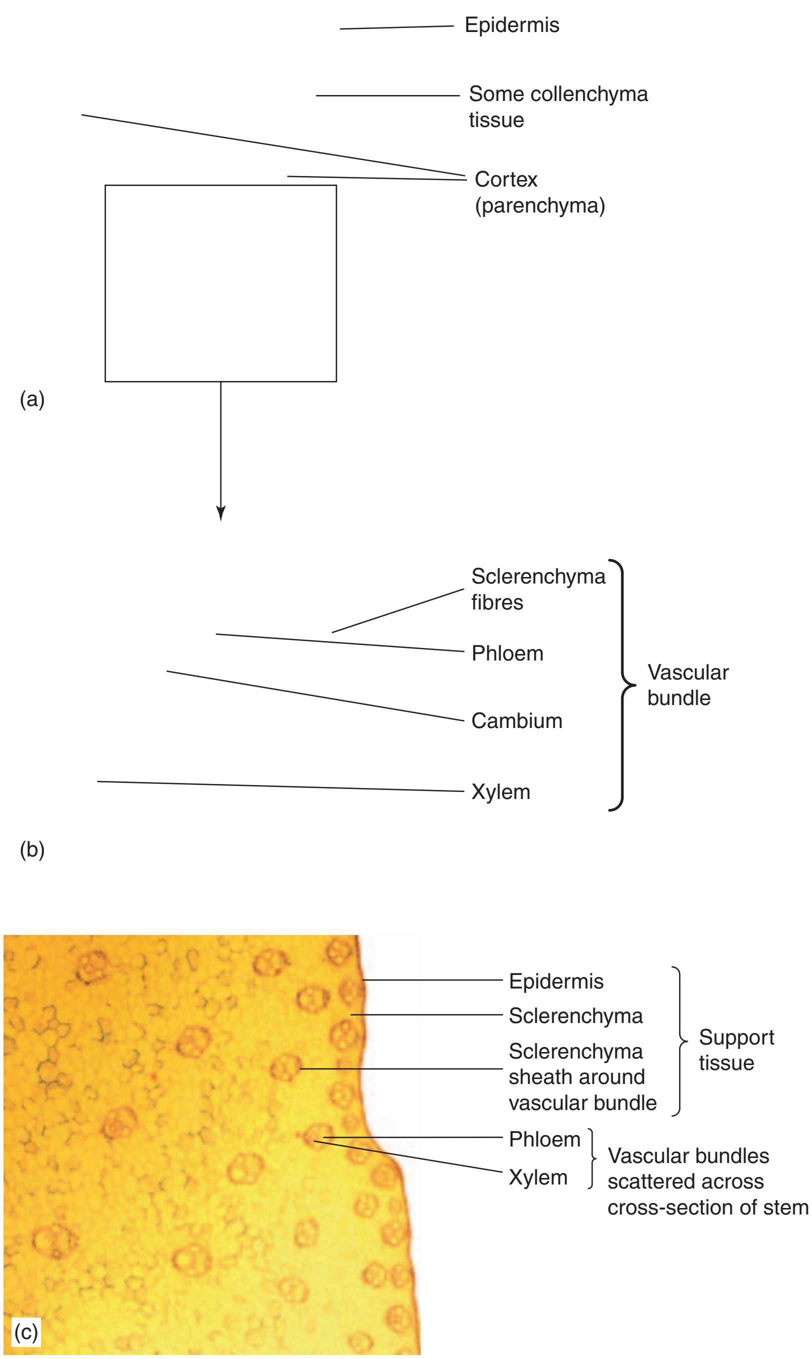


Figure 6.4 **Transverse sections of a typical dicotyledonous stem** (*Helianthus annuus*) (a) and (b), a typical monocotyledonous stem (c) (*Zea*) and diagrams

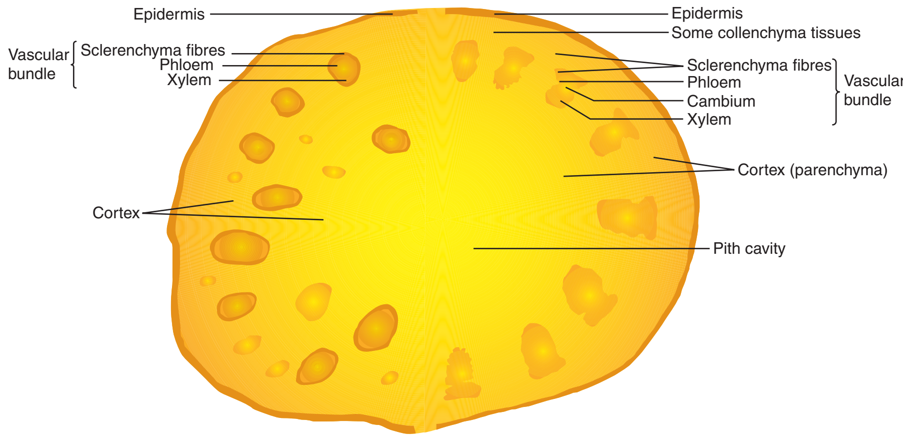


Figure 6.4 (d) A comparison between the stem tissue of monocotyledons (*Zea mays*) on the left and dicotyledonous (*Helianthus*) on the right

of water results in the partial collapse of the parenchyma cells and this becomes apparent as wilting. Parenchyma cells also carry out other functions, when required. Many of these cells contain chlorophyll (giving the stems their green colour) and so are able to photosynthesize. They release energy, by respiration, for use in the surrounding tissues. In some plants, such as the potato, they are also capable of acting as food stores (the potato tuber which stores starch). They are also able to undergo cell division, a useful property when a plant has been damaged. This property has practical significance when plant parts such as cuttings are being propagated, since new cells can be created by the parenchyma to heal wounds and initiate root development.

Contained in the cortex are **vascular bundles**, so named because they contain two vascular tissues that are responsible for transport. The first, **xylem**, contains long, wide, open-ended cells with very thick lignified walls, able to withstand the high pressures of water with dissolved minerals which they carry. The second vascular tissue, **phloem**, consists again of long, tube-like cells, and is responsible for the transport of food manufactured in the leaves carried to the roots, stems or flowers (see translocation). The phloem tubes, in contrast to xylem, have fairly soft cellulose cell walls. The end-walls are only partially broken down to leave sieve-like structures (sieve tubes) at intervals along the phloem tubes. Alongside every phloem tube cell, there is a small companion cell, which regulates the flow of liquids down the sieve tube. The phloem is seen on either side of the xylem in the marrow stem, but is found to the outside of the xylem in most other species. Phloem is penetrated by the stylets of feeding aphids (see Chapter 14). Also contained within the vascular bundles is the **cambium** tissue, which contains actively dividing cells producing more xylem and phloem tissue as the stem grows.

Figure 6.5 **A shredded leaf of *Phormium tenax*** showing fibres of xylem tissue

Stem growth

Growth of stems is initiated in the **apical**, or terminal, **bud** at the end of the stem (the apex). Deep inside the apical bud is a tiny mass of small, delicate jelly-like cells, each with a conspicuous nucleus but no cell vacuole. This mass is the **apical meristem (**see Figure 6.6). Here, cells divide frequently to produce four kinds of meristematic tissues. The first, at the very tip, continues as meristem cells. The second (protoderm) near the outside develops into the epidermis. The third (procambium) becomes the vascular bundles. The fourth (ground meristem) turns into the parenchyma, collenchyma, and sclerenchyma tissues of the cortex and pith. In addition to its role in tissue formation, the apical meristem also gives rise to small leaves (bud scales) that collectively protect the meristem. These scales and the meristem together form the **bud** (see p79). It should be noted that any damage to the sensitive meristem region by aphids, fungi, bacteria or herbicides would result in distorted growth. A fairly common example of such a distortion is **fasciation**, a condition that resembles a number of stems fused together. Buds located lower down the stem in the angle of the leaf (the axil) are called **axillary buds**; they contain a **lateral meristem** and often give rise to side branches.

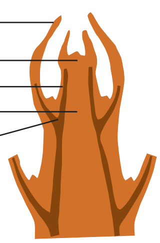


Figure 6.6 **The tip of a dicotyledonous stem** showing the four meristematic areas

In some plant families, e.g. the Graminae, the meristem remains at the base of the leaves, which are therefore protected against some herbicides, e.g. 2,4-D (see Chapter 13). This also means that grasses re-grow from their base after animals have grazed them. The new blades of grass grow from meristems between the old leaf and the stem. This means grasses can be **mown** which enables us to create lawns. The process of cutting back the grass also leads to it sending up several shoots instead of just one. This process of **tillering** helps thicken up the turf sward to make it such a useful surface for sport, as well as decoration. Mowing kills the dicotyledonous plants that have their stems cut off at the base and lose their meristems. However, many species are successful lawn weeds by growing in **prostrate** form; the foreshortened stem (very short internodes) creates a **rosette** of leaves that helps to conserve water, shades out surrounding plants and the growing point stays below the cutting height of the mower.

Elongation of the plant stem takes place in two stages. Firstly, cell division, described above, contributes a little. The second phase is cell **expansion**, which occurs at the base of the meristem. Here, the tiny unspecialized mer-istem cells begin to take in water and nutrients to form a cell vacuole. As a result, each cell elongates, and the stem rapidly grows. In the expansion zone, other developments begin to occur.

Cell differentiation

Most importantly, the cells begin to create their cell walls, and the connections between cells (plasmodesmata). The exact shape and chemical composition of the wall is different for each type of tissue cell, since it has a particular function to perform as described earlier;

sclerenchyma and collenchyma cells have walls thickened with lignin and cellulose while xylem and phloem vessels have developed walls and structures for transport. Leaf tissues similarly develop from parenchyma cells and form specialized tissues to carry out the process of photosynthesis. Leaf structure is described in Chapter 8.

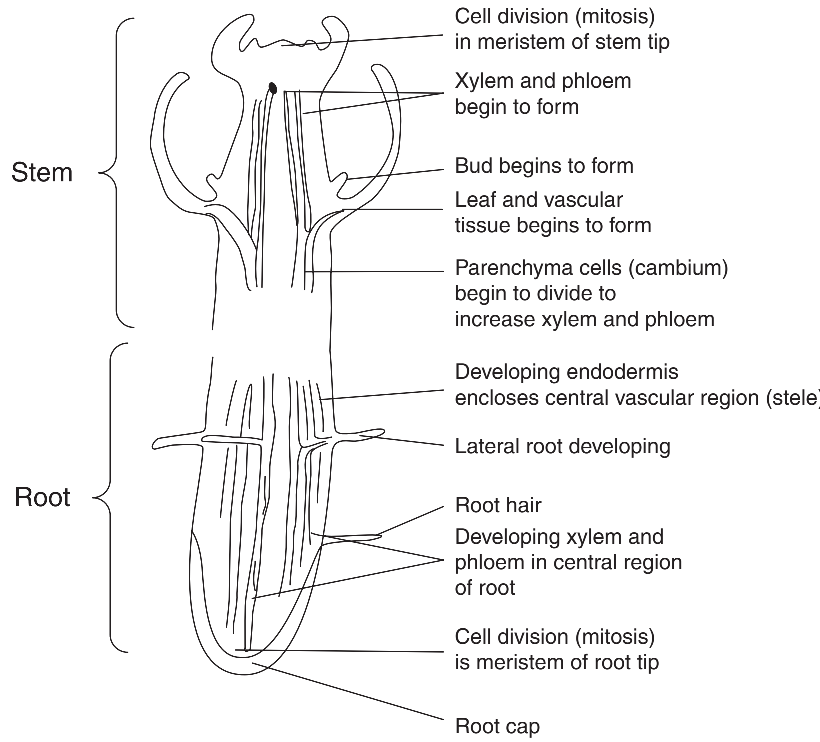


Figure 6.7 **Diagram of stem and root** showing areas of differentiation.

Secondary growth

As the stem length increases, so width also increases to support the bigger plant and supply the greater amount of water and minerals required.

Secondary growth results in the thickening of stems and roots and, in many cases, the production of wood.

The process in dicotyledons is called **secondary growth** (see Figure 6.8). Additional phloem and xylem are produced on either side of the cambium tissue, which now forms a complete ring. As these tissues increase towards the centre of the stem, so the circumference of the stem must also increase. Therefore a secondary ring of cambium (cork cambium) is formed, just to the inside of the epidermis, the cells of which divide to produce a layer of corky cells on the outside of the stem. This layer will increase with the growth of the tissue inside the stem, and will prevent loss of water if cracks should occur. As more secondary growth takes place, so more phloem and xylem tissue is produced but the phloem tubes, being soft, are squashed as the more numerous and very hard xylem vessels occupy more and more of the cross-section of the stem. Eventually, the majority of the stem consists of secondary xylem that forms the **wood**.

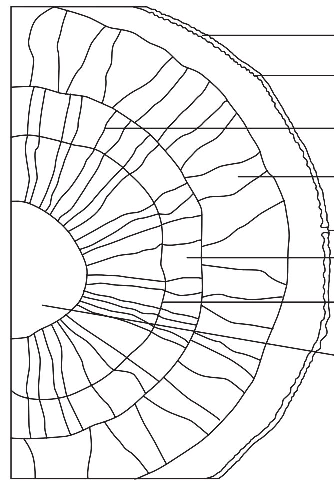


Figure 6.8 **Cross-section of lime** (*Tilia europea*) stem showing tissues produced in secondary growth

The central region of xylem sometimes becomes darkly stained with gums and resins (**heartwood)** and performs the long-term function of support for a heavy trunk or branch. The outer xylem, the **sapwood**, is still functional in transporting water and nutrients, and is often lighter in colour. The xylem tissue produced in the spring has larger diameter vessels than autumn-produced xylem, due to the greater volume of water that must be transported; a distinct ring is therefore produced where the two types of tissue meet. As these rings will be formed each season, their number can indicate the age of the branch or trunk; they are called **annual rings**. The phloem tissue is pushed against the cork layers by the increasing volume of xylem so that a woody stem appears to have two distinct layers, the wood in the centre and the **bark** on the outside.

If **bark** is removed, the phloem also will be lost, leaving the vascular cambium exposed. The stem's food transport system from leaves to the roots is thus removed and, if a trunk is completely **ringed** (or 'girdled'), the plant will die. Rabbits or deer in an orchard may cause this sort of damage. 'Partial ringing', i.e. removing the bark from almost the whole of the circumference, can achieve a deliberate reduction in growth rate of vigorous tree fruit cultivars and woody ornamental species. Initially, the **bark** is smooth and shiny, but with age it thickens and the outer layers accumulate chemicals (including suberin) that make it an effective protection against water loss and pest attack. This part of the bark (called **cork)** starts to peel or flake off. This is replaced from below and the cork gradually takes on its characteristic colours and textures. Many trees such as silver birch, London Plane, *Prunus serrula*, *Acer davidii* and many pines and rhododendrons have attractive bark and are particularly valued for winter interest (see Figure 6.9).

Since the division of cells in the cambium produces secondary growth, it is important that when **grafting** a **scion** (the material to be grafted) to a **stock**, the vascular cambium tissues of both components be positioned as close to each other as possible (see p92). The success of a graft depends very much on the rapid **callus** growth derived from the cambium, from

(a) (b) (c) (d)

(e) (f) (g) (h)

(i) (j) (k) (l)

Figure 6.9 **Examples of the decorative effects of tree bark** (a) *Myrtus luma* (b) *Euonymus alatus* (c) *Eucalytus parvifolia* (d) *Quercus agrifolia* (e) *Caucasian Wing-nut (Pterocarya fraxinifolia)* (f) *Eucalyptus urnigera* (g) *Pinus nigra ssp. Salzmannii* (h) *Betula utilis jacquemontii* (i) White Willow (*Salix alba*) (j) *Prunus serula tibetica* (k) Date Plum (*Diospyros lotus*) (l) Black Walnut (*Juglans nigra*)

which new cambial cells form and subsequently from which the new xylem and phloem vessels form to complete the union. The two parts then grow as one to carry out the functions of the plant stem.

A further feature of a woody stem is the mass of lines radiating outwards from the centre, most obvious in the xylem tissues. These are **medullary**

rays, consisting of parenchyma tissue linking up with small areas on the bark where the corky cells are less tightly packed together (**lenticels**). These allow air to move into the stem and across the stem from cell to cell in the medullary rays. The oxygen in the air is needed for the process of **respiration**, but the openings can be a means of entry of some diseases, e.g. Fireblight. Other external features of woody stems include the **leaf scars** which mark the point of attachment of leaves fallen at the end of a growing season, and can be a point of entry of fungal spores such as apple canker.

Monocotyledonous stem

Figure 6.10 **Bark of silver birch** showing **lenticels**

This has the same functions as those of a dicotyledon; therefore the cell types and tissues are similar. However, the arrangement of the tissues does differ because increase in diameter by **secondary growth** does not take place. The stem relies on extensive sclerenchyma tissue for support that, in the maize stem shown in Figure 6.4, is found as a sheath around each of the scattered vascular bundles. Monocotyledonous stem structures are seen at their most complex in the palm family. From the outside, the trunk would appear to be made of wood, but an internal investigation shows that the stem is a mass of sclerified vascular bundles. The absence of secondary growth in the vascular bundles makes the presence of cambium tissue unnecessary.

Secondary thickening is found not only in trees and shrubs, but also in many herbaceous perennials and annuals that have woody stems. However, trees and shrubs do exhibit this feature to the greatest extent.

Tissues of the root

The layer with the root hairs, the **epidermis**, is comparable with the epidermis of the stem; it is a single layer of cells which has a protective as well as an absorptive function. Inside the epidermis is the parenchymatous **cortex** layer. The main function of this tissue is respiration to produce energy for growth of the root and for the absorption of mineral nutrients. The cortex can also be used for the storage of food where the root is an overwintering organ (see p79).

The cortex is often quite extensive and water must move across it in order to reach the transporting tissue that is in the centre of the root. This central region, called the **stele**, is separated from the cortex by a single layer of cells, the **endodermis**, which has the function of controlling the passage of water into the stele. A waxy strip forming part of the cell wall of many of the endodermal cells (the Casparian strip) prevents water from moving into the cell by all except the cells outside it, called **passage cells**.

Water passes through the endodermis to the **xylem** tissue, which transports the water and dissolved minerals up to the stem and leaves. The arrangement of the xylem tissue varies between species, but often appears in transverse section as a star with varying numbers of 'arms'. **Phloem** tissue is responsible for transporting carbohydrates from the leaves as a food supply for the production of energy in the cortex.

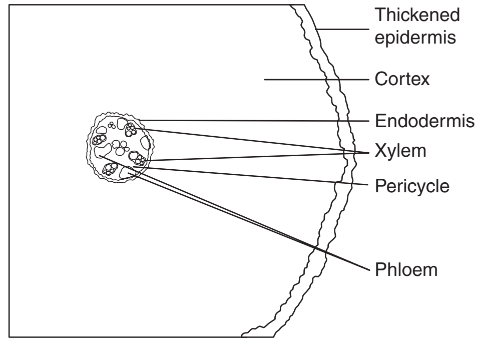


Figure 6.11 **Cross-section of *Ranunculus* root** showing thickened outer region, large area of cortex and central vascular region or stele enclosed in an endodermis.

A distinct area in the root inside the endodermis, the **pericycle**, supports cell division and produces lateral roots, which push through to the main root surface from deep within the structure. Roots age and become thickened with waxy substances, and the uptake rate of water becomes restricted.

Check your learning

1. Define the term 'tissue'.
2. List the main types of tissue found in the plant.
3. Explain the function of the tissues named.
4. State the tissues involved in the strengthening in monocotyledons.
5. State the function of the cell components.
6. Describe the role of meristems in cell division.
7. Describe the process of secondary growth in dicotyledons.
8. Describe how the internal structure of a root differs from that of the stem.

Further reading

Bowes, B.G. (1996). *A Colour Atlas of Plant Structure*. Manson Publishing Ltd.
Clegg, C.J. (2003). *Green Plants: the Inside Story*. III Adv Biology series. Hodder Murray.
Clegg, C.J. and Cox, G. (1978). *Anatomy and Activities of Plants*. John Murray.
Cutler, D.F. (1978). *Applied Plant Anatomy*. Longman.
Ingram, D.S. *et al.* (eds) (2002). *Science and the Garden*. Blackwell Science Ltd.
Mauseth, J.P. (1998). *Botany – An Introduction to Plant Biology*. Saunders.

Chapter 7 Plant reproduction

Summary

This chapter includes the following topics:

- **Types of inflorescence**
- **Flower structure**
- **Function of flower parts**
- **Characteristics of flowers**
- **Tepals**
- **Seeds and fruits**

with additional information on:

- **Parthenocarpy**

Figure 7.1 *Euphorbia cyparissias* 'Fens Ruby'

(a) (b) (c)

(d) (e) (f)

(g) (h) (i)

(j) (k)

Figure 7.2 Range of flowers as organs of **sexual reproduction** having similar basic structure, but varying appearance having adapted for successful pollination or by plant breeding (*see* chapter 10) (a) *Iris chrysographes* 'Kew Black'; (b) *Eryngium giganteum*, ('Miss Willmott's ghost'); (c) *Trollius chinensis* 'Golden Queen'; (d) *Rosa* 'L.D.Braithwaite'; (e) *Hemerocallis* 'Rajah'; (f) *Aquilegia fragrans*; (g) *Oenothera* 'Apricot Delight; (h) *Helenium* 'Wyndley'; (i) *Helleborus xhybridus*; (j) *Nepeta nervosa*; (k) *Primula vialii*

Flowers

Types of inflorescence

The organs of sexual reproduction in the flowering plant division are flowers, and variation in their arrangement can be identified and named:

- **spike** is an individual, unstalked series of flowers on a single flower stalk, e.g. Verbascum;

(a) (b) (c) (d)

(e) (f)

Figure 7.3 **Inflorescence types**, (a) spike; *Verbascum* (b) raceme; Foxglove and (c) *Veronica*; (d) corymb, *Achillea*; (e) umbel, Hogweed; (f) capitulum, *Inula*

- **raceme** consists of individual stalked flowers, the stalks all the same length again spaced out on a single undivided main flower stalk, e.g. foxglove (see Figure 7.3), hyacinth, lupin, wallflower;
- **compound racemes** have a number of simple racemes arranged in sequence on the flower stalk, e.g. grasses;
- **corymb** is similar to a raceme except that the flower stalks, although spaced out along the main stalk, are of different lengths so that the flowers are all at the same level, e.g. *Achillea* (see Figure 7.3). A very common sight in hedgerows;
- **umbel** has stalked flowers reaching the same height with the stalks seeming to start at the same point on the main stem, e.g. hogweed (see Figure 7.3);
- **capitulum** or composite flower forms a disc carrying flower parts radiating out from the centre, as if compressed from above, e.g. *Inula* (see Figure 7.3), daisy, chrysanthemum.

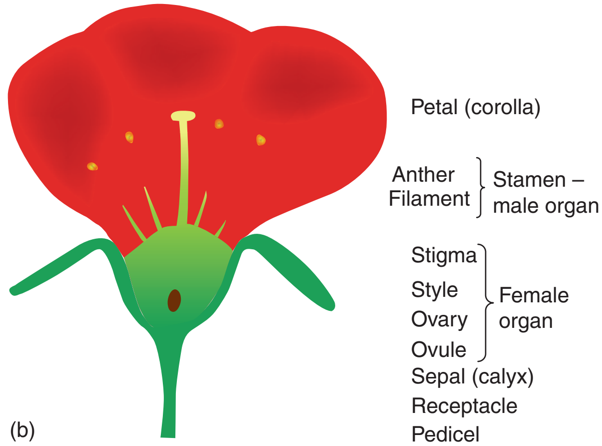
The number and arrangement of flower parts are the most important features for classification and are a primary feature in plant identification (see Chapter 4, p67).

Flower structure

The flower structure is shown in Figure 7.4.

The flower is initially protected inside a flower bud by the **calyx** or ring of **sepals**, which are often green and can therefore photosynthesize. The development of the flower parts requires large energy expenditure by the

(a)



(b)

Figure 7.4 **Flower structure**, e.g. (a) flower of *Glaucium corniculatum* and (b) diagram of typical flower to show structures involved in the process of sexual reproduction

plant, and therefore vegetative activities decrease. The **corolla** or ring of **petals** may be small and insignificant in **wind-pollinated flowers**, e.g. grasses (see p134), or large and colourful in **insect-pollinated species** (see p135). The colour and size of petals can be improved in cultivated plants by breeding, and may also involve the multiplication of the petals or **petalody**, when fewer male organs are produced.

The flower may include other parts:

- Tepals, where the outer layers of the flower have a similar appearance, making the sepals and petals indistinguishable. They are common in monocotyledons such as tulips (see Figure 7.5) and lilies.
- Androecium, the male organ, consists of a **stamen which** bears an **anther** that produces and discharges the **pollen grains**.
- Gynaecium, the female organ, is positioned in the centre of the flower and consists of an **ovary** containing one or more **ovules** (egg cells). The **style** leads from the ovary to a **stigma** at its top where pollen is captured.
- The flower parts are positioned on the **receptacle**, which is at the tip of the **pedicel** (flower stalk).
- **Nectaries** may develop on the receptacle, at the base of the petals; these have a secretory function, producing substances such as nectar which attract pollinating organisms.
- Associated with the flower head or **inflorescence** are leaf-like structures called **bracts**, which can sometimes assume the function of insect attraction, e.g. in *Poinsettia*.

The flowers of many species have both male and female organs (hermaphrodite), but some have separate male and female flowers (monoecious), e.g. *Cucurbita*, walnut, birch (*Betula*), whereas others produce male and female flowers on different plants (dioecious), e.g. holly, willows, *Skimmia japonica* and ***Ginkgo biloba***.

Figure 7.5 **Tulip 'Attila'**, e.g. of tepals – outer layers of flower are similar

A plant possessing flowers with both male and female organs is **hermaphrodite**.

Species with separate male and female flowers on the same plant are **monoecious**.

Species which produce male and female flowers on different plants are **dioecious**.

The seed

The seed, resulting from sexual reproduction, creates a new generation of plants that bear characteristics of both parents. The plant must survive often through conditions that would be damaging to a growing vegetative organism. The seed is a means of protecting against extreme conditions of temperature and moisture, and is thus the **overwintering stage**.

Figure 7.6 **Seeds**: a range of species, from top – runner bean, left to right – leek, artichoke, tomato, lettuce, Brussels sprout, cucumber, carrot, beetroot

Seed structure

The basic seed structure is shown in Figure 7.7. The main features of the seed are:

- **embryo**, in order to survive the seed must contain a small immature plant protected by a seed coat;
- **testa**, the seed coat, is formed from the outer layers of the ovule after **fertilization**;
- **micropyle**, a weakness in the testa, marks the point of entry of the pollen tube prior to fertilization;
- **hilum**, this is the point of attachment to the fruit.

The embryo consists of a **radicle**, which will develop into the primary root of the seedling, and a **plumule**, which develops into the shoot system, the two being joined by a region called the **hypocotyl**. A single seed leaf (**cotyledon**) will be found in monocotyledons, while two are present as part of the embryo of dicotyledons. The cotyledons may occupy a large part of the seed, e.g. in beans, to act as the food store for the embryo.

Seed coat (testa)
Hilum
Plumule
Hypocotyl
Radicle
Cotyledon

(a)

(b)

Figure 7.7 **The structure of the seed**, (a) runner bean seed just beginning to germinate and showing developing radicle showing a geotropic response (*see* page 000), (b) long section of bean seed showing structure

The **seed** is formed from the ovule of the flower and is the result of the reproductive process.

In some species, e.g. grasses and Ricinus (castor oil plant), the food of the seed is found in a different tissue from the cotyledons. This tissue is called **endosperm** and is derived from the fusion of extra cell nuclei, at the same time as fertilization. Plant food is usually stored as the carbohydrate, starch, formed from sugars as the seed matures, e.g. in peas and beans. Other seeds, such as sunflowers, contain high proportions of fats and oils, and proteins are often present in varying proportions. The seed is also a rich store of nutrients that it requires when a seedling, such as phosphate (see p367).

The seed structure may be specialized for wind dispersal, e.g. members of the Asteraceae family, including groundsel, dandelion and thistle, which have parachutes, as does *Clematis* (Ranunculaceae). Many woody species such as lime (*Tilia*), ash (*Fraxinus*), and sycamore (*Acer*) produce winged fruit. Other seed-pods are explosive, e.g. balsam and hairy bittercress. Organisms such as birds and mammals distribute hooked fruits such as goosegrass and burdock, succulent types (e.g. tomato, blackberry, elderberry), or those that are filled with protein (e.g. dock). Dispersal mechanisms are summarized in Table 7.1.

Seeds are contained within fruits which provide a means of protection and, often, dispersal.

The fruiting plant

The development of the true fruit involves either the expansion of the ovary into a juicy **succulent** structure, or the tissues becoming hard and dry. In false fruits other parts, such as the inflorescence, e.g. pineapple and mulberry, and the receptacle, as in apple, become part of the structure

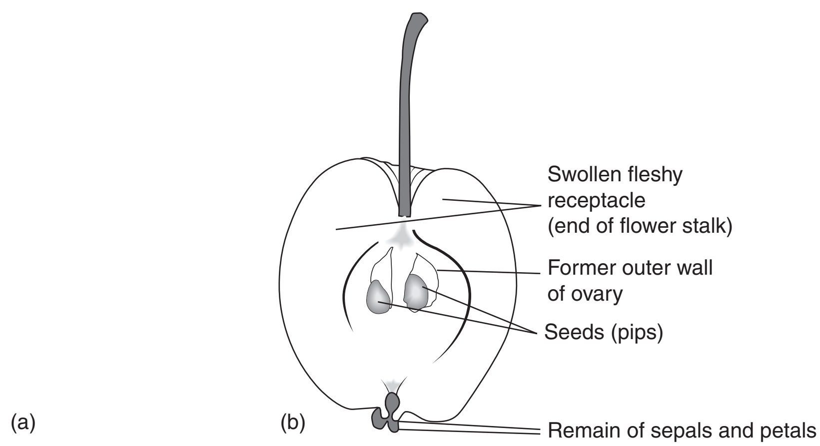


Figure 7.8 **Apple – a** false fruit (pome) (a) LS of crab apple and (b) showing structure

The **fruit** is the protective and distributary structure for the seed and forms from the ovary after fertilization.

The succulent fruits are often eaten by animals, which help seed dispersal, and may also bring about chemical changes to break dormancy mechanisms (see p151). Some fruits (described as being **dehiscent**), release their seeds into the air. They do this either by an explosive method as seen in brooms and poppies; or by tiny feathery parachutes, seen in willow herb and groundsel. Dry fruits may rot away gradually to release their seeds by an **indehiscent** action. Different adaptations of fruit, many of which are of economic import ance, and the methods by which seeds are dispersed are summarized in Table 7.1 and illustrated in Figure 7.9.

A **false fruit** is formed from parts other than, or as well as, the ovary wall.

Table 7.1 Fruits and the dispersal of seeds

True Fruits (formed from the ovary wall after fertilization):		
Succulent (indehiscent)	Drupes	Cherry, plum Blackberry (collection of drupes)
	Berries	Gooseberry, Marrow, banana
Dry indehiscent	Schizocarps	Sycamore
	Samara	Trefoil
	Lomentum	Hogweed
	Cremocarb	Hollyhocks
	Carcerulus	Acorn, rose, strawberry
	Achenes (nuts)	
Dry dehiscent	Capsules	Poppy, Violet, Campanula
	Siliquas	Wallflowers, stocks
	Siliculas	Shepherd's purse, honesty
	Legumes	Pea, bean, lupin
	Follicles	Delphinium, monkshood
False Fruits (formed from parts other than, or as well as, the ovary wall):		
From inflorescence	Pineapple, mulberry	
From receptable	Apple, pear	
Method of seed dispersal	**Type of fruit**	**Examples**
Animals	Succulent	Elderberry, blackberry – eaten by birds
		Mistletoe, yew – stick to beaks
	Hooked	Burdock, goose-grass – catch on fur
Wind	Winged	Ash, sycamore, lime, elm
	Parachutes	Dandelion, clematis, thistles
	Censer (dry capsules)	Poppy, campion, antirrhinum
Explosion	Pods	Peas, lupins, gorse, vetches, geranium

Fruit set

The process of pollination, in most species, stimulates fruit set. The hormones, in particular gibberellins, carried in the pollen, trigger the production of auxin in the ovary, which causes the cells to develop. In species such as cucumber, the naturally high content of auxin enables fruit production without prior fertilization, i.e. **parthenocarpy**, a useful phenomenon when the object of the crop is the production of seedless fruit. Such activity can be simulated in other species, especially when poor conditions of light and temperature have caused poor fruit set in species such as tomato and peppers. Here, the flowers are sprayed with an auxin-like chemical, but the quality of fruit is usually inferior. Pears can be sprayed with a solution of gibberellic acid to replace the need for pollination. Fruit ripening occurs as a result of hormonal changes and

Fruits

Succulent

(a) Drupe, e.g. Sloe

(b) Berry, e.g. *Viburnum*

Dry indehiscent

Samara, e.g. Sycamore

Lomentum, e.g. Trefoil

Cremocarb, e.g. Hogweed

Carcerulus, e.g. Hollyhock

Achene, e.g. Acorn

Dry dehiscent

Capsule, e.g. Poppy

Siliqua

Silicula, e.g. Honesty

Legume, e.g. Lupin

Follicle, e.g. Monkshood

Seed dispersal

Eaten by animals e.g. Blackberry

Hooked, e.g. Burdock

Winged, e.g. Ash

Parachute, e.g. Dandelion

Censer, e.g. Antirrhinum

Pod, e.g. *Geranium*

Figure 7.9 **Fruit types** and seed dispersal involves in tomatoes a change in the sugar content, i.e. at the crucial stage called **climacteric**. After this point, fruit will continue to ripen and also respire after removal from the plant. Ethylene is released by ripening fruit, which contributes to deterioration in store. Early ripening can be brought about by a spray of a chemical, e.g. ethephon, which stimulates the release of ethylene by the plant, e.g. in the tomato.

Reproduction in simple multicellular green plants

The seed-producing plants represent the most important division of the plant kingdom in horticulture. Other, simpler multicellular green plants reproduce sexually, but also asexually. **Alternation of generations** exists when two stages of quite distinct types of growth occur. In ferns (Pteridophyta), a vegetative stage produces a spore forming body on the underside of leaves (see Figure 7.10). Spores are released and, with suitable damp conditions, germinate to produce a sexual leafy stage in which male and female organs develop and release cells which fertilize and develop in the body of the plant. These spores then germinate while nourished by the sexual leafy stage and develop in turn into a new vegetative plant. Ferns can be produced in cultivation by spores if provided with damp sterile conditions to allow the tiny spores to germinate without competition (see Figure 7.11). Vegetative propagation by division of plants or rhizomes is common.

Many plants are able to reproduce both sexually and asexually by vegetative propagation. This is described in detail in Chapter 12.

Figure 7.10 **Fern spores** on underside of leaves, *Dryopteris erythrosora* and *Phyllitis scolopendrium Cristata*

Figure 7.11 **Germinating fern spores** and plantlets

Check your learning

1. Describe the main types of inflorescence of flowering plants.
2. Describe the structure and function of the parts of a typical dicotyledonous flower.
3. Describe the structure of a seed.
4. Define the terms: monoecious, dioecious, hermaphrodite, seed, fruit, false fruit.
5. Describe the main types of fruit, namely dry, hard, fleshy, indehiscent and give an example of each.

Further reading

Bleasdale, J.K.A. (1983). *Plant Physiology in Relation to Horticulture*. Macmillan.

Leopold, A.C. (1977). *Plant Growth and Development*. 2nd edn. McGraw-Hill.

Raven, P.H. *et al.* (2005). *Biology of Plants*. W.H. Freeman.

Wareing, P.F. and Phillips, I.D.J. (1981). *The Control of Growth and Differentiation in Plants*. Pergamon.

Chapter 8 Plant growth

Summary

This chapter includes the following topics:

- **Photosynthesis**
- **Leaf structure**
- **Respiration**

with additional information on:

- **Lighting of crops**
- **Storage**
- **Carbon chemistry**

Figure 8.1 **Pumpkins** representing the large amount of growth a plant can produce

In any horticultural situation, growers are concerned with controlling and even manipulating plant growth. They must provide for the plants the optimum conditions to produce the most efficient growth rate and the end product required. Therefore the processes that result in growth are explored in order that the most suitable or economic growth can be achieved. Photosynthesis is probably the single most important process in plant growth. Respiration is the process by which the food matter produced by photosynthesis is converted into energy usable for growth of the plant. Photosynthesis and respiration make these processes possible, and the balance between these results in growth. It must be emphasized that growth involves the plant in hundreds of chemical processes, occurring in the different organs and tissues throughout the plant.

Growth is a difficult term to define because it really encompasses the totality of all the processes that take place during the life of an organism. However, it is useful to distinguish between the processes which result in an increase in size and weight, and those processes which cause the changes in the plant during its life cycle, which can usefully be called development, described in Chapters 7 and 11.

Photosynthesis

The following environmental requirements for photosynthesis are explained in detail below:

- carbon dioxide
- light
- adequate temperature
- water (see also Chapters 9 and 10).

All living organisms require organic matter as food to build up their structure and to provide chemical energy to fuel their activities. Whilst photosynthesis is the crucial process, it should be remembered that a multitude of other processes are occurring all over the plant. Proteins are being produced, many of which are enzymes necessary to speed up chemical reactions in the leaf, the stem, the root, and later in the flower and fruit. The complex carbohydrate, cellulose, is being built up as cell walls of almost every cell. Nucleo-proteins are being provided in meristematic areas to enable cell division. These are three examples of many, to show that growth involves much more than just photosynthesis and respiration.

Photosynthesis is the process in the chloroplasts of the leaf and stem by which green plants manufacture food in the form of high energy carbohydrates such as sugars and starch, using light as energy.

All the complex organic compounds, based on carbon, must be produced from the simple raw materials, water and carbon dioxide. Many organisms are unable to manufacture their own food, and must therefore feed on already manufactured organic matter such as plants or animals. Since large animals predate on smaller animals, which themselves feed on plants, all organisms depend directly or indirectly on photosynthesis occurring in the plant as the basis of a **food web** or chain (see p53).

A summary of the process of photosynthesis is given in Table 8.1 as a word formula and as a chemical equation. This apparently simple equation represents, in reality, two different stages in the production of glucose. The first, the 'light reaction' occurs during daylight, and splits water into hydrogen and oxygen. The second, the 'dark reaction' occurring at night, takes the hydrogen and joins it to carbon dioxide to make glucose.

Table 8.1 Two ways to represent the chemistry involved in photosynthesis

a.	Written in a conventional way, the process can be expressed in the following way: carbon dioxide plus water plus light gives rise to glucose plus oxygen (when in the presence of chlorophyll)
b.	Written in the form of a chemical equation, which represents molecular happenings at the sub-microscopic level, the above sentence becomes: 6 C_2O molecules + 6 H_2O molecules plus light give rise to 1 $C_6H_{12}O_6$ molecule + 6 O_2 molecules (when in the presence of chlorophyll)

Most plant species follow a **'C–3'** process of photosynthesis where the intermediate chemical compound contains three carbon atoms (C–3) before producing the six-carbon glucose molecule (C–6). Many C–3 plants are not able to increase their rate of photosynthesis under very high light levels.

In contrast, a **'C–4'** process is seen in many tropical families, including the maize family, where plants which use an intermediate compound containing four carbon atoms (C4) are able to continue to respond to very high levels of light, thus increasing their productivity.

A third process, called **'CAM'** (Crassulacean Acid Metabolism) was first discovered in the stonecrop family. Here, the intermediate chemical is a different four-carbon compound, malic acid. This third process has more recently been found in several other succulent plant families (including cacti), all of which need to survive conditions of drought. Such plants need to keep their stomata closed during the heat of the day, but this prevents the entry of carbon dioxide. During the night, carbon dioxide is absorbed and stored as malic acid, ready for conversion to glucose the next day. CAM plants do not normally grow very fast because they are not able to store large quantities of this malic acid, and thus their potential for glucose production is limited.

Carbon chemistry

All living organisms, from viruses to whales, have the element carbon at the centre of their chemistry. The study of this element's chemical activity is called **organic** chemistry. Originally, it was thought that all organic compounds came from living organisms, but modern chemistry has brought synthetic urea fertilizer and DDT, which are organic.

Unusually in the range of chemical elements, carbon (like silicon) has a combining power, or valency, of four (see p387 for **basic chemistry**). This means that each carbon atom can react with four other atoms, whether they are atoms of other elements such as hydrogen, or with more carbon atoms. Since the four chemical bonds from the carbon atom point in diametrically opposite directions, it can be seen that molecules containing carbon are three dimensional, a feature which is very important in the chemistry of living things.

Carbon normally forms **covalent** (non-ionic) bonds in its molecules. Here, the bond shares the electrons, and so there is no chemical charge associated with the molecule (see also ionic bonds). Two of the simplest molecules to contain carbon are carbon dioxide and methane (see Figure 8.2).

Carbon dioxide, or CO_2, is a constituent of the air we breathe and the sole source of carbon for almost all plants. In this compound, the carbon attaches to two oxygen atoms, each with a valency of two.

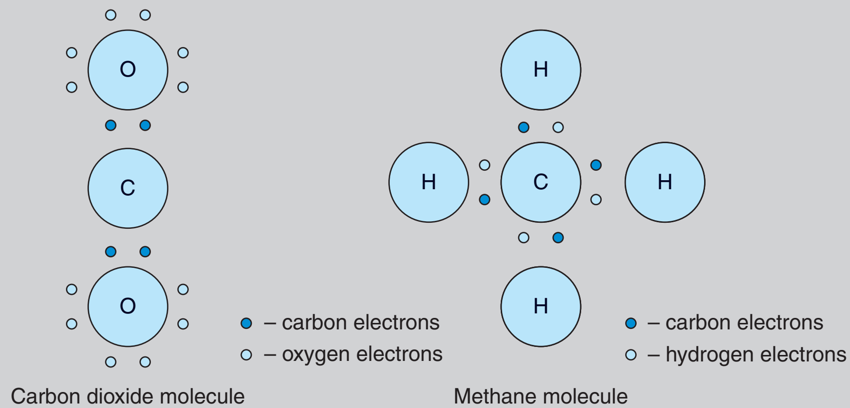


Figure 8.2 Carbon dioxide and methane

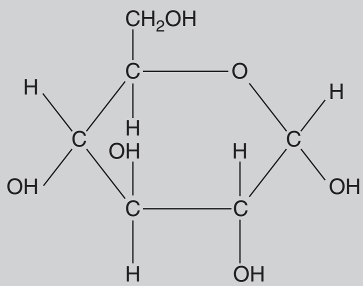


Figure 8.3 Sugar molecule

Methane, or CH_4, is often referred to as 'marsh gas' and is the major constituent of the North Sea gas supply. In this compound, the carbon atom is bonded with four hydrogen atoms, each of which has a valency of one. Most fuels, such as petrol, are chemically related to methane, but with more carbon atoms in the molecule. This family of chemicals (containing progressively more carbons in the molecule are methane, butane, propane and octane) is collectively called the **hydrocarbons**. The molecules in petrol mainly contain eight carbon atoms, hence the term 'octane'.

Slightly more complicated is the glucose molecule ($C_6H_{12}O_6$). Here there is a circular molecule and Figure 8.3 indicates its three-dimensional structure. Glucose is the molecule produced by photosynthesis. It is the starting point for the synthesis of all the many molecules used by the plant, i.e. starch, cellulose (see Figure 8.4), proteins, pigments, auxins, DNA, etc. These molecules may contain chains with hundreds of carbon atoms joined in slightly different ways, but the basic chemistry is the same. All the valency (see p388) requirements of carbon, oxygen and hydrogen are still met.

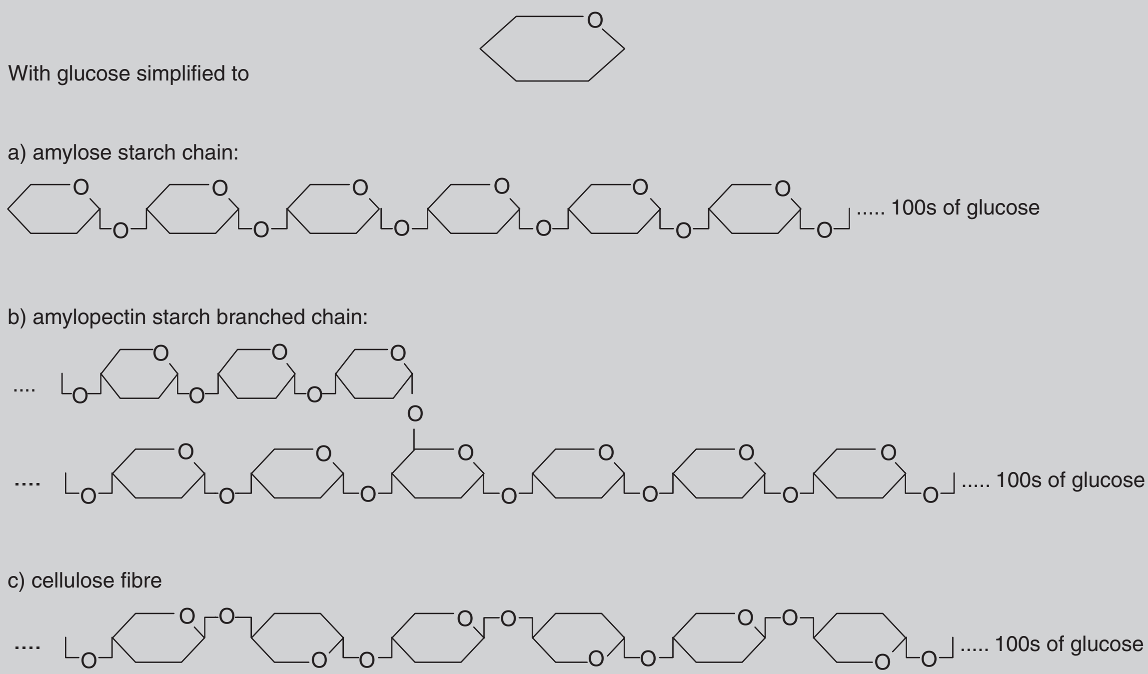


Figure 8.4 Starch and cellulose molecules

Requirements for photosynthesis

Carbon dioxide

In order that a plant may build up organic compounds such as sugars, it must have a supply of carbon which is readily available. **Carbon dioxide** is present in the air in concentrations of 330 ppm (parts per million) or 0.03 per cent, and can diffuse into the leaf through the stomata. Carbon dioxide gas moves ten thousand times faster in air than it would in solution through the roots. The amount of carbon dioxide in the air immediately surrounding the plant can fall when planting is very dense, or when plants have been photosynthesizing rapidly, especially in an unventilated greenhouse.

This reduction will slow down the rate of photosynthesis, but a grower may supply additional carbon dioxide inside a greenhouse or polythene tunnel to **enrich** the atmosphere up to about three times the normal concentration, or an optimum of 1000 ppm (0.1 per cent) in lettuce. Such practices will produce a corresponding increase in growth, provided other factors are available to the plant. If any one of these is in short supply, then the process will be slowed down. This principle, called the law of limiting factors, states that the factor in least supply will limit the rate of the process, and applies to other non- photosynthetic processes in the plant. It would be wasteful, therefore, to increase the carbon dioxide concentration artificially, e.g. by burning propane gas, or releasing pure carbon dioxide gas, if other factors were not proportionally increased.

Light

Light is a factor required for photosynthesis to occur. In any series of chemical reactions where one substance combines with another to form a larger compound, energy is needed to fuel the reactions. Energy for photosynthesis is provided by light from the sun or from artificial lamps. As with carbon dioxide, the amount of light energy present is important in determining the rate of photosynthesis – simply, the more light or greater **illuminance** (intensity) absorbed by the plant, the more photosynthesis can take place. Light energy is measured in joules/square metre, but for practical purposes the light for plant growth is measured according to the light falling on a given area, that is lumens per square metre (lux). More recently, the unit 'microwatts per sq. metre' has been introduced. One lux, in natural sunlight, is equal to microwatts per sq. metre. Whilst the measurement of illuminance is a very useful tool for the grower, it is difficult to state the plant's precise requirements, as variation occurs with species, age, temperature, carbon dioxide levels, nutrient supply and health of the plant.

Figure 8.5 **CO_2 burner** enriches the glasshouse environment, so helping provide an optimum growing environment

However, it is possible to suggest approximate limits within which photosynthesis will take place; a minimum intensity of about 500–1000 lux enables the plant's photosynthesis rate to keep pace with **respiration**, and thus maintain itself. The maximum amount of light many plants can usefully absorb is approximately 30 000 lux, while good growth in many plants will occur at 10 000–15 000 lux. Plant species adapted to shade conditions, however, e.g. *Ficus benjamina* , require only 1000 lux. Other shade-tolerant plants include Taxus spp., Mahonia and Hedera. In summer, light intensity can reach 50 000–90 000 lux and is therefore not limiting, but in winter months, between November and February, the low natural light intensity of about 3000–8000 lux is the limiting factor for plants actively growing in a heated greenhouse or polythene tunnel. Care must be taken to maintain clean glass or polythene, and to avoid condensation that restricts light transmission. Intensity can be increased by using artificial lighting, which can also extend the length of day, which is short during the winter, by **supplementary lighting**. This method is used for plants such as lettuce, bedding plants and brassica seedlings.

Total replacement lighting

Growing rooms which receive no natural sunlight at all use controlled temperatures, humidities, and carbon dioxide levels, as well as light. Young plants which can be grown in a relatively small area, and which are capable of responding well to good growing conditions in terms of growth rate, are often raised in a growing room.

The type of lamp

Lamps are chosen for increasing intensity, and therefore more photosynthesis. All such lamps must have a relatively high efficiency of conversion of electricity to light, and only **gas discharge** lamps are able to do this. Light is produced when an electric arc is formed across the gas filament enclosed under pressure inside an inner tube. Light, like other forms of energy, e.g. heat, X-rays and radio waves, travels in the form of waves, and the distance between one wave peak and the next is termed the wavelength. Light wavelengths are measured in nanometres (nm); 1 nm = one thousandth of a micrometre. Visible light wavelengths vary from 800 nm (red light – in the long wavelength area) to 350 nm (blue light – in the short wavelength area), and a combination of different wavelengths (colours) appears as white light. Each type of lamp produces a characteristic wavelength range and, just as different coloured substances absorb and reflect varying colours of light, so a plant absorbs and reflects specific wavelengths of light.

Since the photosynthetic green pigment chlorophyll absorbs mainly red and blue light and reflects more of the yellow and green part of the spectrum, it is important that the lamps used produce a balanced wavelength spectrum to include as high a proportion of those colours as possible, in order that the plant makes most efficient use of the light provided. The gas included in a lamp determines its light characteristics. The two most commonly used gases for horticultural lighting are mercury vapour, producing a green blue light with no red, and sodium, producing yellow light. This limited spectrum may be modified by the inclusion of fluorescent materials in the inner tube, which allow the tube to re-emit wavelengths more useful to the plant emitted by the gas and re-emit the energy as a shorter wavelength. Thus, modified mercury lamps produce the desirable red light missing from the basic emission.

Low-pressure mercury-filled tubes produce diffuse light and, when suitably grouped in banks, provide uniform light close to plants. These are especially useful in a growing room, provided that they produce a broad spectrum of light as is seen in the 'full spectrum fluorescent tubes'. Gas enclosed at **high pressure** in a second inner tube produces a small, high intensity source of light. These small lamps do not greatly obstruct natural light entering a greenhouse and, while producing valuable uniform supplementary illumination at a distance, cause no leaf scorch. Probably the most useful lamp for supplementary lighting in a greenhouse is a high-pressure sodium lamp, which produces a high intensity of light, and is relatively efficient (27 per cent).

Figure 8.6 **High-pressure sodium lamp** is used for supplementary lighting

Carbon dioxide **enrichment** should be matched to artificial lighting in order to produce the greatest growth rate and most efficient use of both factors.

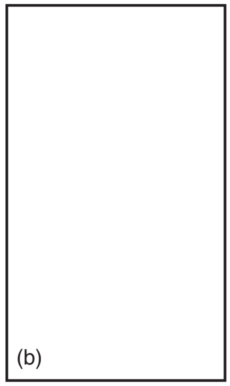
Temperature

The complex chemical reactions which occur during the formation of carbohydrates from water and carbon dioxide require the presence of chemicals called **enzymes** to accelerate the rate of reactions. Without these enzymes, little chemical activity would occur. Enzyme activity in living things increases with temperature from 0°C to 36°C, and ceases at 40°C. This pattern is mirrored by the effect of air temperature on the rate of photosynthesis. But here, the optimum temperature varies with plant species from 25°C to 36°C as optimum. It should be borne in mind that at very low light levels, the increase in photo-synthetic rate with increased temperature is only limited. This means that any input of heating into the growing situation during cold weather will be largely wasted if the light levels are low.

Integrated environmental control in a greenhouse is a form of computerized system developed to maintain near-optimum levels of the main environmental factors (light, temperature and carbon dioxide) necessary for plant growth. It achieves this by frequent monitoring of the greenhouse using carefully positioned sensors. Such a system is able to avoid the low temperature/light interaction described above. The beneficial effects to plant growth of lower night temperatures compared with day are well known in many species, e.g. tomato. The explanation is inconclusive, but the accumulation of sugars during the night appears to be greater, suggesting a relationship between photosynthesis and respiration rates. Such responses are shown to be related to temperature regimes experienced in the areas of origin of the species.

Temperature adaptations

Adaptation to extremes in temperature can be found in a number of species; for example resistance to high temperatures above 40°C in **thermophiles**; resistance to **chilling injury** is brought about by lowering the freezing point of cell constituents. Both depend on the stage of development of the plant, e.g. a seed is relatively resistant,



(b)

(a)

Figure 8.7 **The glasshouse environment** may be controlled by means of (a) a computer situated in the glasshouse, while (b) conditions are monitored throughout the glasshouse

but the hypocotyl of a young seedling is particularly vulnerable. Resistance to chilling injury is imparted by the cell membrane, which can also allow the accumulation of substances to prevent freezing of the cell contents. **Hardening off** of plants by gradual exposure to cold temperatures can develop a change in the cell membrane, as in bedding plants and peas. Examples of plant hardiness are found in Table 4.3.

Water

Water is required in the photosynthesis reaction but this represents only a very small proportion of the total water taken up by the plant (see transpiration). Water supply through the xylem is essential to maintain leaf turgidity and retain fully open stomata for carbon dioxide movement into the leaf. In a situation where a leaf contains only 90 per cent of its optimum water content, stomatal closure will prevent carbon dioxide entry to such an extent that there may be as much as 50 per cent reduction in photosynthesis. A visibly wilting plant will not be photosynthesizing at all.

Minerals

Minerals are required by the leaf to produce the **chlorophyll** pigment that absorbs most of the light energy for photosynthesis. Production of chlorophyll must be continuous, since it loses its efficiency quickly. A plant deficient in iron, or magnesium especially, turns yellow (**chlorotic**) and loses much of its photosynthetic ability. **Variegation** similarly results in a slower growth rate.

The leaf

The leaf is the main organ for photosynthesis in the plant, and its cells are organized in a way that provides maximum efficiency. The upper epidermis is transparent enough to allow the transmission of light into the lower leaf tissues. The sausage-shaped palisade mesophyll cells are packed together, pointing downwards, under the upper epidermis. The sub-cellular **chloroplasts** within them carry out the photosynthesis process. The absorption of light by chlorophyll occurs at one site and the energy is transferred to a second site within the chloroplast where it is used to build up carbohydrates, usually in the form of insoluble starch. The spongy mesophyll, below the palisade mesophyll, has a loose structure with many air spaces. These spaces allow for the two-way diffusion of gases. The carbon dioxide from the air is able to reach the palisade mesophyll; and oxygen, the waste product from photosynthesis, leaves the leaf. The numerous stomata on the lower leaf surface are the openings to the outside by which this gas movement occurs. The numerous small vascular bundles (veins) within the leaf structure contain the xylem vessels that provide the water for the photosynthesis reaction. The phloem cells are similarly present in the vascular bundles, for the removal of sugar to other plant parts. Figure 8.8 shows the

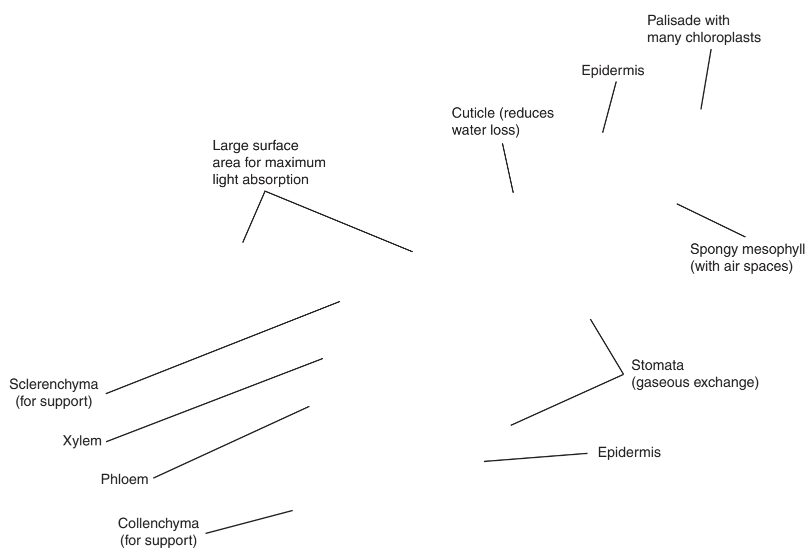


Figure 8.8 **Cross-section of *Ligustrum*** leaf showing its structure as an efficient photosynthesizing organ

structure of the leaf and its relevance to the process of photosynthesis. A newly expanded leaf is most efficient in the absorption of light, and this ability reduces with age. The movement of the products of photosynthesis is described in Chapter 9.

Pollution

Gases in the air, which are usually products of industrial processes or burning fuels, can cause damage to plants, often resulting in scorching symptoms of the leaves. Fluoride can accumulate in composts and be present in tap water, so causing marginal and tip scorch in leaves of susceptible species such as *Dracaena* and *Gladiolus*. Sulphur dioxide and carbon dioxide may be produced by faulty heat exchangers in glasshouse burners, especially those using paraffin. Scorch damage over the whole leaf is preceded by a reddish discolouration.

Respiration

Respiration is the process by which sugars and related substances are broken down to yield energy, the end-products being carbon dioxide and water.

In order that growth can occur, the food must be broken down in a controlled manner to release energy for the production of useful structural substances such as cellulose, the main constituent of plant cell walls, and proteins for enzymes. This energy is used also to fuel cell division and the many chemical reactions that occur in the cell.

The energy requirement within the plant varies, and reproductive organs can respire at twice the rate of the leaves. Also, in apical meristems, the processes of cell division and cell differentiation require high inputs of energy. In order that the breakdown is complete, oxygen is required in the process of aerobic respiration. A summary of the process is given in Table 8.2.

Table 8.2 A summary of the process of aerobic respiration

a. Written in a conventional way, the process can be expressed in the following way: glucose plus oxygen gives rise to carbon dioxide plus water plus energy in the mitochondria of the cell.
b. Written in the form of a chemical equation, which represents molecular happenings at the sub-microscopic level, the above sentence becomes: 1 $C_6H_{12}O_6$ molecule plus 6 O_2 molecules give rise to 6 CO_2 molecules plus 6 H_2O molecules plus energy in the mitochondria of the cell.

It would appear at first sight that respiration is the reverse of photosynthesis (see p111). This supposition is correct in the sense that photosynthesis creates glucose as an energy-saving strategy, and respiration breaks down glucose as an energy releasing mechanism. It is also correct in the sense that the simple equations representing the two processes are mirror images of each other.

It should, however, be emphasized that the two processes have two notable differences. The first is that respiration in plants (as in animals) occurs in all living cells of all tissues at all times in leaves, stems, flowers, roots and fruits. Photosynthesis occurs predominantly in the palisade mesophyll tissue of leaves. Secondly, respiration takes place in the torpedo-shaped organelles of the cell called mitochondria. Photosynthesis occurs in the oval-shaped chloroplasts. Details of biochemistry, beyond the scope of this book, would reveal how different these processes are, in spite of their superficial similarities. In the absence of oxygen, inefficient anaerobic respiration takes place and incomplete breakdown of the carbohydrates produces alcohol as a waste product, with energy still trapped in the molecule. If a plant or plant organ such as a root is supplied with low oxygen concentrations in a waterlogged or compacted soil, the consequent alcohol production may prove toxic enough to cause root death. Over-watering, especially of pot plants, leads to this damage and encourages damping-off fungi.

Storage of plants

The actively growing plant is supplied with the necessary factors for photosynthesis and respiration to take place. Roots, leaves or flower stems removed from the plant for sale or planting will cease to photosynthesize, though respiration continues. Carbohydrates and other storage products, such as proteins and fats, continue to be broken down to release energy, but the plant reserves are depleted and dry weight reduced. A reduction in the respiration rate should therefore be considered for stored plant material, whether the period of storage is a few days, e.g. tomatoes and cut flowers, or several months, e.g. apples.

Attention to the following factors may achieve this aim:

- **Temperature**. The enzymes involved in respiration become progressively less active with a reduction in temperatures from 36°C (optimum) to 0°C. Therefore, a cold store employing temperatures between 0°C and 10°C is commonly used for the storage of materials such as cut flowers, e.g. roses; fruit, e.g. apples; vegetables, e.g. onions; and cuttings, e.g. chrysanthemums, which root more readily later. Long-term storage of seeds in **gene banks** (see Chapter 10) uses liquid nitrogen at 20°C.
- **Oxygen and carbon dioxide**. Respiration requires oxygen in sufficient concentration; if oxygen concentration is reduced, the rate of respiration will decrease. Conversely, carbon dioxide is a product of the process and as with many processes, a build-up of a product will cause the rate of the process to decrease. A controlled environment store for long-term storage, e.g. of top fruit, is maintained at 0° C–5°C according to cultivar, and is fed with inert nitrogen gas to exclude oxygen. Carbon dioxide is increased by up to 10 per cent for some apple cultivars.
- **Water loss**. Loss of water may quickly desiccate and kill stored material, such as cuttings. Seeds also must not be allowed to lose so much water that they become non-viable, but too humid an environment may encourage premature germination with equal loss of viability.

Check your learning

1. State an equation in words which describes the process of photosynthesis.
2. Explain how optimum levels of temperature, carbon dioxide, water and light sustain maximum photosynthesis.
3. Describe the anatomy of a typical leaf as an organ of photosynthesis.
4. State an equation in words which describes the process of respiration.
5. Explain how optimum levels of oxygen, water and temperature affect the rate of respiration.

Further reading

Attridge, T.H. (1991). *Light and Plant Responses*. CUP.

Bickford, E.D. *et al.* (1973). *Lighting for Plant Growth*. Kent State University Press.

Bleasdale, J.K.A. (1983). *Plant Physiology in Relation to Horticulture*. Macmillan.

Brown, L.V. (2008). *Applied Principles of Horticultural Science*. 3rd edn. Butterworth-Heinemann.

Capon, B. (1990). *Botany for Gardeners*. Timber Press.

Grow Electric Handbook No. 2 (1974). *Lighting in Greenhouses*, Part 1. Electricity Council.

Hopkins, W.G. and Huner, N.P.A. (2004). *Introduction to Plant Physiology*. John Wiley & Sons.

Ingram, D.S. *et al.* (eds) (2002). *Science and the Garden*. Blackwell Science Ltd.

MAFF (1978). *Carbon Dioxide Enrichment for Lettuce*, HPG51, HMSO.

Sutcliffe, J. (1977). *Plants and Temperature*. Edward Arnold.

Thompson, A.K. (1996). *Postharvest Technology of Fruit and Vegetables*. Blackwell Science Ltd.

Chapter 9 Transport in the plant

Summary

This chapter includes the following topics:

- **Water movement in the plant**
- **Diffusion and osmosis**
- **Xylem and phloem**
- **Transpiration and water loss**
- **Effect of evaporation, temperature and humidity**
- **Stomata**
- **Minerals in the plant**

with additional information on:

- **Sugar movement in plants**

Figure 9.1 **Apple** (Cox on M1) excavated at 16 years to reveal distribution of roots. Note the vigorous main root system near the surface with some penetrating deeply (courtesy of Dr E.G. Coker)

Water

Water is the major constituent of any living organism and the maintenance of a plant with optimum water content is a very important part of plant growth and development (see Soil Water, Chapter 19). Probably more plants die from lack of water than from any other cause. **Minerals** are also raw materials essential to growth (see p126), and are supplied through the root system.

Functions of water

The plant consists of about 95 per cent water, which is the main constituent of **protoplasm** or living matter. When the plant cell is full of water, or **turgid**, the pressure of water enclosed within a membrane or vacuole acts as a means of support for the cell and therefore the whole plant, so that when a plant loses more water than it is taking up, the cells collapse and the plant may wilt. Aquatic plants are supported largely by external water and have very little specialized support tissue. In order to survive, any organism must carry out complex chemical reactions, which are explained, and their horticultural application described, in Chapter 8. Raw materials for these chemical reactions must be transported and brought into contact with each other by a suitable medium; water is an excellent solvent. One of the most important processes in the plant is photosynthesis, and a small amount of water is used up as a raw material in this process.

- **Diffusion** is a process whereby molecules of a gas or liquid move from an area of high concentration to an area where there is a relatively lower concentration of the diffusing substance, e.g. sugar in a cup of tea will diffuse through the tea without being stirred – eventually! If the process is working against a concentration gradient, energy is needed.
- **Osmosis** can therefore be defined as the movement of water from an area of low salt concentration to an area of relatively higher salt concentration, through a partially permeable membrane. The greater the osmotic pressure then the faster water moves into the root cells, a process which is also affected by increased temperature.

Movement of water

Water moves into the plant through the roots, the stem, and into the leaves, and is lost to the atmosphere. Water vapour moves through the **stomata** (see p117) by diffusion from inside the leaf into the air immediately surrounding the leaf where there is a lower relative humidity (see p41).

The pathway of water movement through the plant falls into three distinct stages:

- water uptake;
- movement up the stem;
- transpiration loss from the leaves.

Water uptake

The movement of water into the roots is by a special type of diffusion called **osmosis**. Soil water enters root cells through the **cell wall** and **membrane**. Whereas the cell wall is permeable to both soil water and the dissolved inorganic minerals, the cell membrane is permeable to water, but allows only the smallest molecules to pass through, somewhat like a sieve. Therefore the cell membrane is considered to be a **partially permeable membrane**.

A greater concentration of minerals is usually maintained inside the cell compared with that in the soil water. This means that, by osmosis, water will move from the soil into the cell where there is relatively lower concentration of water, as there are more inorganic salts and sugars. The greater the difference in concentration of inorganic salts the faster water moves into the root cells.

If there is a build-up of salts in the soil, either over a period of time or, for example, where too much fertilizer is added, water may move out of the roots by osmosis, and the cells are then described as **plasmolyzed**. Cells that lose water this way can recover their water content if the conditions are rectified quickly, but it can lead to permanent damage to the cell interconnections (see p88). Such situations can be avoided by correct dosage of fertilizer and by monitoring of conductivity levels in greenhouse soils and NFT systems (see Chapter 22).

Movement of water in the roots

It is the function of the root system to take up water and mineral nutrients from the growing medium and it is constructed accordingly, as described in Chapter 6. Inside the epidermis is the parenchymatous cortex layer. The main function of this tissue is respiration to produce energy for growth of the root and for the absorption of mineral nutrients. The cortex can also be used for the storage of food where the root is an overwintering organ (see p92).

The cortex is often quite extensive and water moves across it in order to reach the transporting tissue that is in the centre of the root. Movement is relatively unrestricted as it moves through the intercell spaces and the lattice work of the cell wall (see p88). The central region, the **stele**, is separated from the cortex by a single layer of cells, the **endodermis**, which has the function of controlling the passage of water into the stele. A waxy strip forming part of the cell wall of many of the endodermal cells (the Casparian strip) prevents water from moving into the cell by all except the cells outside it, called **passage cells**. In this way, the volume of water passing into the stele is restricted. If such control did not occur, more water could move into the transport system than can be lost through the leaves. In some conditions, such as in high air humidity (see p41), more water moves into the leaves than is being lost to the air, and the more delicate cell walls in the leaf may burst. This condition is known as **oedema**, and commonly occurs in *Pelargonium* as dark green patches becoming brown, and also in weak-celled plants such as lettuce, when it is known as **tipburn**, because the margins of the leaves in particular will appear scorched. **Guttation** may occur when liquid water is forced onto the leaf surface.

Xylem tissue transports the water and dissolved minerals up to the stem and leaves.

Water passes through the endodermis to the **xylem** tissue (see p 92), which transports the water and dissolved minerals up to the stem and leaves. The arrangement of the xylem tissue varies between species, but often appears in transverse section as a star with varying numbers of 'arms' (see Figure 6.11).

A distinct area in the root inside the endodermis, the **pericycle**, supports cell division and produces lateral roots, which push through to the main root surface from deep within the structure. Roots, as with stems, age and become thickened with waxy substances, and the uptake rate of water becomes restricted. Root anatomy is described in Chapter 6.

Movement of water up the stem

Three factors contribute to water movement up the stem:

- **root pressure** by which osmotic forces (see p122) push water up the stem to a height of about 30 cm. This can provide a large proportion of the plant's water needs in smaller annual species;
- **capillary action** (attraction of the water molecules for the sides of the xylem vessels), which may lift water a few centimetres, but which is not considered a significant factor in water movement;
- **transpiration pull** is the major process that moves soil water to all parts of the plant.

Transpiration

Transpiration is the loss of water vapour from the leaves of the plant.

Any plant takes up a lot of water through its roots; for example, a tree can take up about 1000 litres (about 200 gallons) a day. Approximately 98 per cent of the water taken up moves through the plant and is lost by transpiration; only about 2 per cent is retained as part of the plant's structure, and a yet smaller amount is used up in photosynthesis.

The seemingly extravagant loss through leaves is due to the unavoidably large pores in the leaf surface (**stomata)** essential for carbon dioxide diffusion (see Figure 8.8). However, two other points should be considered here:

- water vapour diffuses outward through the leaf stomata more quickly than carbon dioxide (to be used for photosynthesis) entering. However, the plant is able to partially close the stomata to reduce water loss without causing a carbon dioxide deficiency in the leaf;
- the diffusion rate of water vapour through the stomata leads to a leaf cooling effect enabling the leaf to function whilst being exposed to high levels of radiation.

The plant is able to reduce its transpiration rate because the **cuticle** (a waxy waterproof layer) protects most of its surface and the stomata are able to close up as the cells in the leaf start to lose their turgor (see leaf structure p117). The stomatal pore is bordered by two sausage-shaped guard cells, which have thick cell walls near to the pore. When the guard cells are fully turgid, the pressure of water on the thinner walls causes the cells to buckle and the pore to open. If the plant begins to lose more water, the guard cells lose their turgidity and the stomata close to prevent any further water loss. Stomata also close if carbon dioxide concentration in the air rises above optimum levels.

A remarkable aspect of transpiration is that water can be pulled ('sucked') such a long way to the tops of tall trees. Engineers have long known that columns of water break when they are more than about 10 m long, and yet even tall trees such as the giant redwoods pull water up a hundred metres from ground level. This apparent ability to flout the laws of nature is probably due to the small size of the xylem vessels, which greatly reduce the possibility of the water columns collapsing.

A further impressive aspect of the plant structure is seen in the extreme ramifications of the xylem system in the veins of the leaf. This fine network ensures that water moves by transpiration pull right up to the spongy mesophyll spaces in the leaf (see p117), and avoids any water movement through living cells, which would slow the process down many thousand times.

If the air surrounding the leaf becomes very humid, then the **diffusion** of water vapour will be much reduced and the rate of transpiration will decrease. Application of water to greenhouse paths during the summer, **damping down** (see p15), increases relative humidity and reduces transpiration rate. While the air surrounding the leaf is moving, the humidity of air around the leaf is low, so that transpiration is maintained and greater water loss is experienced.

Windbreaks (see p38) reduce the risk of desiccation of crops. Ambient temperatures affect the rate at which liquid water in the leaf evaporates and thus determines the transpiration rate (see p124).

A close relationship exists between the daily fluctuation in the rate of transpiration and the variation in solar radiation. This is used to assess the amount of water being lost from cuttings in mist units (see misting p176); a light-sensitive cell automatically switches on the misting. In artificial conditions, e.g. in a florist shop, transpiration rate can be reduced by providing a cool, humid and shaded environment. **Plasmolyzed** leaf cells can occur if highly concentrated sprays cause water to leave the cells and result in scorching (see p123).

The evaporation of water from the cells of the leaf means that in order for the leaf to remain turgid, which is important for efficient photosynthesis, the water lost must be replaced by water in the xylem. Pressure is created in the xylem by the loss from an otherwise closed system and water moves up the petiole of the leaf and stem of the plant by suction (see **transpiration pull**). If the water in the xylem column is broken, for example when a stem of a flower is cut, air moves into the xylem and may restrict the further movement of water when the cut flower is placed in vase water. However, by cutting the stem under water

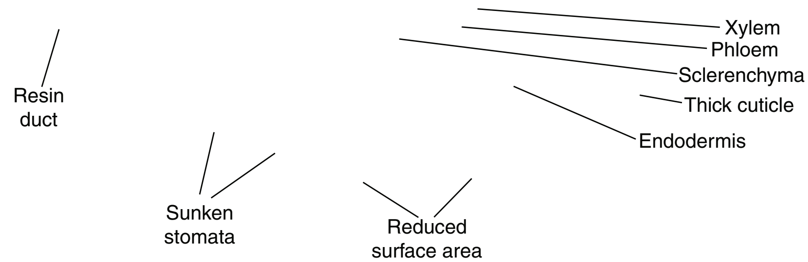


Figure 9.2 **Cross-section of pine leaf** (*Pinus*) showing some adaptations to reduce water loss

the column is maintained and water enters at a faster rate than if the plant was intact with a root system.

Anti transpirants are plastic substances which, when sprayed onto the leaves, will create a temporary barrier to water loss over the whole leaf surface, including the stomata. These substances are useful to protect a plant during a critical period in its cultivation; for example, conifers can be treated while they are moved to another site.

Structural adaptations to the leaf occur in some species to enable them to withstand low water supplies with a reduced surface area, a very thick cuticle and sunken guard cells protected below the leaf surface (see Figures 9.2 and 9.3). Compare this cross-section with that of a more typical leaf shown in Figure 8.8. In extreme cases, e.g. cacti, the leaf is reduced to a spine, and the stem takes over the function of photosynthesis and is also capable of water storage, as in the stonecrop (*Sedum*). Other adaptations are described on p81.

Minerals

Essential minerals are those inorganic substances necessary for the plant to grow and develop normally. They can be conveniently divided into two groups. The **major nutrients (macronutrients)** are required in relatively large quantities whereas the **micronutrients (trace elements)** are needed in relatively small quantities, usually measured in parts per million, and within a narrow concentration range to avoid deficiency or toxicity. The list of essential nutrients is given in Table 9.1.

Non-essential minerals, such as sodium and chlorine, appear to have a role in the plants but not as a universal requirement for growth and development. Sodium is made use of in many plants, notably those of estuarine origins, but whilst it does not appear to be essential there is an advantage in using agricultural salt on some crops such as beet or carrots. Aluminium plays an important part in the colour of *Hydrangea*

Figure 9.3 **Transverse section of Marram Grass leaf**, showing adaptations to prevent water loss; outer thick cuticle, curling by means of hinge cells to protect inner epidermis, stomata sunken into surface to maintain high humidity

Table 9.1 Nutrient requirements

Macronutrients (major nutrients)		**Micronutrients** (trace elements)	
N	Nitrogen	Fe	Iron
P	Phosphate	Bo	Boron
K	Potassium	Mn	Manganese
Mg	Magnesium	Cu	Copper
Ca	Calcium	Zn	Zinc
S	Sulphur	Mo	Molydenum

flowers (see p84) and silicon occurs in many grasses to give them a cutting edge or sharp ridges on their leaves.

Functions and deficiency symptoms of minerals in the plant

Many essential minerals have very specific functions in the plant cell processes. When in short supply (**deficient**) the plant shows certain characteristic symptoms, but these symptoms tend to indicate an extreme deficiency. To ensure optimal mineral supplies, growing media analysis or plant tissue analysis (see p377) can be used to forecast low nutrient levels, which can then be addressed.

Nitrogen is a constituent of **proteins**, nucleic acids and chlorophyll and, as such, is a major requirement for plant growth. Its compounds comprise about 50 per cent of the dry matter of protoplasm, the living substance of plant cells.

Deficiency causes slow, spindly growth in all plants and yellowing of the leaves (chlorosis) due to lack of chlorophyll. Stems may be red or purple due to the formation of other pigments. The high mobility of nitrogen in the plant to the younger, active leaves leading to the old leaves showing the symptoms first.

Phosphorus is important in the production of nucleic acid and the formation of adenosine triphosphate (see ATP p89). Large amounts are therefore concentrated in the meristem. Organic phosphates, so vital for the plant's respiration, are also required in active organs such as roots and fruit, while the seed must store adequate levels for germination. Phosphorus supplies at the seedling stage are critical; the growing root has a high requirement and the plant's ability to establish itself depends on the roots being able to tap into supplies in the soil before the reserves in the seed are used up (see p367).

Deficiency symptoms are not very distinctive. Poor establishment of seedlings results from a general reduction in growth of stem and root systems. Sometimes a general darkening of the leaves in dicotyledonous plants leads to brown leaf patches, while a reddish tinge is seen in monocotyledons. In cucumbers grown in deficient peat composts or NFT, characteristic stunting and development of small young leaves leads to brown spotting on older leaves.

Potassium. Although present in relatively large amounts in plant cells, this mineral does not have any clear function in the formation of important cell products. It exists as a cation and acts as an osmotic regulator, for example in guard cells (*see* p125), and is involved in resistance to chilling injury, drought and disease.

Deficiency results in brown, scorched patches on leaf tips and margins (see Figure 21.4), especially on older leaves, due to the high mobility of potassium towards growing points. Leaves may develop a bronzed appearance and roll inwards and downwards.

Magnesium is a constituent of chlorophyll. It is also involved in the activation of some enzymes and in the movement of phosphorus in the plant.

Deficiency symptoms appear initially in older leaves because magnesium is mobile in the plant. A characteristic interveinal chlorosis appears (see Figure 21.5), which subsequently become reddened and eventually necrotic (dead) areas develop.

Calcium is a major constituent of plant cell walls as calcium pectate, which binds the cells together. It also influences the activity of meristems especially in root tips. Calcium is not mobile in the plant so the deficiency symptoms tend to appear in the younger tissues first. It causes weakened cell walls, resulting in inward curling, pale young leaves, and sometimes death of the growing point. Specific disorders include ‘topple’ in tulips, when the flower head cannot be supported by the top of the stem, ‘blossom end rot’ in tomato fruit, and ‘bitter pit’ in apple fruit.

Sulphur is a vital component of many proteins that includes many important enzymes. It is also involved in the synthesis of chlorophyll. Consequently a deficiency produces a chlorosis that, due to the relative immobility of sulphur in the plant, shows in younger leaves first.

Iron and **manganese** are involved in the synthesis of chlorophyll; although they do not form part of the molecule they are components of some enzymes required in its synthesis. Deficiencies of both minerals result in leaf chlorosis. The immobility of iron causes the younger leaves to show interveinal chlorosis first. In extreme cases, the growing area turns white.

Boron affects various processes, such as the translocation of sugars and the synthesis of gibberellic acid in some seeds (*see* dormancy p131). Deficiency causes a breakdown and disorganization of tissues, leading to early death of the growing point. Characteristic disorders include ‘brown heart’ of turnips, and ‘hollow stem’ in brassicas. The leaves may become misshapen, and stems may break. Flowering is often suppressed, while malformed fruit are produced, e.g. ‘corky core’ in apples, and ‘cracked fruit’ of peaches.

Copper is a component of a number of enzymes. Deficiency in many species results in dark green leaves, which become twisted and may prematurely wither.

Zinc, also involved in enzymes, produces characteristic deficiency symptoms associated with the poor development of leaves, e.g. ‘little leaf’ in citrus and peach, and ‘rosette leaf’ in apples.

Molybdenum assists the uptake of nitrogen, and although required in very much smaller quantities, its deficiency can result in reduced plant nitrogen levels. In tomatoes and lettuce, deficiency of molybdenum can lead to chlorosis in older leaves, followed by death of cells between the veins (interveinal necrosis) and leaf margins. Tissue browning and infolding of the leaves may occur and in *Brassicae*, the ‘whiptail’ leaf symptom involves a dominant midrib and loss of leaf lamina.

Mineral uptake

Minerals are absorbed to form the soil solution (see Chapter 21). The plants take up only water-soluble material so all supplies of nutrients including fertilizers and manures must be in the form of **ions** (charged particles). The movement of the elements in the form of **ions** occurs in the direction of root cells containing a higher mineral concentration

Figure 9.4 **Cross-section of *Zea mais* root** showing its structure in the absorption and transport of water and minerals

than the soil, i.e. **against a concentration gradient**. The passage in the water medium across the root cortex is by simple diffusion, but transport across the endodermis requires a supply of energy from the root cortex. The process is therefore related to temperature and oxygen supply (see respiration p118).

Nutrients are taken up predominantly by the extensive network of fine roots that grow in the top layers of the soil (see Figure 9.1). Damage to the roots near the soil surface by cultivations should be avoided because it can significantly reduce the plant's ability to extract nutrients. It is recommended that care should be taken to ensure that trees and shrubs are planted so their roots are not buried too deeply and many advocate that the horizontally growing roots should be set virtually at the surface to give the best conditions for establishment.

The surface thickening that occurs in the ageing root does not significantly reduce the absorption ability of most minerals, e.g. potassium and phosphate, but calcium is found to be principally taken up by the young roots.

Sugars

Movement of sugars in the plant

Phloem tissue is responsible for transporting carbohydrates from the leaves as a food supply for the production of energy in the cortex.

The product of photosynthesis (see p110) in most plants is starch (some plants produce sugars only), which is stored temporarily in the chloroplast or moved in the phloem to be more permanently stored in the seed, the stem cortex or root, where specialized storage organs such as **rhizomes** and **tubers** may occur (see p158).

The movement or **translocation** of materials around the plant in the phloem and xylem is a complex operation. **Phloem** is principally responsible for the transport of the products of photosynthesis as soluble sugars, usually sucrose, which move under pressure to areas of need, such as roots, flowers or storage organs. Each phloem **sieve-tube cell** (see p92) has a smaller companion cell that has a high metabolic rate. Energy is thus made available to the protoplasm at the end of each sieve-plate, which is able to 'pump' dilute sugar solutions around the plant. The flow can be interrupted by the presence of disease organisms such as club root (see p244).

Check your learning

1. Define the term transpiration and describe the environmental factors which affect it.
2. Describe the pathway and plant tissues involved in water and mineral movement through the plant.
3. Define the terms diffusion and osmosis.
4. Explain how evaporation and consequent water loss can be controlled in the plant by stomata and structural adaptations.

Further reading

Clegg, C.J. and Cox, G. (1978). *Anatomy and Activities of Plants*. John Murray.
Ingram, D.S. *et al.* (eds) (2002). *Science and the Garden*. Blackwell Science Ltd.
Mauseth, J.P. (1998). *Botany – An Introduction to Plant Biology*. Saunders.
Moorby, J. (1981). *Transport Systems in Plants*. Longman.
Scott Russell, R. (1982). *Plant Root Systems: Their Function and Interaction with the Soil*. McGraw-Hill.
Sutcliffe, J. (1971). *Plants and Water*. Edward Arnold.
Sutcliffe, J.F. and Baker, D.A. (1976). *Plant and Mineral Salts*. Edward Arnold.

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Chapter 10 Pollination and fertilization

Summary

This chapter includes the following topics:

- **Pollination**
- **Fertilization**
- **Compatability and incompatibility**
- **Parthenocarpy**
- **Polyploids, including triploids**
- **F1 hybrid breeding**

with additional information on the following:

- **The genetic code**
- **Cell division**
- **Inheritance of characteristics**
- **Other breeding programmes**
- **Monohybrid and dihybrid crosses**
- **Mutations**
- **New breeding technology**
- **Breeders' rights**
- **Gene Banks**

Figure 10.1 **Bees and other pollinating insects** are attracted to large, colourful flowers

Introductory principles

Ever since growers first selected seed for their next crop, they have influenced the genetic make-up and potential of succeeding crops. A basic understanding of plant breeding principles is useful if horticulturists are to understand the potential and limits of what plant cultivars can achieve, and so that they can make realistic requests to the plant breeder for improved cultivars. Plant breeding now supplies a wide range of plant types to meet growers' specific needs. The plant breeder's skill relies on their knowledge of flower biology, cell biology and genetics. Desirable plant characters such as yield, flower colour and disease resistance are selected and incorporated by a variety of methods. This chapter attempts to give a background to the principles used by plant breeders.

Plant breeding follows two scientific findings. Firstly, characteristics of a species are commonly passed on from one generation to the next (**heredity**). Secondly, sexual reproduction is also able to generate different characteristics in the offspring (**variation**). A plant breeder relies on the principles of heredity to retain desirable characteristics in a breeding programme, while new characteristics are introduced in several ways to produce new cultivars.

The processes of pollination and fertilization are first discussed as they are the plant processes that lead to the genetic make-up of the plant that follows.

Pollination

The flower's function is to bring about sexual reproduction (the production of offspring following the fusion of male and female nuclei). The male and female nuclei are contained within the pollen grain and ovule respectively and pollination is the transfer process. Cross-pollination ensures that variation is introduced into new generations of offspring.

Self pollination occurs when pollen comes from the same flower (or a different flower on the same plant) as the ovule, common in Fabaceae (bean family).

Pollination is the plant process whereby a male pollen grain is transferred from the anther to the stigma of the flower, thus enabling fertilization to take place.

Cross-pollination occurs when pollen comes from a flower of a different plant, with a different genetic make-up from the ovule, common in Brassicaceae (cabbage family).

Natural agents of cross-pollination are mainly wind and insects.

Wind-pollinated flowers. The characteristics of wind-pollinated flowers are their small size, their green appearance (lacking coloured petals), their absence of nectaries and scent production, and their production of large amounts of pollen which is intercepted by large stigmas. They also often have proportionally large stigmas that protrude from the flower to maximize the chances of intercepting pollen grains in the air.

(a) (b) (c)

Figure 10.2 **Wind-pollinated species** have small, inconspicuous flowers, e.g. (a) *Stipa calamagrostis* (b) *Cyperus chira* (c) *Luzula nivea*

The commonest examples of wind-pollinated plants are the grasses, and trees with catkins such as *Salix* (willow), *Betula* (birch), *Corylus* (hazel), *Fagus* (beech), *Quercus* (oak). The Gymnosperma (conifers) also have wind-pollination from the small male cones.

(a) (b) (c)

Figure 10.3 **Insect-pollinated flowers**, e.g. (a) Day Lily (*Hemerocallis*) (b) *Digitalis stewartii* (c) *Verbascum* 'Cotswold Queen', are brightly coloured and sometimes have guidelines in the petals to attract insects

Insect-pollinated flowers. The characteristics of insect-pollinated flowers are brightly coloured petals (and scent production) to attract insects, and the presence of nectaries to entice insects with sugary food. Insects such as bees and flies collect the pollen on their bodies as they fly in and out and carry it to other flowers. In tropical countries, slugs, birds, bats and rodents are also pollinators. Some floral mechanisms, e.g. in snapdragon and clover, physically prevent entry of smaller non-pollinating insects and open only when heavy bees land on the flower. Other plant species, such as *Arum* lily, trap pollinating insects for a period of time to give the best chance of successful fertilization.

Certain *Primula* spp. have stigma and stamens of differing lengths to encourage cross-pollination; in thrum-eyed flowers, the anthers emerge further from the flower than the stigma, so that insects rub against them when reaching into the flower tube; in pin-eyed flowers, the stigma protrudes from the flower and will catch the pollen from the same place on the insect body, so ensuring cross-pollination (see Figure 10.4).

(a) (b)

(c) (d)

Figure 10.4 Structural mechanisms to encourage **cross-pollination** in insect-pollinated flowers are shown in (a) and (b) snapdragon flowers where the flower only opens to the weight of the bee on the lower petal and (c) and (d) *Primula* flowers where the stamens and style are arranged differently

Bees in pollination

The well-known social insect, the honey bee (*Apis mellifera)*, is helpful to horticulturists. The female worker collects pollen and nectar in special pockets (honey baskets) on its hind legs. This is a supply of food for the hive and, in collecting it, the bee transfers pollen from plant to plant. Several crops, such as apple and pear, do not set fruit when self-pollinated. The bee therefore provides a useful function to the fruit grower. In large areas of fruit production the number of resident hives may be insufficient to provide effective pollination, and in cool, damp or windy springs, the flying periods of the bees are reduced.

It may therefore be advantageous for the grower to introduce beehives into the orchards during blossom time, as an insurance against bad weather. One hive is normally adequate to serve 0.25 ha of fruit. Blocks of four hives placed in the centre of a 1 ha area require foraging bees to travel a maximum distance of 70 m. In addition to honey bees, wild species, e.g. the potter flower bee (*Anthophora retusa)* and red-tailed bumble-bee (*Bombus lapidarius)*, increase fruit set, but their numbers are not high enough to dispense with the honey bee hives.

All species of bee are killed by broad spectrum insecticides, e.g. deltamethrin, and it is important that spraying of such chemicals be restricted to early morning or evening during the blossom time period when hives have been introduced.

In commercial greenhouses, the pollination of crops such as tomatoes and peppers is commonly achieved by in-house nest-boxes of bumble-bees, *Bombus terrestris* (see Figure 10.5). Plant breeders may use blowflies in glasshouses to carry out pollination. They also perform mechanical transfer of pollen by means of small brushes.

When a pollen grain arrives at the stigma of the same plant species, it absorbs sugar and moisture from the stigma's surface and then germinates to produce a **pollen tube**. The pollen tube contains the 'male' nucleus (and also an extra 'second nucleus'). These nuclei are carried in the pollen tube as they grow down inside the style and into the ovary wall.

Fertilization

After entering the ovule, the male nucleus fuses with the female nucleus, their chromosomes becoming intimately associated. The term '**gamete**' is used to describe the agents, both male and female, that are involved in fertilization. In animals, the gametes are the eggs and sperms. In plants, they are the ovules and pollen.

Figure 10.5 **Bumble-bee boxes** provided in glasshouse for pollination of tomatoes

Fertilization. The union of male and female gametes to produce a zygote (fertilized ovule).

Incompatible, in relation to fertilization, is a genetic mechanism that prevents self fertilization, thus encouraging cross-pollination, e.g. in Brassicaceae. The mechanism operates by inhibiting any of the following four processes:

- pollen germination;
- pollen tube growth;
- ovule fertilization;
- embryo development.

Compatible, in relation to fertilization , is a genetic mechanism that allows self fertilization, thus encouraging self pollination, e.g. in Fabaceae.

Parthenocarpy, where fertilization does not occur before fruit formation, is a useful phenomenon when the object of the crop is the production of seedless fruit, as in cucumber. It is usually accompanied by a high level of auxin in the plant and may be induced in pears by a spray of gibberellic acid.

Parthenocarpy is the formation of fruit without prior fertilization.

The fertilized ovule (**zygote**) undergoes repeated cell division of its young unspecialized cells before beginning to develop tissues through differentiation (see p93), that form the embryo within the seed.

Additionally, however, it should be noted that there is often a second fertilization within the ovule, which has led to the term 'double fertilization'. The second fertilization involves the 'second nucleus' of the pollen tube (mentioned above) fusing with two extra ('polar') nuclei present in the ovule itself. The resulting tissue consequently contains three sets of chromosomes (triploid, see p146) and is called **endosperm**. Endosperm is a short-term food supply used by the embryo to help its growth. Endosperm is found in the seeds of many plant families, but is best developed in the grass family. In maize seed, for example, the endosperm often represents more than half the seed volume. Anyone making popcorn will be eating 'exploded endosperm'.

Not all parts of a seed are derived from embryo or endosperm origins. The outer coat (testa) is formed from the outer layers of the ovule and is thus maternal in origin. Also, the ovary, which contained the ovules in the flower before fertilization, develops and expands to form the fruit of the plant (see seed structure, p103).

In the previous sections of this chapter, descriptions have been given of the plant processes that lead to the development of a seed. Genetics also requires some knowledge of the microscopic details of reproductive cells and of the biological processes in which they are involved, since this knowledge explains how plant characteristics are passed on from generation to generation.

The genetic code

All living plant cells contain a nucleus which controls every activity in the cell (see p00). Within the nucleus is the chemical deoxyribonucleic acid (DNA), a very large molecule made up of thousands of atoms (see also carbon chemistry, p111). DNA contains hundreds of sub-units (nucleotides), each of which contains a chemically active zone called a 'base'. There are four different bases: guanine, cytosine, thymine and adenine. The sequence of these bases is the method by which genetic information is stored in the nucleus, and also the means by which information is transmitted from the nucleus to other cell organelles (this sequence is called the **genetic code**). A change in the base sequencing of a plant's code will lead to it developing new characteristics. These very long molecules of DNA are called **chromosomes**. Each species of plant has a specific number of chromosomes. The cells of tomato (*Lycopersicum esculentum)* contain 24 chromosomes, the cells of *Pinus* and *Abies* species 24 and onions 16 (human beings have 46). Each chromosome contains a succession of units, called **genes**, containing many base units. Each gene usually is the code for a single characteristic such as flower colour or disease resistance. Scientists have been able to correlate many gene locations with plant characteristics that they control. Microscopic observation of cells during cell division reveals two similar sets of chromosomes, e.g. in tomatoes a total of 12 similar or homologous pairs. The situation in a nucleus where there are two sets of chromosomes is termed the **diploid** condition. A gene for a particular characteristic, such as flower colour, has a precise location on one chromosome, and on the same location of the homologous chromosome. For each characteristic, therefore, there are at least two alleles (alternative forms of the gene), one on each chromosome in the homologous pair, which provide genetic information for that characteristic. The fact that every living plant cell which has a nucleus has a complete set of all genetic information (**totipotency**) means that cells have the information to become any specialized cell in the plant. Therefore, when organs are removed from their usual place, as in vegetative propagation, they are able to develop new parts, such as adventitious roots, using this information. Vegetative propagation is described in detail in Chapter 12.

Cell division

When a plant grows, the cell numbers increase in the growing points of the stems and roots, the division of one cell producing two new ones. Genetic information in the nucleus is reproduced exactly in the new cells to maintain the plant's characteristics. The process of **mitosis** achieves this (see p89). Each chromosome in the parent cell produces a duplicate of itself, thus producing sufficient material for the two new daughter cells. A delicate, spindle-shaped structure ensures the separation of chromosomes, one complete set into each of the new cells. A dividing cell wall forms across the old cell to complete the division.

Meiosis

In the anthers and ovaries (parts of the plant producing the sex cells; the pollen and ovules respectively) cell division needs to be radically different. Sexual reproduction involves the fusion of genetic material contributed by the sex cells of each parent (see fertilization). Half of the chromosomes in the cells of an offspring are therefore inherited from the male parent, and half from the female. To ensure that the chromosome number in the offspring is equal to that of the parents, the number of chromosomes in the male and female sex cells (pollen and ovule) must be halved. This halving is achieved by a special division process, meiosis, in the anthers and ovaries. It ensures the separation of each homologous chromosome from its partner so that each sex cell contains only one complete set of chromosomes. This cell condition is termed **haploid**.

Inheritance of characteristics

As mentioned above, genetic information is passed from parent to offspring when material from male and female parent comes together by fusion of the sex cells. Genes from each parent can, in combination, produce an intermediate form, a mixture of the parents' characteristics in the offspring; e.g. a gene for red flowers inherited from the male parent, combined with a gene for white flowers from the female parent, could produce pink-flowered offspring, if both conditions are equal (see below). If one gene, however, was completely dominant over the other, e.g. if the red gene inherited from the male parent was **dominant** over the white female gene, all offspring would produce red flowers (see Figure 10.6). The non-dominant (**recessive**) white gene will still be present as part of the genetic make-up of the offspring cells and can be passed on to the next generation. If it then were to combine at fertilization with another white gene, the offspring would be white-flowered.

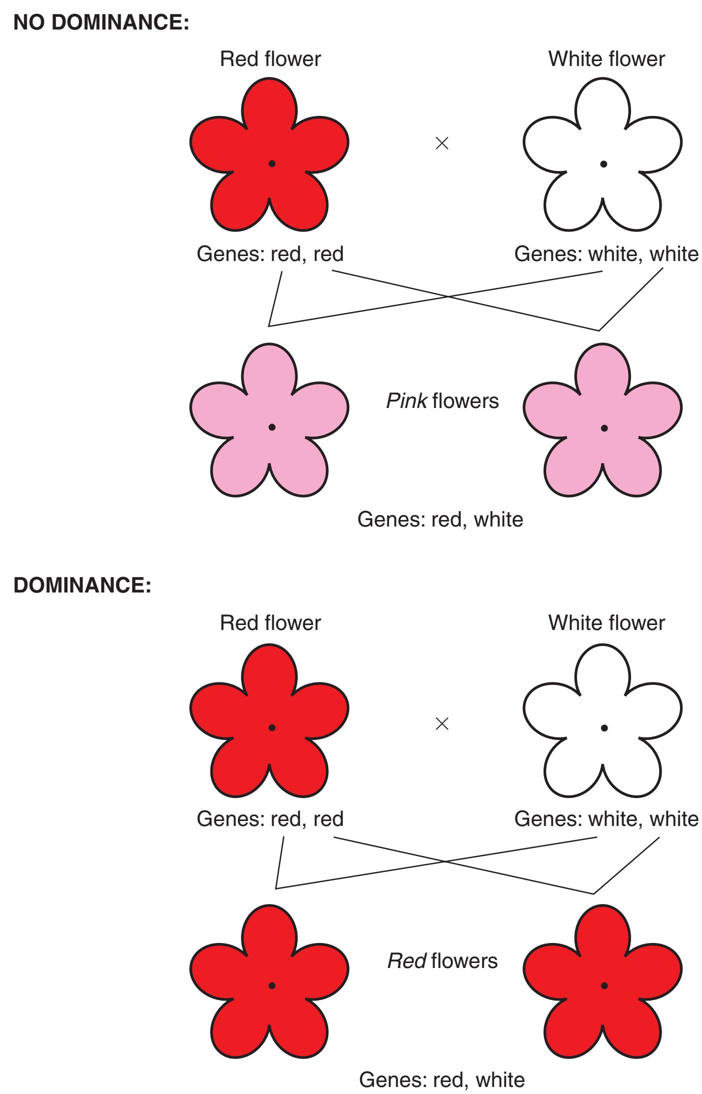

Figure 10.6 The pattern of inheritance of **genes**

The example above considers the inheritance of **one** pair of genes by a single offspring (**monohybrid cross**). However, many sex cells are produced from one flower in the form of pollen grains and ovules, and these give rise to many seeds in the next generation. The plant breeder tries to **predict** the ratio (or percentage) of offspring with each option (in this case, the ratio of red- flowered offspring to white-flowered offspring).To understand this prediction process, consider now the same example of flower colour in a little more detail.

If a red-flowered plant, containing two genes for red (described as **pure**), is carefully fertilized (**crossed**) with a 'pure' white-flowered plant, the red-flowered plant supplies in this case pollen as the male parent, and the white-flowered plant supplies ovule as the female parent. As both parents are pure, the male parent can produce only one type of sex cell, containing the 'red' version (**allele**) of the gene, and the female parent only the white (**allele**). Since all pollen grains will carry 'red' genes and all ovules 'white' , then in the absence of dominance, the only possible combination for the first generation (or **F1**) is pink offspring, each containing an allele for red and an allele for white (i.e. **impure**). Figure 10.7 illustrates this inheritance by using letters to describe genes, **R** to represent a red-inducing gene, and **r** to represent a white-inducing gene.

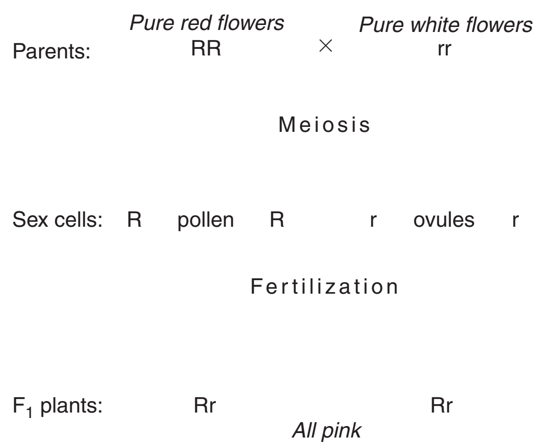

Figure 10.7 **Simple inheritance**: production of the F1 generation

The **genotype** (the genetic make-up of a cell) can be represented by using letters, e.g. Rr. The **phenotype** (the outward appearance e.g. red, pink or white flower) results from the genotype's action. If these plants from the F1 generation were now used as parents and crossed (or perhaps self-pollinated), then the results in the second or **F2** generation would be as shown in Figure 10.8, i.e. 25 per cent of the population would have the phenotype of red flowers, 50 per cent pink flowers and 25 per cent white flowers (a ratio of 1:2:1). The plant breeder, by analysing the ratios of each colour, would be able to calculate which colour genes were present in the parents, and whether the 'colour' was pure.

More usually, one of the alleles at the gene site exhibits dominance and the other is recessive. As a result, when offspring inherit both alleles (dominant and recessive), there is no intermediate phenotype; only the dominant gene expresses itself (the recessive is masked). It was the monk Gregor Mendel working in a monastery in what is now Brno in

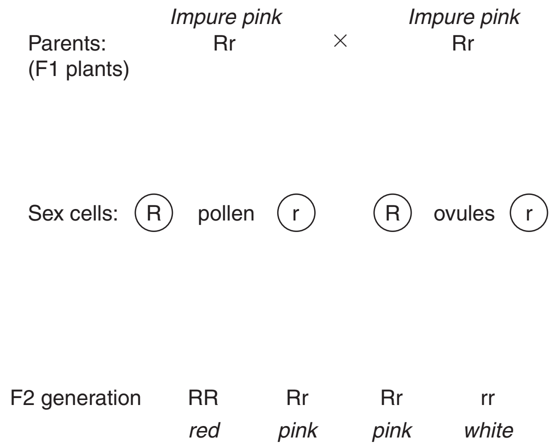

Figure 10.8 **Simple inheritance**: production of the F2 generation

the Czech Republic in the middle of the eighteenth century who laid the foundations of genetics with his breeding experiments.

He used peas and worked with single characteristics such as the height of the plant. He crossed tall with short plants and found that in the second or F2 generation the plants were either tall or short; there were no middle-sized phenotypes. They were found to be in the ratio of three tall to one short plant. Similarly, he crossed pure (homozygous) round pea parents (RR) with pure (homozygous) wrinkled pea parents (rr). When crossing the two pure parents (RR × rr), the genotype of the first generation, or F1, follows the pattern as shown in Figure 10.7, but all the plants produced round peas, i.e. the round pea allele was dominant in peas.

When the second or F2 generation was produced the genotype followed the pattern shown in Figure 10.8, but there were three round peas to every one wrinkled pea type. Both RR and Rr genotypes produced the same phenotype; only a double recessive (rr) produced plants with wrinkled peas. He went on to look at other simple 'single gene characteristics' including seed colour (yellow dominant and green recessive) and flower colour (purple dominant and white recessive). In all these cases he found that the ratio of phenotypes in the second or F2 generation was 3:1. By observation he established the **Principle of Segregation** which states that the phenotype is determined by the pair of alleles in the genotype and only one allele of the gene pair can be present in a single gamete (i.e. passed on by a parent).

Dihybrid cross. Mendel then went on to investigate the crossing of plants that differed in **two** contrasting characters. The results of crossing tall purple-flowered peas with short white-flowered ones produced all tall purple-flowered peas. As Mendel showed, they all had the same genotype (TtPp) and the same phenotype. The F2 generation produced from these parents is illustrated in Figure 10.9, where the combinations are shown in a Punnet Square (or 'checkerboard' – a useful way of showing the genotypes produced in a cross). Note that each gene has behaved independently; there are 12 tall to four short (ratio 3:1) and 12 purple to four white-flowered plants (3:1).

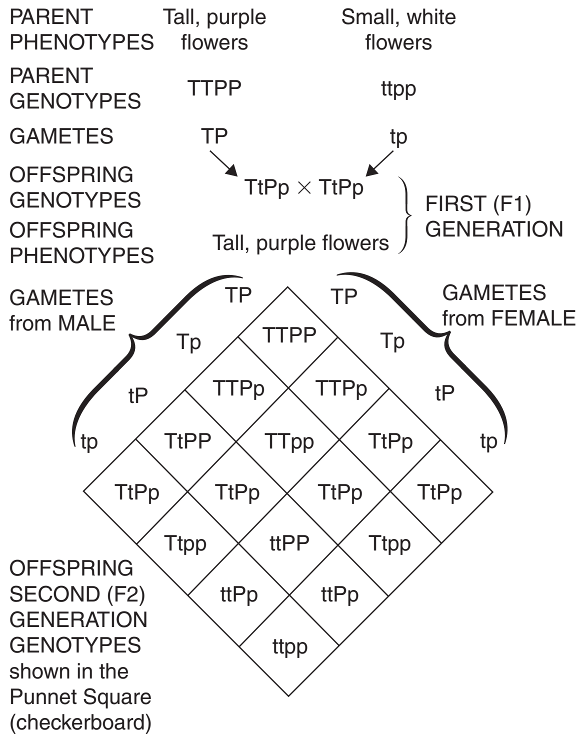

Figure 10.9 **Punnet square** showing a dihybrid cross

This example illustrates Mendel's **Principle of Independent Assortment** which states that the alleles of **unlinked** genes (i.e. genes not on the same chromosome) behave independently at meiosis. The cross involving two independent genes produces combinations of phenotypes in the ratio 9:3:3:1.

For the cross TtPp × TtPp, the genotypes produced are shown in Figure 10.9 and the phenotypes are as follows:

9 Tall, purple-flowered plants		
	1	TTPP
	2	TTPp
	2	TtPP
	4	TtPp
3 Tall, white-flowered plants		
	2	TTpp
	1	Ttpp
3 Short, purple-flowered plants		
	2	ttPP
	1	ttPp
1 Short, white-flowered plants		
	1	ttpp

Not all genes act independently in the way shown above. Some are **linked** by being on the same chromosome and so they will usually appear together. The number of grouped genes is equal to the number of chromosome pairs for the species (seven for peas).

F1 hybrid breeding

Breeders may choose to produce seeds for the commercial market which are all F1 offspring or sometimes called F1 hybrids. F1 hybrid seeds are important to the grower since, given a uniform environment, all plants of the same cultivar will produce a uniform crop because they are all genetically identical (see Figure 10.10). Crops grown from F1 hybrid seed such as cabbage, Brussels sprouts and carrots can be harvested at one time and they have similar characteristics of yield. Similarly, F1 hybrid flower crops will have uniformity of colour and flower size.

Figure 10.10 **Uniformity** of crop in **F1 hybrid** *Poinsettias*

Another feature of F1 hybrids is **hybrid vigour**. Plants crossed from parents with quite different characteristics will display the feature to a marked extent, giving outstanding growth, especially in good growing conditions. The desirable characteristics of the two parents, such as disease resistance, good plant habit, high yield and good fruit or flower quality, may be incorporated along with established characteristics of successful commercial cultivars by means of the F1 hybrid breeding programme.

F1 hybrid seed production first requires suitable parent stock, which must be pure for all characteristics. In this way, genetically identical offspring are produced, as described in Figure 10.7. The production of pure parent plants involves repeated self pollination (selfing) and selection, over eight to twelve generations, resulting in suitable **inbred** parent lines. During this and other self pollination programmes, vigour is lost (the parent plants do not look impressive) but, of course, the vigour is restored by hybridization.

The parent lines must now be cross-pollinated to produce the F1 hybrid seed. It is essential to avoid self pollination at this stage, therefore one of the lines is designated the male parent to supply pollen. The anthers in the flowers of the other line, the female parent, are removed, or treated to prevent the production of viable pollen. The growing area must be isolated to exclude foreign pollen, and seed is collected only from the female parent. This seed is more expensive than most other commercial seed, due to the complex breeding programme requiring intensive labour. Seed collected from the planted commercial F1 hybrid crop represents the F2, and will produce plants with very diverse characteristics (Figure 10.8). Some F2 seed, however, is deliberately produced by breeders for flowering plants, such as geraniums and fuchsias, where a variety of colour and habit is required for bedding plant display.

Other breeding programmes

In addition to F1 hybrid breeding, where specific improvements are achieved, plant breeders may wish to bring about more general improvements to existing cultivars, or introduce characteristics such as disease resistance. Programmes are required for crops which self-pollinate (**inbreeders**), or those which cross-pollinate (**outbreeders**), and two of these strategies are described.

Pedigree breeding is the most widely used method in plant breeding by both amateurs and professionals. Two plants with different desirable characteristics are crossed to produce an F1 population. These F1 plants of very similar genotype are then crossed (called '**selfed**') and any offspring with useful characteristics are selected for further selfing to produce a line of desirable plants. After repeated selfing and selection, the characteristics of the new lines are compared with existing cultivars and assessed for improvements. Further field trials will determine a new type's suitability for submission and possible registration as a new cultivar. If a plant breeder wants to produce a strain adapted to particular conditions (e.g. a cultivar with hardiness), exposure of plants of a selected cultivar to the desired conditions will eliminate unsuitable plants, allowing the hardy plants to set seed. Repetition of this process gradually adapts the whole population. Selection for other characteristics such as earliness may be selected by harvesting seed early.

Disease resistance breeding (see also p290). A genetic characteristic enables the plant to combat fungal attack. The disease organism may itself develop a corresponding genetic capacity to overcome the plant's resistance by mutation. The introduction of disease resistance into existing cultivars often requires a **backcross breeding** programme. This involves a commercial cultivar lacking resistance crossed with a wild plant which exhibits resistance. For example, a lettuce cultivar may lack resistance to downy mildew (*Bremia lactucae*), or a tomato cultivar lack tomato mosaic virus resistance.

This commercial cultivar is crossed with a resistant wild plant to produce an F1, then an F2. From this F2, plants having both the characteristics of the commercial cultivar and also disease resistance are selected. The process continues with backcrossing of these selected plants with the original commercial parent to produce an F1, from which an F2 is produced. More commercial characteristics may be incorporated by further backcrossing and selection over a number of generations, until all the characteristics of the commercial cultivar are restored, but with the additional disease resistance.

Polyploids

Polyploids are plants with cells containing more than the diploid number of chromosomes; e.g. a triploid has three times the haploid number, a tetraploid four times and the polyploid series continues in many species up to octaploid (eight times haploid). An increase in size of cells, with a resultant increase in roots, fruit and flower size of many species of chrysanthemums, fuchsias, strawberries, turnips and grasses, is the result of polyploidy. There is a limit to the number of chromosomes that a species can contain within its nucleus. Polyploidy occurs when duplication of chromosomes (see mitosis) fails to result in mitotic cell division. The multiplication of a polyploid cell within a meristem may form a complete polyploid shoot that, after flowering and fertilization,

Polyploidy occurs when duplication of chromosomes fails to result in mitotic cell division.

may produce polyploid seed. Polyploidy can occur spontaneously, and has led to many variant types in wild plant populations. It can be artificially induced by the use of a mitosis inhibitor, colchicine.

Triploids

The crossing of a tetraploid and a diploid gives rise to a triploid. Triploids, having an odd number of chromosomes which are unable to pair up during meiosis, are often infertile in nature. But there are a few important examples in horticulture, notably 'Bramley's Seedling' apple cultivar. Pollen from such cultivars is sterile, being derived from an irregular meiosis division in the anthers. The presence nearby of suitable pollinator cultivars such as 'James Grieve' and 'Grenadier' provide suitable viable pollen at the same flowering time as 'Bramley's Seedling'. Thus two pollinators are required, i.e. one to pollinate the Bramley's Seedling and a second to pollinate the pollinator. An alternative strategy for a private gardener is the inclusion of a pollinator onto the triploid tree by means of a suitable graft (see p176), the result is sometimes called a 'family tree'. Polyploidy only becomes significant in the plant when the mutated cell is part of a meristem.

Mutations

Spontaneous changes in the content or arrangement of chromosomes (**mutations**), whether in the cells of the vegetative plant or in the reproductive cells, occur in nature at the rate of approximately one cell in one million. These changes to the plant DNA are one of the most important causes of new alleles (see p141) leading to changes in the characteristics of the individual. Extreme chromosome alterations result in malformed and useless plants, but slight rearrangements may provide horticulturally desirable changes in flower colour or plant habit. Such desirable mutations have been seen in plants such as chrysanthemum, *Dahlia* and *Streptocarpus*. Mutation breeding also produces these variations, but using irradiation treatments with X-rays, gamma rays or mutagenic chemicals increases the mutation rate. In both situations (natural mutations and induced mutations), the mutation only becomes significant in the plant when the mutated cell originates in a meristem, where it proceeds to create a mass of novel genetic tissues (and organs).

When a shoot with a different coloured flower or leaf arises, it is often referred to as a **sport**. A more extreme example of a mutation is a **chimaera**. This occurs when organs (and even whole plants) have two or more genetically distinct kinds of tissues existing together. This often results in variegation of the leaves, as seen in some *Acer* and *Pelargonium* species. Horticulturists use one form or other of vegetative propagation to preserve and increase the genetic novelty. These useful mutations may give rise to potential new cultivars in just one generation. (See Figure 10.11)

Figure 10.11 **Chimaera** (distinct genetical tissues) in variegated horseradish

Recombinant DNA technology

For the plant breeder it has historically been difficult to predict whether the progeny from a breeding programme would show the desired characteristics. The term **recombinant DNA technology** refers to a modern method of breeding that enables novel sources of DNA to be integrated with greater certainty into a plant's existing genotype. Two new techniques have appeared in the last few years that have enabled this major shift in breeding practice.

The first technique is **marker-assisted breeding** . Breeders are now able to analyze chromosome material and establish what DNA sequence is present on the chromosome. Some plant characters such as disease resistance are hard to evaluate in newly bred plants, as infection may be difficult to achieve under test conditions. Since the breeders are now able to recognize the chromosome DNA sequence for plant resistance, they can apply this knowledge by analyzing newly bred plants for this desirable character. Whilst resistance to a disease may be complex, involving several genes acting together, the marker-assisted technique has proved a powerful form of assistance in this area.

The second technique is **genetic modification** (now known as **GM)**, or genetic engineering. By this method, genes derived from other plant species can be incorporated into the species in question. The commonest technique involves the bacterium *Agrobacterium tumifasciens*. This organism (see also p263) causes crown gall disease on plants such as apple. The bacterium contains a circular piece of DNA (plasmid) that on entering plant cells can integrate its DNA into that of the infected plant cell. Breeders are able to develop strains of *A. tumifasciens* in large numbers. The new strains can be induced to accept, in their plastids, a desirable gene taken from other variants of the same plant species, or taken from other species. Wounded plants infected by a bacterial strain begin to multiply the newly acquired gene by integrating it into the cells of the plant. Tissues developing around the point of infection can then be used for micro-propagation of the new genetically-modified cultivar.

Confirmation of successful genetic change can be achieved most easily when the newly introduced gene is already linked in the bacterial plasmid by a marker gene. Two common kinds of marker were used initially, resistance to an antibiotic and resistance to a herbicide. In this way, the breeder was able to test whether incorporation of a desirable new character was successful by exposing it to the antibiotic or herbicide concerned. Alternative methods to the use of antibiotic markers have been sought. There seems little doubt that major advances in the quantity and quality of horticultural crops could follow GM methods of breeding. However, there are fears that such methods could result in deterioration of food quality or pose a threat to the environment.

The Plant Varieties and Seeds Act, 1964

This Act protects the rights of producers of new cultivars. The registration of a new cultivar is acceptable only when its characteristics are shown to be significantly different from any existing type. Successful registration enables the plant breeder to control the licence for the cultivar's propagation, whether by seed or vegetative methods. Separate schemes operate for the individual genera of horticultural and agricultural crops, but all breeding activities may benefit from the 1964 Act. Producers of licenced plants pay a royalty fee to the breeder.

Gene banks

As new cultivars are produced and grown for use in modern horticulture, old cultivars and wild sources of variation (which could be a source of valuable characteristics and be useful in future breeding programmes) are being lost. Since initiatives in 1974, there continues to be much interest in gene conservation and several gene banks have been established. A gene bank provides a means of storing large quantities of seed of diverse origins at low temperatures, while some plant material (i.e. that which cannot be stored as seed) is maintained by tissue culture (see p177).

Check your learning

1. Define the terms, pollination, self pollination and cross-pollination.
2. Describe two characteristics of wind-pollinated flowers and two characteristics of insect pollinated flowers.
3. Define, in relation to fertilization, the terms compatible and incompatible.
4. Define the term parthenocarpy and explain its importance in horticulture.
5. Describe the characteristics of F1 hybrids and explain the meaning of hybrid vigour.

Further reading

Bos, I. and Calligari, P. (2007). *Selection Methods in Plant Breeding*. Kluwer.
George, R.A.T. (1999). *Vegetable Seed Production*. Longman.
Have, van der, D.J. (1979). *Plant Breeding Perspectives*, Wageningen. Centre for Agricultural Publishing and Documentation.
Ingram, D.S. *et al.* (eds) (2002). *Science and the Garden*. Blackwell Science Ltd.
North, C. (1979). *Plant Breeding and Genetics in Horticulture*. Macmillan.
Simmonds, N.W. (1979). *Principles of Crop Improvement*. Longman.
Watts, L. (1980). *Flower and Vegetable Breeding*. Grower Books.

Chapter 11 Plant development

Summary

This chapter includes the following:

- **Growth and development**
- **Seed germination**
- **Seed viability and dormancy**
- **Tropisms**
- **The vegetative plant**
- **Photoperiodism**

with additional information on:

- **Apical dominance**
- **Juvenility**
- **Pruning**
- **Extended flower life**
- **The ageing plant**

Figure 11.1 **Autumn colour** in the leaves of *Parthenocissus tricuspida* (Boston Ivy), developing in response to environmental changes

Growth and development

Growth is a difficult term to define because it really encompasses the totality of all the processes that take place during the life of an organism. However, it is useful to distinguish between growth as the processes which result in an increase in size and weight (described in Chapter 8), and those processes which cause the changes in the plant during its life cycle, which can usefully be called **plant development**. This is described here through the typical life cycle of plants, from seed to senescence.

Seeds

Seed germination

Details of the structure of seeds can be found in Chapter 7.

The main requirements for the successful germination of most seed are as follows:

Seed germination is the emergence of the radicle through the testa, usually at the micropyle.

- **Water supply** to the seed is the first environmental requirement for germination. The water content of the seed may fall to 10 per cent during storage, but must be restored to about 70 per cent to enable full chemical activity. Water initially is absorbed into the structure of the testa in a way similar to a sponge taking up water into its air space, i.e. by **imbibition**. This softens the testa and moistens the cell walls of the seed so that the next stages can proceed. The cells of the seed take up water by **osmosis**, often assuming twice the size of the dry seed. The water provides a suitable medium for the activity of enzymes in the process of respiration. A continuous water supply is now required if germination is to proceed at a consistent rate, but the growing medium, whether it is outdoor soil or compost in a seed tray, must not be waterlogged, because **oxygen** essential for aerobic respiration would be withheld from the growing embryo. In the absence of oxygen, **anaerobic respiration** occurs and eventually causes death of the germinating seed, or suspended germination, i.e. **induced dormancy**.
- **Temperature** is a very important germination requirement, and is usually specific to a given species or even cultivar. It acts by fundamentally influencing the activity of the enzymes involved in the biochemical processes of respiration, which occur between 0°C and 40°C. However, species adapted to specialized environments respond to a narrow range of germination temperatures. For example, cucumbers require a minimum temperature of 15°C and tomatoes 10°C. On the other hand, lettuce germination may be inhibited by temperatures higher than 30°C and in some cultivars, at 25°C, a period of induced dormancy occurs. Some species, such as mustard, will germinate in temperatures just above freezing and up to 40°C, provided they are not allowed to dry out.
- **Light** is a factor that may influence germination in some species, but most species are indifferent. Seed of *Rhododendron, Veronica* and

Phlox is inhibited in its germination by exposure to light, while that of celery, lettuce, most grasses, conifers and many herbaceous flowering plants is slowed down when light is excluded. This should be taken into account when the covering material for a seedbed is considered (see tilth). The colour (wavelength) of light involved may be critical in the particular response created. Far red light (720 nm), occurring between red light and infra-red light and invisible to the human eye, is found to inhibit germination in some seeds, e.g. birch, while red light (660 nm) promotes it. A canopy of tall deciduous plants filters out red light for photosynthesis. Seeds of species growing under this canopy receive mainly far red light, and are prevented from germinating. When the leaves fall in autumn, these seeds will germinate in response to the now available red light and to the low winter temperatures.

Typical germination process

Seed dormancy

As soon as the embryo begins to grow out of the seed, i.e. **germinates**, the plant is vulnerable to damage from cold or drought. Therefore, the seed must have a mechanism to prevent germination when poor growing conditions prevail. **Dormancy** is a period during which very little activity occurs in the seed, other than a very slow rate of respiration. Seeds will not germinate until dormancy is broken.

A **thick testa** prevents water and oxygen, essential in germination, from entering the seed. Gradual breakdown of the testa, occurring through bacterial action or freezing and thawing, eventually permits germination following unsuitable conditions. The passing of fruit through the digestive system of an animal, such as a bird, may promote germination, e.g. in tomato, cotoneaster and holly. Many species, e.g. fat hen, produce seed with variable dormancy periods, to spread germination time over a number of growing seasons. Spring soil cultivations can break the seed coat and induce germination of weed seeds (see p185). This structural dormancy, in horticultural crops, may present germination problems in plants such as rose rootstock species and *Acacia*. Physical methods using sandpaper or chemical treatment with sulphuric acid (collectively known as **scarification**) can break down the seed coat and therefore the dormancy mechanism.

Chemical inhibitors may occur in the seed to prevent the germination process. **Abscisic acid** at high concentrations helps maintain dormancy while, as dormancy breaks, progressively lower levels occur, with a simultaneous increase in concentrations of growth promotors such as gibberellic acid and cytokinins. Inhibitory chemicals located just below the testa may be washed out by soaking in water.

Cold temperatures cause similar breaks of dormancy in other species (**stratification**), the exact temperature requirement varying with the period of exposure and the plant species. Many alpine plants require a 4°C stratification temperature while other species, e.g. *Ailanthus*, *Thuja*, ash and many other trees and shrubs, require both moisture and the chilling treatment. The chemical balance inside the seed may be changed in favour of germination by treatment with chemicals such as gibberellic acid and potassium nitrate.

An **undeveloped embryo** in a seed is incapable of germinating until time has elapsed after the seed is removed from the parent plant, i.e. the **after ripening** period has occurred, as in the tomato and many tropical species, such as palms. Some seeds such as *Acacia* are recorded to have a dormancy of more than a hundred years.

The practical implications of the above are considered in detail in Chapter 12.

Seed viability

There are a number of essential germination requirements for a successful seedling emergence to occur. A **viable seed** has the potential for germination, given the required external conditions. Its viability, therefore, indicates the activity of the seed's internal organs, i.e. whether the seed is 'alive' or not. Most seeds remain viable until the next growing season, a period of about eight months, but many can remain dormant for a number of years until conditions are favourable for germination. In general, viability of a batch of seed diminishes with time, its maximum viability period depending largely on the species. For example, celery seed quickly loses viability after the first season, but wheat has been reported to germinate after scores of years. The germination potential of any seed batch will depend on the storage conditions of the seed, which should be cool and dry, slowing down respiration and maintaining the internal status of the seed. These conditions are achieved in commercial seed stores by means of sensitive control equipment. Packaging of seed for sale takes account of these requirements and often includes a waterproof lining of the packet, which maintains constant water content in the seeds.

The Seeds Acts

In the UK the Seeds Acts control the quality of seed to be used by growers. A seed producer must satisfy the minimum requirements for species of vegetables and forest tree seed by subjecting a seed batch to a government testing procedure. A sample of the seed is subjected to standardized ideal germination conditions, to find the proportion that is viable (**germination percentage**). The germination and emergence under less ideal field conditions (**field emergence**), where tilth and disease factors are variable, may be much lower than germination percentage.

The sample is also tested for **quality** which provides information, available to the purchaser of the seed, covering trueness to type; that is, whether the characteristics of the plants are consistent with those of the named cultivar; the percentage of non-seed material, such as dust; the percentage of weed seeds, particularly those of a poisonous nature (see Weeds Act, Chapter 13). The precise regulations for sampling and testing, and requirements for specific species, have changed slightly since the 1920 Act, the 1964 Act (which also included the details of plant varieties), and the entry of Britain into the European Community. Some control under EC regulations is made of the provenance of forestry seed, as the geographical location of its source is important in relation to a number of factors, including response to drought, cold, dormancy, habit, and pest and disease susceptibility.

The seedling

Within the seed is a food store that provides the means to produce energy for germination. Once the food store has been exhausted, the seedling must rapidly become independent in its food supply and begin to photosynthesize. It must therefore respond to stimuli in its environment to establish the direction of growth. Such a response is termed **a tropism**, and is very important in the early survival of the seedling (Figure 11.2).

A **tropism** is a directional growth response to an environmental stimulus.

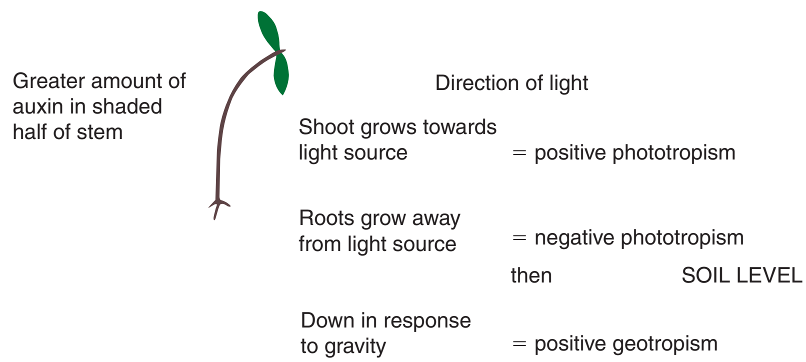

Figure 11.2 **Geotropism and phototropism** shown as mechanisms assisting the survival of the seedling

Geotropism is a directional growth response to gravity. The emergence of the radicle from the testa is followed by growth of the root system, which must take up water and minerals quickly so that the shoot system may develop. A seed germinating near the surface of a growing medium must not put out roots that grow on to the surface and dry out, but the roots must grow downwards to tap water supplies. Conversely, the plumule must grow away from the pull of gravity so the leaves develop in the light.

Etiolation is the type of growth which the shoot produces as it moves through the soil in response to gravity. The developing shoot is delicate and vulnerable to physical damage, and therefore the growing tip is often protected by being bent into a plumular hook. The stem grows quickly, is supported by the structure of the soil and therefore is very thin and spindly, stimulated by friction in the soil which causes release of ethylene. The leaves are undeveloped, as they do not begin to function until they move into the light. Mature plants that are grown in dark conditions also appear etiolated.

Seedling development

Hypogeal germination occurs when the cotyledons develop above ground outside the seed.

Epigeal germination occurs when the testa merges above ground initially enclosing the cotyledons.

The emergence of the plumule above the growing medium is usually the first occasion that the seedling is subjected to light. This stimulus inhibits the extension growth of the stem so that it becomes thicker and stronger, but the seedling is still very susceptible to attack from pests and damping-off diseases. The leaves unfold and become green in response to light, which enables the seedling to photosynthesize and so support its development. The first leaves to develop, the cotyledons, derive from the seed and may emerge from the testa while still in the soil, as in peach and broad bean (**hypogeal** germination), or be carried with the testa into the air, where the cotyledons then expand (**epigeal** germination), e.g. in tomatoes and cherry.

(a) (b)

Figure 11.3 Seed germination: (a) **epigeal** germination on left in leek and tree lupin, **hypogeal** germination on right in runner bean (b) later stage showing hypogeal in bean on left and epigeal in tree lupin on right

Phototropism occurs so the shoot grows towards a light source that provides the energy for photosynthesis. A bend takes place in the stem just below the tip as cells in the stem away from the light grow larger than those near to the light source. A greater concentration of auxin in the shaded part of the stem causes the extended growth (see Figure 11.2). Roots display a negative phototropic response, growing away from light when exposed at the surface of the growing medium, e.g. on a steep bank. The growth away from light may supersede the root's geotropic response, and will cause the roots to grow back into the growing medium.

Hydrotropism is the growing of roots towards a source of water. The explanation of this tropism has not been found, but it can be shown to occur. The **cotyledons** that emerge from the testa contribute to the growth of the seedling in photosynthesis, but the **true leaves** of the plant, which often have a different appearance to the cotyledon, very quickly unfold.

Apical dominance

After the germination of the seed, the plumule establishes a direction of growth, due partly to the geotropic and phototropic forces acting on it. Often the terminal bud of the main stem sustains the major growth pattern, while the axillary buds are inhibited in growth to a degree that depends on the species.

In tomatoes and chrysanthemums, the lateral shoots have the potential to grow out, but are inhibited by a high concentration of auxin, which accumulates in these buds. The source of the chemical is the terminal bud, which maintains the inhibition. In commercial chrysanthemum production, the removal of the main shoot (stopping) is a common practice. It takes away the auxin supply to the axillary buds, which are then able to grow out to create a larger, more balanced inflorescence. Conversely, the practice of **disbudding** in chrysanthemums and carnations, takes out the axillary buds to allow the terminal bud to develop into a bigger bloom that benefits from the greater food availability.

Conditions for early plant growth

Many plant species are propagated in glasshouses. A few principles are described here to help ensure success. Seed trays should be thoroughly cleaned to prevent the occurrence of diseases such as 'damping off' (see p246). Fresh growing medium should be used for these tiny plants that have little resistance to disease. Compost low in soluble fertilizer is less likely to scorch young plants. Compost should be firmed down in containers to provide closer contact with the developing root system.

With very small seed there is a danger that too many seeds are sown together, with the result that the seedlings intertwine and are hard to separate. This problem can often be avoided by diluting batches of very small seed with some fine sand before sowing. Small seed samples need to be sown on the surface of the compost and then covered with only a fine sprinkling of compost. In this way, their limited food reserves are not overtaxed as they struggle through the compost to reach the light.

Water quality is important with young plants. Mains water is recommended, as it will be free from diseases. Water butts and reservoirs need particular scrutiny to avoid problems. Water that has been left to reach the ambient temperature of the glasshouse is less likely to harm seedlings. The compost in seed trays should be kept permanently moist (but not waterlogged), as seedling roots dry out easily. Glass or plastic covers placed over seed trays will help prevent moisture loss, and these can be removed when root establishment has occurred and seedlings are pushing against the covers.

As soon as seedlings have expanded their cotyledon leaves, they should be carefully transferred ('pricked off') from the seed tray and placed in another tray filled with compost having higher levels of fertility. The seedlings should be spaced at approximately 2.5 cm intervals, thus providing a root volume for increased growth. Later, plants will be transferred to pots ('potted-on') to allow for further growth.

Plants growing in glasshouses are tender. The cuticle covering leaves and stems is very thin. Growth is rapid and the stem's mechanical strength is likely to be dependant on tissues such as collenchyma and parenchyma rather than the sturdier xylem vessels (see p92). When a plant is transferred from a glasshouse to cooler, windier outside conditions (for example in spring), it may become stressed, lose leaves and stop growing. It is advisable to 'harden off' plants before this stressful exposure. Reducing heat and increasing ventilation in the glasshouse are two ways of achieving this aim. Traditionally plants were moved out into cold frames to gradually expose them to the conditions into which they are to be planted. Moving plants out during the day and back inside overnight for a number of weeks, is another strategy.

The vegetative plant

The role of the vegetative stage in the life cycle of the plant is to grow rapidly and establish the individual in competition with others. It must therefore photosynthesize effectively and be capable of responding to good growing conditions. Growing rooms with near-ideal conditions of light, temperature and carbon dioxide utilize this capacity that will reduce with the ageing of the plant (see Chapter 8).

Juvenility

The **juvenile** stage is a period after germination that is capable of rapid vegetative growth and is unlikely to flower.

The early growth stage of the plant, **juvenile** growth, is characterized by certain physical appearances and activities that are different from those found in the later stages or in **adult** growth. Often leaf shapes vary; e.g. the juvenile ivy leaf is three-lobed while the adult leaf is more oval, as shown in Figure 11.4. The habit of the plant is also different; the juvenile stem of ivy tends to grow horizontally and is vegetative in nature, while the adult growth is vertical and bears flowers. Other examples are common in conifer species where the complete appearance of the plant is altered by the change in leaf form, for example, *Chamaecyparis fletcheri* and many *Juniperus* species such as *J. chinensis*. In the genera *Chamaecyparis* and *Thuja*, the juvenile condition can be achieved permanently by repeated vegetative propagation producing plants called **retinospores**, which are used as decorative features.

Figure 11.4 **Juvenile** growth on left, showing adventitious roots and lobed leaf, **adult** growth on right showing flowers and entire leaf, in ivy (Hedera helix)

Leaf retention is also a characteristic of juvenility. It can be significant in species such as beech (see Figure 11.5), where the phenomenon is exaggerated, and the trees can be pruned back to the vegetative growth. This can create additional protection in **windbreaks** although the barrier created tends to be too solid to provide the ideal wind protection (see p38).

Many species that require an environmental change to stimulate flower initiation, such as the Brassicas that require a cold period, will not respond to the stimulus until the juvenile period is over; about eleven weeks in Brussels sprouts.

The adult stage essential for sexual reproduction is less useful for vegetative propagation than the responsive juvenile growth, a condition due probably to the hormonal balance in the tissues. Figure 11.4 shows the spontaneous production of adventitious roots on the ivy stem. Adult growth should be removed from **stock plants** (see p174) to leave the more successful juvenile growth for cutting.

Figure 11.5 **Leaf retention** in the lower **juvenile** branches of beech (*Fagus sylvatica*); compare with the bare adult branches

The ability of the plant to reproduce vegetatively is widely used in horticulture and these methods, both natural and artificial, are detailed in Chapter 12.

Vegetative propagation

Although the life cycle of most plants leads to sexual reproduction, **all plants have the potential to reproduce asexually or by vegetative propagation, when pieces of the parent plant are removed and develop into a wholly independent plant**. All living cells contain a nucleus with a complete set of genetical information (*see* genetic code, Chapter 10), with the potential to become any specialized cell type. Only part of the total information is brought into operation at any one time and position in the plant.

If parts of the plant are removed, then cells lose their orientation in the whole plant and are able to produce organs in positions not found in the usual organization. These are described as **adventitious** and can, for example, be roots on a stem cutting, buds on a piece of root, or roots and buds on a piece of leaf used for vegetative propagation. Many plant species use the ability for vegetative propagation in their normal pattern of development, in order to increase the number of individuals of the species in the population. The production of these vegetative **propagules**, as with the production of seed, is often the means by which the plant survives adverse conditions (*see* overwintering), acting as a food store which will provide for the renewed growth when it begins. The stored energy in the swollen tap roots of dock and dandelion enable these plants to compete more effectively with seedlings of other weed and crop species, which would also apply to roots of *Gypsophila paniculata*, carrots and beetroot.

Stems are telescoped in the form of a **corm** in freesia and cyclamen, or swollen into a **tuber** in potato, or a horizontally growing underground **rhizome** in iris and couch grass. Leaves expanded with food may

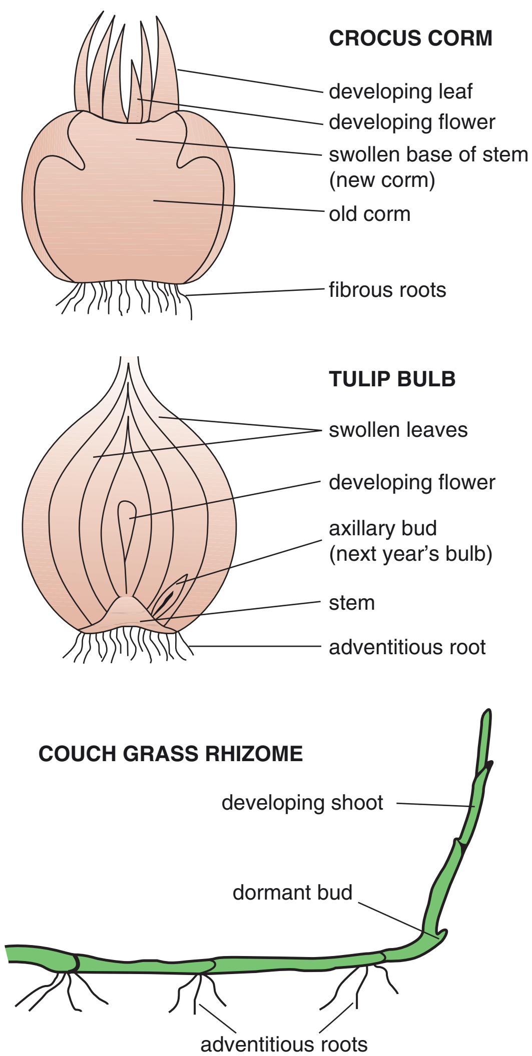

Figure 11.6 **Structure of organs** responsible for over-wintering and vegetative propagation

form a large bud or **offset** found in lilies. A **bulb**, as seen in daffodils, tulips, and onions, is largely composed of succulent white leaves enveloping the much reduced stem, found at the base of the bulb (see Figure 11.6).

Other natural means of propagation include lateral stems, which grow horizontally on the soil surface to produce nodal, adventitious roots and subsequently plantlets, e.g. **runners** or **stolons** of strawberries and yarrow. The adventitious nature of stems is exploited when they are deliberately bent to touch the ground, or enclosed in compost, in the method known as **layering**, used in carnations, some apple rootstocks, many deciduous shrubs such as *Forsythia*, and pot plants such as *Ficus* and *Dieffenbachia*. The roots of species, especially in the Rosaceae family, are able to produce underground adventitious buds that grow into aerial stems or **suckers**, e.g. pears, raspberries. By all these methods of runners, layering and suckers, the newly developing plant (**propagule**) will subsequently become detached from the parent plant by the disintegration of the connecting stem or root.

Growth retardation

Stem extension growth is controlled by auxins produced by the plant and also by gibberellins that can dramatically increase stem length, especially when externally applied. Growth retardation may be desirable, especially in the production of compact pot plants from species that would normally have long stems, e.g. chrysanthemums, tulips and *Azaleas*. Therefore, artificial chemicals, such as daminozide (Figure 11.7), which inhibit the action of the growth promoting hormones can retard the development of the main stem and also stimulate the growth of side shoots to produce a bushier, more compact plant. Flower production may be inhibited but this can be countered by the application of flower stimulating chemicals.

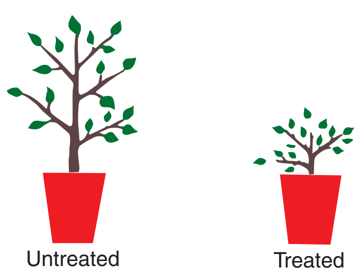

Figure 11.7 **Chemical growth retardant** is incorporated into compost used for pot plants such as chrysanthemum

Pruning

Parts of plants can be **pruned** (removed) to reduce the competition within the plant for the available resources. In this way, the plant is encouraged to grow, flower or fruit in a way the horticulturist requires. A reduction in the number of flower buds of, for example, chrysanthemum, will cause the remaining buds to develop into larger flowers; a reduction in fruiting buds of apple trees will produce bigger apples, and the reduction in branches of soft fruit and ornamental shrubs will allow the plants to grow stronger when planted densely. Pruning will also affect the shape of the plant, as meristems previously inhibited by apical dominance will begin to develop. The success of such pruning depends very much on the skill of the operator, as a good knowledge of the species habit is required.

A few general principles apply to most **pruning** situations:

- **Young** plants should be trained in a way that will reflect the eventual shape of the more mature plant (formative pruning). For example a young apple tree (called a 'maiden') can be pruned to have one dominant 'leader' shoot, which will give rise to a taller, more slender shape. Alternative pruning strategies will lead to quite different plant shapes. Pruning back all branches in the first few years forms a bush apple. A cordon is a plant where there is a leader shoot, often trained at 45 degrees to the ground, with all side shoots pruned back to one or two buds. Cordon fruit bushes are usually grown against walls or fences. Similarly, fans and espalier forms can be developed.
- The **pruning cut** should be made just above a bud that points in the required direction (usually to the outside of the plant). In this way, the plant is less likely to acquire too dense growth in its centre.
- **Pruning should remove any shoots that are crossing**, as they will lead to dense growth. Some plants, such as roses and gooseberries, are made less susceptible to disease attack by the creation of an open centre to produce a more buoyant (less humid) atmosphere.
- **Weak shoots should be pruned the hardest** where growth within the plant is uneven and strong shoots pruned less, since pruning causes a stimulation of growth.
- **Species that flower on the previous year's growth** of wood (e.g. *Forsythia*) should be pruned soon after flowering has stopped. Conversely, species that flower later in the year on the present year's wood, e.g. *Buddleia davidii*, should be pruned the following spring.

Root pruning was used to restrict over-vigorous cultivars, especially in fruit species, but this technique has been largely superseded by the use of dwarfing rootstock grafted onto commercially grown scions. Root pruning is still seen, however, in the growing of Bonsai plants. Pruning is largely concerned with creating the shape of a plant, and controlling apical dominance, but the removal of dead, damaged and diseased parts is also an important aspect.

The flowering plant

The progression from a vegetative to a flowering plant involves profound physical and chemical changes. The stem apex displays a more complex appearance under the microscope as flower initiation occurs, and is followed, usually irreversibly, by the development of a flower. The stimulus for this change may simply be genetically derived, but often an environmental stimulus is required which links flowering to an appropriate season.

Photoperiodism is a day length stimulated developmental response by the plant.

Photoperiodism

Photoperiodism is a term used to describe the plants various responses to day length, explained here in terms of flowering; other responses include bud dormancy and leaf fall.

Many plant species flower at about the same time each year, e.g. in the UK *Magnolia stellata* in April, *Philadelphus delavayi* in June and chrysanthemum in September. In many cases, flowering is in response to the changing day length, which is the most consistent changing environmental factor, in comparison with above-ground temperature which is more variable.

In a day length sensitive species, the flowering process is 'switched on' by a specific period of daylight (or darkness) called its **critical period**. In the chrysanthemum the critical period is sixteen hours of daylight (or eight hours of darkness), which occurs in September in the UK. If repeated over several weeks, the internal structure of the buds begins to change from a vegetative meristem to a flowering meristem (see p00).

The Phytochrome 'Switch'

Since 1920 much research has attempted to explain the photoperiodic flowering response, including using artificial lighting and investigating genetic and biochemical control. Recently, the following stages have been identified, namely switching on at the leaf, mobilizing leaf genes, moving the message from leaf to bud, and developing a flowering meristem. The first stage represents one of the best examples of the horticulturist manipulating the biology of the plant and an understanding of the science has enabled the grower to control the flowering process with the consequent valuable worldwide industry of year-round flower production. **Phytochrome** is the chemical produced by the plant to operate the switching mechanism.

Phytochrome is a large blue-coloured molecule (molecular weight about 125 000). It is made up of two relatively small colour-sensitive sub-molecules (chromophores) and two very long protein chains. It is thought that the chromophores change their shape in response to light, and that this vital 'day-length message' is passed through the proteins to the next stage in the flowering sequence described. Investigations of phytochrome suggest that, in addition to its involvement in the flowering stimulus, the chemical is used in as many as 24 other light-induced reactions ranging from opening a seed's plumule hook as it emerges from the soil (see p154) to increasing the respiration rate of cells.

A two-way chemical process is involved, requiring a different light colour for each direction. Phytochrome Pr660 is sensitive to red light of wavelength 660 nm, found in daylight from dawn to dusk. Pr660 is changed to a less stable form of phytochrome (Pfr730) after a days' exposure. Pfr730 refers to phytochrome as far red light, is found in shaded conditions and is the form which brings about the plant response.

Day length sensitive plants respond to changing seasons as either **long day plants** or short day plants. In species such as Hosta, sweet pea, Lobelia and radish, long days are essential for flowering, while the flowering of carnations and snapdragons, among others, is improved. In these species, the presence of Pfr730 in a concentration above a critical limit results in the promotion of flowering, because the summer nights are not long enough to allow sufficient Pfr730 to revert back to Pr660. A more accurate term here therefore would be 'short night plant'.

- **Day neutral** species are switched on to flowering by a range of situations involving plant size and development and temperature, e.g. Begonia elatior and tomato.

- **Short day plants**, e.g. chrysanthemum, poinsettia and kalanchoe, respond differently in that the presence of Pfr730 above a critical limit inhibits flowering. In chrysanthemum the critical period of dark is eight hours and this condition over a period of several weeks will induce flowering. To enable all-year-round production as cut flowers and pot plants, the day length manipulation is sophisticated. Immature plants must initially be prevented from flowering, then flower buds must later be induced, often at a time of year when the natural day length would not be suitable.

Artificial control of flowering

A long night may be broken artificially using a technique called **night-break lighting**. Incandescent tungsten bulbs produce a high proportion of red light and are cheap to run. Hung about 1 m above the crop and spaced to give about 150 lux for four hours ensures that the Pfr730 critical level is not reached. **Cyclic lighting** saves electricity and uses a series of brief alternating light and dark cycles to replace one continuous break. High pressure sodium lamps are used where they are installed for supplementary lighting (see p114), this saves expense in providing two systems. Crops such as chrysanthemums can be induced to flower in the summer by imposing a long night regime artificially, using opaque black cloth or plastic curtains to cover the crop (see Figure 11.8). A night of nine to fifteen hours causes the Pfr730 level to drop below the critical limit and the flowering process to be initiated.

Figure 11.8 **Daylength control** provided by blackout curtains to control flowering in chrysanthemum.

Flower initiation

Flower initiation can be stimulated largely by photoperiodic or temperature changes, or a complex interaction between temperature and day length. Cold temperatures experienced during the winter bring about flower initiation (i.e. **vernalization**) in many biennial species such as *Brassica*, lettuce, red beet, *Lunaria* and onion. The period for the response depends on the exact temperature, as with budbreak and seed dormancy (see stratification). The optimum temperature for many of these responses is about 4°C. Hormones are involved in causing the flower apex to be produced. The balance of auxins, gibberellins and cytokinins is important, but some species respond to artificial treatment of one type of chemical; for example, the day length requirement for chrysanthemum plants can be partly replaced by gibberellic acid sprays.

Extended flower life

The flower opens to expose the organs for sexual reproduction. The life of the flower is limited to the time needed for pollination and fertilization, but it is often commercially desirable to extend the life of a cut flower or flowering pot plant. In cut flowers, water uptake must be maintained and dissolved nutrients for opening the flower bud are termed an **opening solution**.

Vase life can be extended by the addition of sterilants and sugar to the water. A **sterilant**, e.g. silver nitrate, in the water can reduce the risk of blockage of xylem by bacterial or fungal growth. **Ethylene** has a considerable effect on flower development, and can bring about premature death (**senescence**) of the flower after it begins to open. Cut flowers should therefore never be stored near to fruit, e.g. apples or bananas, which produce ethylene. Some chemicals, such as sodium thiosulphate, reduce the production of ethylene in carnations and therefore extend their life.

Removal of dead flowers

The removal of dead flowers, an activity called **dead-heading**, is an effective way to help maintain the appearance of a garden border. Examples of species needing this procedure are seen in bedding plants which flower over several months, e.g. African Marigold (*Tagetes erecta*); in herbaceous perennials, e.g. Delphinium and Lupin; in small shrubs, e.g. *Penstemon fruticosus*; and in climbers, e.g. sweet pea and *Rosa* 'Pink Perpetue'. As flowers age, they begin to use up a considerable amount of the plant's energy in the production of fruits. Also, hormones produced by the fruit inhibit flower development. With species such as those mentioned above, the maturation of fruits will considerably reduce the plant's ability to continue producing flowers. The act of dead-heading, therefore, will greatly improve subsequent flowering. An added bonus is that plants that have been dead-headed may continue to flower many weeks longer than those allowed to retain their dead flowers.

Many species such as Wax Begonia (Begonia *x semperflorens-cultorum*), and Busy Lizzie (*Impatiens wallerana*) used as bedding plants have been specially bred as F1 hybrids (see p144) where, in this case, flowers do not produce fruits containing viable seed. In such cases, there is not such a great need to deadhead, but this activity will help prevent unsightly rotting brown petals from spoiling the appearance of foliage and newly-produced flowers.

The ageing plant

At the end of an annual plant's life, or the growing season of perennial plants, a number of changes take place. The changes in colour associated with autumn are due to pigments that develop in the leaves and stems and are revealed as the chlorophyll (green) is broken down and absorbed by the plant.

Pigments are substances that are capable of absorbing light; they also reflect certain wavelengths of light which determine the colour of the pigment. In the actively growing plant, chlorophyll, which reflects mainly green light, is produced in considerable amounts, and therefore the plant, especially the leaves, appears predominantly green. Other pigments are present; e.g. the carotenoids (yellow) and xanthophylls (red), but usually the quantities are so small as to be masked by the chlorophyll. In some species, e.g. copper beech (*Fagus sylvat-ica*) other pigments predominate, masking chlorophyll. These pigments also occur in many species of deciduous plants at the end of the growing season, when chlorophyll synthesis ceases prior to the abscission of the leaves. Many colours are displayed in the leaves at this time in such species as *Acer platanoides*, turning gold and red, *Prunus cerasifera* 'Pissardii' with light purple leaves, European larch with yellow leaves, Virginia creeper (*Parthenocissus* and *Vitus spp*.) with red leaves, beech with brown leaves, *Cotoneaster* and *Pyracantha* with coloured berries, and *Cornus* species, which have coloured stems. These are used in **autumn colour** displays at a time when fewer flowering plants are seen outdoors (see Figure 11.9).

In deciduous woody species the leaves drop in the process of **abscission**, which may be triggered by shortening of the day length. In order to reduce risk of water loss from the remaining leaf scar, a corky layer is formed before the leaf falls. Auxin production in the leaf is reduced, this stimulates the formation of the abscission layer, and abscisic acid is involved in the process. Auxin sprays can be used to achieve a premature leaf fall in nursery stock plants thus enabling the early lifting of bare-root plants. Ethylene inhibits the action of auxin, and can therefore also cause premature leaf fall, for example, in *Hydrangea* prior to cold treatment for flower initiation.

(a)

(b)

(c)

Figure 11.9 **Autumn colour** in (a) Blueberry, (b) *Viburnum* and (c) *Photinia*, showing loss of chlorophyll and emergence of xanthophylls.

Check your learning

1. Describe the factors which affect seed germination.
2. Define the terms epigeal, hypogeal, dormancy and viability.
3. Describe the process of phototropism.
4. Define the term photoperiodism.
5. Describe two plant growth responses to auxin.

Further reading

Bleasdale, J.K.A. (1983). *Plant Physiology in Relation to Horticulture*. Macmillan.
Cushnie, J. (2007). *How to Prune*. Kyle Cathie.
Gardner, R.J. (1993). *The Grafter's Handbook*. Cassell.
Hart, J.W. (1990). *Plant Tropisms and Other Growth Movements*. Unwin Hyman.
Hartman, H.T. *et al.* (1990). *Plant Propagation, Principles and Practice*. Prentice-Hall.
Leopold, A.C. (1977). *Plant Growth and Development*. 2nd edn. McGraw-Hill.
Machin, B. (1983). *Year-round Chrysanthemums*. Grower Publications.
MAFF. *Quality in Seeds*. Advisory Leaflet 247.
MAFF (1979). *Guide to the Seed Regulations*. (HMSO).
Stanley, J. and Toogood, A. (1981). *The Modern Nurseryman*. Faber.
Taiz, L. and Zeiger, E. (2006). *Plant Physiology*. Sinauer Associates.
Thomas, B. and Vince-Prue, D. (1996). *Photoperiodism in Plants*. Academic Press.
Wareing, P.F. and Phillips, I.D.J. (1981). *The Control of Growth and Differentiation in Plants*. Pergamon.

Chapter 12 Plant propagation

Summary

This chapter includes the following topics:

- **Seed propagation**
- **Dormancy**
- **Vegetative propagation**
- **Comparison between seed and vegetative propagation**
- **Budding and grafting**

with additional information on the following:

- **Tissue culture**

Figure 12.1 Bedding plants

A plant's life cycle can be seen to end with the process of senescence (p163) and dying. The time taken to get to this point varies enormously from one species to another with many ephemerals living for only a few months, whereas many trees last for hundreds of years. Before it dies the plant has normally ensured continued life by either sexual or asexual reproduction: not many plants employ both methods to produce offspring. Sexual reproduction leads to the formation of seeds in higher plants (see p67). The ability of plants to reproduce asexually is used in horticulture as vegetative propagation.

Seed propagation

Most plants reproduce sexually, which leads to the formation of seeds (see p103). By the nature of this process the seeds produced show a **variation** in characteristics to a greater or lesser extent. Typically plants produced from seed will not be uniform in their growth and will exhibit differences in size, flower colour, etc. This variation can be controlled by skilled plant breeders (see p144) to the extent that a high degree of uniformity can be achieved in bedding, e.g. for flower colour, and vegetable seeds, e.g. for size and 'once over harvesting' (see hybrids p144).

Sexual reproduction is the production of new individuals by the fusion of a nucleus from the male (in pollen) and that of a female (in the ovule) to form a zygote (see Chapters 7 and 10).

Seeds germinate when provided with the right conditions regarding:

- water
- air (oxygen)
- temperature

and, for some, an exposure to light, or, for others, an absence of light, as described in detail in Chapter 11 (see p150). In some cases germination will not take place even if otherwise favourable conditions prevail (consider the seeds that fall into the warm, moist soil in the autumn but do not germinate until the following spring or later). These seeds are exhibiting dormancy, which has to be broken to allow germination to occur (see p150). This is a survival mechanism that helps prevent the seed start germinating just when conditions are about to become unfavourable for growth.

Physical dormancy is a mechanism, such as a hard seed coat, which has to be broken before water and oxygen can get in. Rather than wait, growers can speed up the process by **scarification**, e.g. sand papering or filing the coat; 'chipping' or 'nicking' it with a knife or, as in the trade, by adding acids. Water can then get in quickly through the thin or damaged seed coat and start the germination process. For many seeds simply adding hot water is sufficient to remove the waterproofing qualities of the seed and let water in.

Physiological dormancy includes the effect of abscisic acid in the dry seed which inhibits development of the embryo. Germination cannot begin until its concentration is reduced. In temperate areas an exposure to prolonged cold gradually destroys the inhibitor. Growers can overcome this mechanism by exposing the seed to cold artificially. **Stratification** is the usual method of overcoming this form of dormancy. The seeds are placed in layers of moist sphagnum moss and grit within a polythene bag. The seeds are allowed to take up water in the warm, but once swollen the bag and its contents are chilled but not frozen. For some species, they are ready to germinate after a month, others take much longer. Once the dormancy of most species is broken they do not develop further until all the normal requirements for germination are met. Care needs to be taken because some species start to germinate once their chilling period has been experienced.

Many seeds develop dormancy on storage. It is possible to avoid the problem by sowing 'green' seed. Seed can be collected when it is mature and with adequate food reserves, but before the dormancy mechanisms become established (soft seed coat, low abscisic acid), and sown straight away.

Purchasing seeds, especially vegetable and flower seeds, has the advantage of convenience and the protection of the regulations (see p152). A check of the date should always be made to ensure that the seeds are from the last seed harvest. The seeds are usually supplied in foil packets. Once opened the seeds deteriorate rapidly so should be sown immediately but, so long as they are kept dry and cold in a resealed packet, most seeds will remain viable for a year and some, often the larger seeds, for many years (see p168).

There are difficulties when it comes to seeds from trees or shrubs because there are fewer regulations to protect the buyer. In the preparation of seeds for sale, the drying process used often:

- increases the dormancy effect (harder coats);
- adversely affects the energy reserves;
- damages the embryo;

so reducing seed viability (see p152).

Seeds, especially finer ones, are often coated (with a clay) to make sowing easier and more precise. This **pelleted seed** can help reduce wastage. Likewise, water-soluble seed tapes can be used. A gel (or wallpaper paste) containing seeds can be used for **fluid drilling**; the gel is squeezed out of a plastic bag like icing a cake. Some seeds that are difficult to germinate can be **primed**; the germination process is started but then arrested. The dried seed purchased can be drilled or sown as normal and rapid and reliable germination follows.

Collecting seed can prove to be cheaper. Although there are attractions in keeping their **own seed**, growers need to be aware of difficulties associated with seed variation (see p144) and the risk of disease (see p147). Seed collectors can ensure they take the seed at the ideal time, especially when the intention is to avoid dormancy problems, and care can be taken in drying so as to minimize loss of viability. Where the hardiness of the plant is in doubt then, although a hardy parent does not always produce hardy seed, the chances of success are raised by taking seed from a known hardy specimen. There are other advantages, particularly when it comes to trees and shrubs, because seed can be taken from desirable forms, beneficial even though there will be variation in the offspring.

The majority of seed should be collected as they ripen. Seed in dry fruits should be collected on a dry day. It should be noted that when enclosed in a fruit, the seed is ready to collect before the fruit matures ready for dispersal. A collecting bag, plastic rather than cloth, to keep hands free is an advantage and it is essential to label samples with the name of the plant and from where collected. The seeds should be kept in small batches and kept cool (to prevent the embryo from heating up). The seed should be prepared for stratification and/or sown as quickly as possible for maximum benefit.

Dry seed needs to be prepared from the material collected. Flower stems can be tied lightly then hung upside down in a dry place with a brown paper bag over them; shake from time to time to collect the seed. Large seed heads should be broken up into trays on paper and left to dry. Cones or small seed heads collected when nearly dry should be placed in an open paper bag and left to complete their drying gently. The flesh of fruits, which often contains germination inhibitor, should have the majority of the flesh removed before being squeezed through a sieve with a presser board. The seeds with any remaining flesh should then be put in a jar of warm water and soaked for a few days after which the water is poured off. This is repeated until the flesh has been removed. The remaining skin is then picked off and the seeds dried. Sieves can be used to remove any superfluous pieces before putting the seed into paper packets ready for sowing.

Storing seed which is to be used within a few days requires little more than keeping them at room temperature in a polythene bag to maintain the moisture levels at which they were collected. If they are to be kept for a few weeks then the seeds need to be stored cool, but not frozen. Seed to be stored for longer periods than this, as when commercially produced for sale, is dried, placed in air proof packets (commonly foil), vacuumed to remove air and kept cool. Some of the large fleshy seeds, such as lilies and hellebores, are best left to mature and collected before they are dispersed. Other seed such as anemones is collected and sown ‘green’, i.e. before maturing.

Sowing and aftercare in protected environments

The ideal conditions for raising plants from seed can be achieved in a protected environment such as a glasshouse or cheaper alternatives such as polythene tunnels or cold frames (see p16).

Most seeds grown in protected culture are sown into **containers** (see Figure 12.2):

- seed trays
- half trays

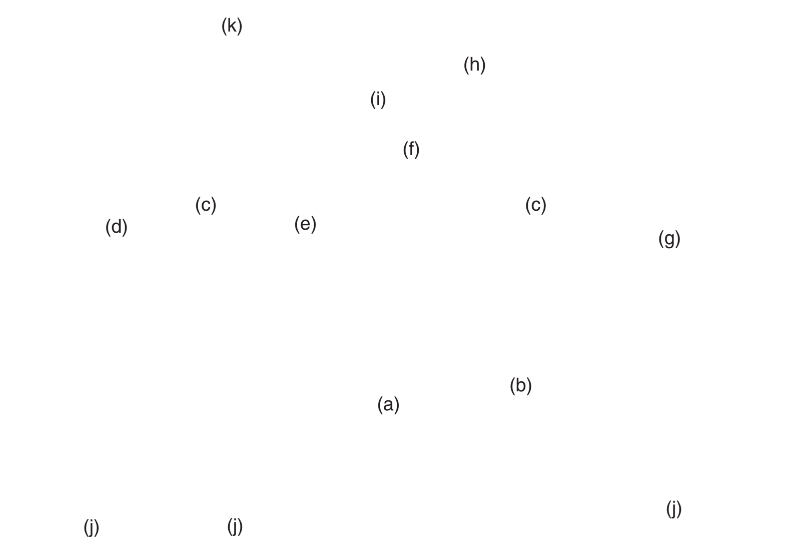

Figure 12.2 **Range of containers for growing plants**: (a) traditional clay pots (b) standard seed tray and half tray (c) standard plastic pots in range of sizes, compared with (d) 'long toms' and (e) half pots (f) biodegradable pots (g) compressed blocks (h) square or (i) round pots in trays (j) various 'strips' in trays and (k) typical commercial polystyrene bedding plant tray.

- pots (as deep as wide)
- pans ('half pots')
- long toms.

These must have adequate drainage to allow excess water out or for the water in the capillary matting to pass into the compost (see p392). Square shapes utilize space better, but are harder to fill properly in the corners. Although more expensive, rigid plastic is easier to manage. Rims on containers give more rigidity and make them easier to stack. Gardeners can make use of plastic food containers so long as they are given sufficient drainage holes. All containers should be clean before use (see hygiene p269). There are also disposable pots made of compressed organic matter, paper or 'whalehide' through which roots will emerge, which makes them useful for the planting out stage.

For production horticulture there is a wider range of materials, including polystyrene, for once only use; cost and presentation of the plants becomes the main consideration. Too large a container is a waste of compost and space whereas one that is too small can lead to the seedlings having to be spaced out before they are ready; if left they become overcrowded and susceptible to damping off diseases (see p246).

Seed composts are commonly equal parts peat and sand mixes with lime and a source of phosphate. **Potting composts** into which seedlings are transferred and young plants established tend to have a higher proportion of peat with lime and a full range of nutrients. Many advocate the use of sterilized loam which makes the compost easier to manage and increasingly alternatives to peat are being utilized (see compost mixes, p390).

Sowing seeds. The container is generously overfilled with seed compost. Care is taken to ensure that there are no air pockets by tapping on the bench and the corners are fully filled. With a sawing action across the container top, the surplus compost is 'struck off' using a straight edge. The compost is then lightly firmed to just below the rim of the container using an appropriately sized presser board. Seeds are then sown on the surface at the rate recommended. Many advocate that when using trays, half the seed is sown then, to achieve an even distribution, the other half is sown after turning the container through 90 degrees. The seeds are then covered with sieved compost or fine grade vermiculite to their own thickness. Finer seeds are often sown in equal parts of fine dry sand to help distribution, lightly pressed into the surface and then left uncovered. Larger or pelleted seed tends to be 'space or station sown' i.e. placed at recommended distances in a uniform manner.

The seeds are then labelled with name of plant and the sowing date. The compost is then watered either from above gently, with a fine rose, or by standing the container in water. A fungicide can be added to the water to protect against damping off diseases. The moist conditions around the seed must be maintained and this is most easily done by covering with a sheet of glass, clear plastic or kitchen film. The container should be kept in a warm place (approximately 20°C). If necessary, a sheet of paper can be used to shade the seeds from the direct sunlight or to minimize temperature fluctuations. There are advantages in placing the seed containers in a closed propagator (see p176). Covers on the container should be removed as soon as the seedlings appear and they must now be well lit to avoid etiolating (see p153), but not exposed to strong sunlight. Watering must be maintained, but without waterlogging the compost. In production horticulture much of the work is done by machines. Pots are rarely filled by hand and increasingly the whole process is automated, including the seed sowing.

Pricking out. When the seedlings are large enough to be handled, they should be transplanted into potting compost prepared as for the seed tray. Each seedling is eased with a dibber, lifted by the seed leaves, dropped into a hole made in the new compost, gently firmed and watered in. The seedlings are normally planted in rows with space, typically 24 to 40 per seed tray, for them to grow on to the next stage.

Many will be planted out when ready, but others will continue in pots and as they need more space they are '**potted off**' (moved into another container). Those continuing in containers are '**potted on**' when they outgrow their container. As they are moved to the next size container, the compost, especially the nutrient level, is chosen to suit the stage reached (see JIP p386).

Hardening off is required to ensure that the seedlings raised in a protected environment can be put out into the open ground without a check in growth caused by the colder conditions, wind chill and variable water supply. As the pricked off seedlings become established they are moved to a cooler situation, typically a cold frame, which starts the process of hardening off by providing a closed environment without heat. After a few weeks the cold frame is opened up a little by day and closed at night. If tender plants are threatened by cold or frosts they can be given extra protection in the form of easily handled insulation such as bubble wrap or coir matting put over the frame. Watering has to be continued and usually the plants will use up the fertilizer in the compost and need applications of liquid fertilizer. The hardening process then continues with the frame lid ('light') gradually being opened up more to allow air circulation day and night. Ideally the plants have been fully exposed to the outdoor conditions by the time it is ready to plant them out.

The young plants are very susceptible to fungal diseases while in the frame because of the high density of planting and the difficulty with keeping the humidity level right. The need to maintain air circulation is essential as the opportunity arises. Excessive feeding with high nitrogen fertilizers should also be avoided because it can create soft growth which makes them vulnerable to disease and excessively soft and vigorous plants can be checked on planting out.

Bedding plants (see Figure 12.1) are raised as described above with the sequence geared to producing the plants ready to plant out at the right time. For this, the time when required and the growth rates of the selected plants needs to be known. Usually the seeds are sown into seed trays or pans with very lightly firmed peat compost. Care should be taken to avoid waterlogging in shallow containers (see p385) which leads to the seeds rotting off, poor seedling development, attack from sciarid fly (see p218) or fungal diseases (see p246). There are methods of raising plants from seed without containers by using blocks of compressed peat (see p393). Larger seeds can be sown into rockwool modules to create 'plug plants' (see p393).

Sowing in the open

The success of sowing outdoors depends greatly on preparing the seedbed; the tilth needs to be matched to the type of seed, soil texture and the expected weather conditions (see p313). The area to be prepared should be free draining. It is thoroughly dug or ploughed depending on the scale of operation. Weeds are buried and organic matter is incorporated in the process. Ideally this is done in the autumn especially if it is a heavy soil; the raw soil is then exposed to the action of frost and rain (see p312). In the spring the mellow, weathered, soil is knocked down with rake or harrow to form the right tilth that provides water and oxygen for seed germination; broad beans can be sown into a very rough seedbed very early in the spring whereas smaller seed sown into warmer conditions should go into a much finer tilth.

Weeds need to be dealt with by creating a false or stale seedbed (see p191), hoeing or using weedkillers. Nutrients, especially phosphate fertilizer, are worked in and the ground levelled to receive the seed. Seed are usually sown in rows (drills) or broadcast, depending on the circumstances. Some seeds will more appropriately be station sown. On a larger scale, seeds are drilled with appropriate equipment. Seeds should be at the right depth, covered to their own diameter and sown when ground temperatures are suitable for the plants concerned (see p39). The sowing rate will depend on the species and the likely losses, which can be estimated from the field conditions, the germination percentage and the viability of the seed (see p152).

There are advantages to providing protection for the developing plants in the form of windbreaks or floating mulches (see p17). Where residual herbicides are not used there needs to be ongoing control of emerging weeds while they are in competition with the seedlings and young plants. If the seedbed was well watered then there should, normally, be no further need to irrigate; indeed there are advantages in not doing this in terms of water conservation, to encourage deeper rooting and prevent capping of the soil (see p313).

Vegetative propagation

Asexual reproduction is the creation of a new individual by the division of the genetic material and cytoplasm of the parent cell.

Adventitious plant tissues or organs are those growing where they are not usually found on the plant i.e. roots that have not arisen from the radicle in the seed and buds that have not developed from the plumule.

All plants have the potential to reproduce asexually. In plants this practice is known as **vegetative propagation**; pieces of the parent plant are removed and these develop into wholly independent plants (see p157).

All living cells contain a nucleus with a complete set of genetic information (see genetic code, Chapter 10), with the potential to become any specialized cell type (totipotency). Only part of the total information is brought into operation at any one time and for any position in the plant. If parts of the plant are removed, then cells lose their orientation in the whole plant and are able to produce organs in positions not found in the usual organization. These are described as **adventitious** and can, for example, be roots on a stem cutting, buds on a piece of root, or roots and buds on a piece of leaf used for vegetative propagation.

Characteristics of propagation from vegetative parts

Vegetative propagation is used in horticulture to produce numbers of plants from a single parent plant. This group of plants, or **clone**, is an extension of the parent plant and therefore all will have the same genetic characteristics. The greatest advantage for horticulturists is to be able to reproduce a cultivar in which all the resulting plants exhibit consistent characteristics. There are some cultivars that can only be reproduced by vegetative means. Seeds produced without fertilization (i.e. by **apomixis)** found in Alchemilla, Rosaceae, Poaceae and Taraxacum present a special case of natural clonal propagation.

In vegetatively propagated cultivars, changes can occur (see mutations) and differing clonal characteristics within the same cultivar can be distinguished in some species, i.e. 'sports' e.g. the leaf colour and plant habit of × *Cupressocyparis leylandii*.

Natural vegetative propagation (see p157)

Many plant species use their ability for vegetative propagation in their normal pattern of development (see vegetative propagation p172). The production of these vegetative **propagules**, as with the production of seed, is to increase numbers and provide a means by which the plant survives adverse conditions. The energy storage for this purpose makes them attractive as food for us, e.g. potatoes, onions, carrots.

All vegetative propagation is a form of division that has been exploited by mankind for a very long time. In many cases little more than breaking up the plant or taking the natural propagules is involved.

Divisions

Most gardeners will be familiar with dividing **herbaceous perennials**. This usually arises because the shoots become overcrowded and the thick clumps that develop often have woody or bare centres. Borders are rejuvenated by carefully lifting the clump ('crown'), preferably with a ball of soil, teasing off most of the soil carefully from the roots and splitting it with back to back forks for good leverage. Whilst smaller specimens can be pulled apart by hand, some are so tough as to require knives or spades. This division can be undertaken in the autumn as plants die down, but is usually better done in the spring as the new shoots appear. The younger sections with strong shoots can be replanted in prepared ground (normally with many surplus pieces to give away or sell). This should be done before the roots have dried and the plants are then watered in.

Alpines (cushions, carpets, mat formers, rosette types) lend themselves to increase by division which is popular because it is cheap, simple and quick. Commonly the divisions are made in mid-spring as the plants begin to grow and they establish most easily. The only problem for gardeners is that it rather spoils the rock garden if separate stocks are not kept; they can restrict themselves to taking rooted pieces from the edge of the clump. Whilst gardeners can plant these straight into the garden, commercially they are grown on in pots until an attractive plant is produced. This is enhanced by the addition of a suitable grit on the surface of the compost.

Aquatic plants can be dealt with in essentially the same way as herbaceous perennials. **Water lilies** are usually lifted in late spring and the growing shoot (the 'eye') is cut away with a piece of the tuber and some root. These pieces are firmed into a pot or basket containing a minimum of sieved clay loam and powdered charcoal and grown on with the water level at the rim. **Marginals** such as reed mace and sweet flag are divided in late spring. The pieces are cleaned up of excess and dying leaves before replanting. **Submerged plants** (oxygenators) tend to be vigorous and need to be reduced on a regular basis. If more plants are wanted then pieces broken off can be tied in bundles with wire and returned to the water.

House plants that develop clumps such as *Maranta*, spider plants (*Chlorophytum*), African violets (*Saintpaulia*) and mother-in-law's-tongue (*Sansevieria*) can be propagated by divisions. This can usually be done by breaking the clump with the fingers to minimize damage to the roots, with help from a knife only to get started if too tough. The pieces are put into a pot just big enough to take the roots with potting compost. Care needs to be taken to fill without leaving cavities by constantly tapping the pot on the bench as it is filled. The plants need to be given a warm environment, ideally in a propagator unit or polythene bag, which will help reduce water losses until established.

Suckers produced by many trees and shrubs can be a problem as they divert energy from the main purpose of the plant and make a messy area around the base. However, they can be used as a source of new plants in the case of many, such as *Rhus typhina*, raspberries and woody house plants or palms. (Suckers arising from grafted material, e.g. roses or apples, will reproduce the rootstock.) Soil from around the base of the plant is removed to expose the point where the suckers can be removed with a knife or pruning shears, ideally with some root attached. Their relatively large size and lack of root means they need to be kept watered until established. They are normally heeled into a trench and in the nursery protection from sun and wind is provided over the next year until there is a good root system.

Rhizomes

Rhizomes such as border irises can be divided as other herbaceous perennials. Again this becomes necessary to get rid of the developing bare patch where the rhizomes grow away from their starting point. Normally about 10 cm of non-woody rhizome is cut off with each fan of leaves. The leaves are reduced to a third to reduce water loss and wind rocking. Some species, such as *Bergenia*, are flowering in the early spring so it is best to lift the plants in mid-winter and remove the rhizomes. These should be washed and the dormant buds found. Sections with a bud can be taken off and rooted in potting compost in trays by burying them horizontally to half their depth. It is advantageous to provide 'bottom heat' by standing the trays on soil warming cables. The plants are not ready to go out until the fibrous roots have emerged from the bottom of the tray and have been 'hardened off'.

Bulbs

Bulbs can yield several plants if divided in an appropriate way. **Scaly bulbs** (see p158) such as lilies and fritillary are propagated by **scaling** whereby the outer scales are pulled off and put in a polythene bag with a suitable moist material such as vermiculite or pushed to half their depth in open propagating compost and covered with polythene. For **tunicate**

bulbs (see p158), such as tulips, the daughter bulbs within the parent bulb can be removed in late summer and grown on in open compost in a warm environment. Bulbs with a tight structure, such as hyacinths and daffodils, are cut into pairs of scales, **twin scaling**. The outer scales are removed and the remaining bulb is cut vertically into several segments. These are then split with a clean knife into pairs of scales with a piece of the base plate and treated as scales. **Chipping** is used with non-scaly bulbs whereby the bulb is simply divided vertically into many pieces, each with a piece of basal plate. For these methods it is important to maintain hygienic conditions and use a suitable fungicide to minimize the introduction of fungal diseases to the cut surfaces.

Artificial methods of propagation

The artificial methods of vegetative propagation encompass most organs of the plant. Cuttings are parts of plants that have been carefully cut away from the parent plant, and which are then used to produce a new plant. Many species can be propagated in this way. Different methods may be necessary for different species. Only healthy parent plants should be used. Hygienic use of knives, compost and containers is strongly recommended. Cuttings are normally taken from parts of the plant exhibiting juvenile growth. Below is a brief description of the most common methods used for taking cuttings.

Cuttings

Stem cuttings can be taken from stems that have attained different stages of maturity. **Hardwood cuttings** are from pieces of dormant woody stem containing a number of buds, which grow out into shoots when dormancy is broken in spring. The base of the cutting is cut cleanly to expose the cambium tissue from which the adventitious roots will grow (e.g. in rose rootstocks, Forsythia, and many deciduous ornamental shrubs). In Hydrangea and currant the stems show evidence of pre-formed adventitious roots (root-initials), which aid the process of root establishment. Hardwood cuttings are normally taken in late autumn (they are 15–25 cm in length), and are often placed with half their length immersed in a growing medium containing half compost and half sand. A 12-month period is often necessary before the cuttings can be lifted.

Semi-ripe cuttings are taken from stems that are just becoming woody. They are normally taken from mid-summer to early autumn. Most cuttings of this kind are 5–10 cm long. Rooting in a sand/compost mixture may be achieved in cold frames or, more quickly, in a heated structure at about 18°C. *Eleagnus* (Oleaster) will root only if heat is provided. Many shrub and tree species, e.g. holly and conifers, are propagated as 'heeled' cuttings. Here, the semi-ripe cutting is taken in such a way that a one centimetre sliver of last year's wood (the **heel)** is still attached. The heel cambium facilitates root formation and, hence, easier establishment of cuttings.

Stems without a woody nature are used for the propagation of plants such as *Fuchsia*, *Pelargonium* and *Chrysanthemum*. These are called **softwood cuttings** (see Figure 12.3), and they are most often taken in late spring and early summer. The area of leaf on these cuttings should be kept to a minimum to reduce water loss. Misting (spraying the plants with fine droplets of water to increase humidity and reduce temperature) can further reduce this risk by slowing down the transpiration rate.

Automatic misting employs a switch attached to a sensitive device used for assessing the evaporation rate from the leaves. The cool conditions favouring the survival of the aerial parts of the cutting, however, do not encourage the division of cells in the cambium area of the root initials. The temperature in the rooting medium may be increased with electric cables producing **bottom heat**. These special conditions for the success of cuttings are provided in propagation benches in a greenhouse.

Figure 12.3 Rooted cuttings

Leaf cuttings are also susceptible to wilting before the essential roots have been formed, and will benefit from mist, provided the wet conditions do not encourage rotting of the plant material. Leaves of plants such as *Begonia*, *Streptocarpus* and *Sansevieria* are divided into pieces from which small plantlets are initiated, while leaves plus petioles are used for *Saintpaulia* propagation. Nursery stock species, e.g. *Camellia* and *Rhododendron*, require a complete leaf and associated axillary bud in a **leaf-bud cutting.**

Root cuttings may be an option when other methods are not seen to succeed. This method is used for species such as *Phlox paniculata* and *Anchusa azurea* (*alkanet*). Roots about a centimetre in thickness are taken in winter and cut into 5 cm lengths. They are inserted vertically into a sand/compost mixture in most species, but thinner-rooted species such as *Phlox* are placed horizontally. It is important that root cuttings are not, inadvertently, placed upside-down, as this will prevent establishment.

Budding and grafting

Grafted plants are commonly used in top-fruit, grapes, roses and amenity shrubs with novel shapes and colours. Rootstocks resistant to soil-borne pests and disease are sometimes used when the desired cultivars would succumb if grown on their own roots, e.g. grapevines, tomatoes and cucumbers grown in border soils. Grafting is not usually attempted in monocotyledons, since they do not produce continuous areas of secondary cambium tissue suitable for successful graft-unions.

Grafting involves the union of a **scion** (portion of stem) with a **rootstock** (root system) taken from another plant. **Budding** is a type of graft that involves inserting a single bud into a stock.

In top fruit, grafting is used for several reasons:

- a grafted plant will establish more quickly than a seedling;
- plants derived from seedlings will show different (usually inferior) qualities of fruiting compared with their commercially useful parent plants so a means of vegetative propagation is advantageous; the cultivars are, therefore, clones derived from one original parent;
- to control the size of the tree through the choice of dwarfing rootstock (see Table 12.1), e.g. the M9 apple rootstock, causes the grafted scion

cultivar to be considerably dwarfed. Reduced levels of auxin and cytokinin in the rootstock possibly, bring this about.

Table 12.1 Fruit rootstock

	Vigorous	Semi-vigorous	Semi-dwarfing	Dwarfing
Apples	MM104	MM106	M26	M9
Pears		Quince A	Quince C	
Plums	Brompton	St Julien A		Pixy

There are numerous grafting methods that have been developed for particular plant species. Several principles common to all methods can be briefly mentioned. Firstly, the scion and stock should be genetically very similar. Secondly, the scion and stock will need to have been carefully cut so that their cambial components are able to come in contact. In this way, there will be a higher likelihood of **callus growth** (resulting from cambial contact), which quickly leads to graft establishment. Thirdly, the graft union should be sealed with grafting tape to maintain the graft contact, to prevent drying-out and to keep out disease organisms such as *Botrytis*. Fourthly, the buds on the stem taken as scion material should, ideally, be dormant (leafy material would quickly dry out). The rootstock should be starting active growth, and thus bring water, minerals, and nutrients to the graft area.

Tissue culture

Tissue culture is a method used for vegetative propagation based on the phenomenon that any part of a plant from a single cell to a whole apical meristem can grow into a whole plant (see totipotency). The explant, the piece of the plant taken, is grown in a sterile artificial medium that supplies all vitamins, mineral and organic nutrients. The medium and explant are enclosed in a sterile jar or tube and subjected to precisely controlled environmental conditions. This method has advantages over conventional propagation techniques, since large numbers of propagules can be produced from one original plant. It has particular value with rare or novel plants. An added advantage is the reduced time taken for bulking up plant stocks. Some species that traditionally propagate only by seed, e.g. orchids and asparagus, can now be grown by this means.

One of the problems of conventional vegetative propagation is that diseases and pests are passed on to the propagules. Disease levels, particularly virus, in their growing tips can be greatly reduced by exposing stock plants to high temperatures. Following this heat-treatment, a **meristem-tip** can be dissected out of the stem and grown in a tissue culture medium, to produce stock that is free from disease (e.g. chrysanthemum stunt viroid, see Chapter 15). This method of propagation is now used for species including *Begonia*, *Alstroemeria*, *Ficus*, *Malus*, *Pelargonium*, Boston fern (*Nephrolepsis exaltata*), roses and many others.

In all the methods described, **cell division** (see mitosis) must be stimulated in order to produce the new tissues and organs. The correct balance of hormones produced by the cells triggers this **initiation**. Auxins are found to stimulate the initiation of adventitious roots of cuttings. In the propagation of cuttings, the bases may be dipped in powder or liquid formulations of auxin-like chemicals such as naphthalene acetic acid to achieve this result. The number of roots is increased and production time reduced. The precise concentration of chemical in the cells is critical in producing the desired growth response. A large amount of hormone can bring about an inhibition of growth rather than promotion. For this reason, manufacturers of **hormone powders** and dips produce several distinct formulations with differing hormone concentrations, relevant to the hardwood, the semi-ripe, and the softwood cutting situations. Also different organs respond to different concentration ranges; e.g. the amount of auxin needed to increase stem growth would inhibit the production of roots. The same principle applies to another group of chemicals important in cell division, the cyto-kinins, which can be applied to increase the incidence of plantlet formation.

Figure 12.4 Tissue Culture

Both auxin and cytokinin must be included in a tissue culture medium, at concentrations appropriate to the species and the type of growth required; the proportions of each determines whether it is roots or stems that are promoted. Short initiation is promoted by a high cytokinin to auxin ratio whereas high auxin to cytokinin ratios favour root initiation. The subsequent weaning of plantlets from their protected environment in tissue culture conditions requires care and usually conditions of high relative humidity, shade and warmth.

Check your learning

1. Compare the production of plants by seed and vegetative propagation with regard to (a) advantages and (b) disadvantages.
2. State the ideal conditions for storing seed for long periods and explain how storage conditions affect the seed.
3. State two types of dormancy in seeds and for each describe how dormancy may be broken.
4. Explain why fruit trees are usually propagated by grafting.
5. State the principles that underlie the practice of tissue culture.

Further reading

Cassells, A.C. and Graham, P.B. (2006). *Dictionary of Plant Tissue Culture*. Haworth Press.
Dirr, M.A. and Heuser, C.W. (2006). *Reference Manual of Woody Plant Propagation from Seed to Tissue Culture*. 2nd edn pb. Varsity Press.
Donnely, D.J. and Vidaver, W.E. (1995). *Glossary of Plant Tissue Culture*. Cassell.
Gardner, R.J. (1993). *The Grafter's Handbook*. Cassell.
Hartman, H.T. *et al.* (1990). *Plant Propagation, Principles and Practice*. Prentice-Hall.
Kyle, L. and Kleyn, J.G. (1996). *Plants from Test Tubes*. 3rd edn. Timber Press.
Macdonald, B. (2006). *Practical Woody Plant Propagation for Nursery Growers*. Timber Press.
McMillan Browse, P. (1979). *Hardy Woody Plants from Seed*. Grower Books.
McMillan Browse, P. (1999). *Plant Propagation*. 3rd edn. Mitchell Beasley.
MAFF. *Quality in Seeds*, Advisory Leaflet 247.
MAFF (1979). *Guide to the Seed Regulations*. (HMSO).
Stanley, J. and Toogood, A. (1981). *The Modern Nurseryman*. Faber.

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Chapter 13 Weeds

Summary

This chapter includes the following topics:

- **Definition of a weed**
- **Damage caused by weeds**
- **Weeds as alternate hosts of pests and diseases**
- **Definitions of ephemeral, annual and perennial weeds**
- **Characteristics of ephemeral, annual and perennial weeds**
- **Spread of weeds**
- **Physical methods of control**
- **Chemical methods of control**
- **Mode of action of herbicides**

with additional information on the following:

- **Identification of weeds**
- **Weed biology**
- **Mosses and Liverworts**

Figure 13.1 **Chickweed and sowthistle** crowding out cabbages

Damage

A **weed** is a plant of any kind that is growing in the wrong place.

Problems caused by weeds may be categorized into seven main areas:

Competition between the weed and the plant for water, nutrients and light may prove favourable to the weed if it is able to establish itself quickly. A large cleaver plant (*Galium aparine*), for example, may compete for a square metre of soil. The cultivated plants are therefore deprived of their major requirement and poor growth results. The extent of this competition is largely unpredict able, varying with climatic factors such as temperature and rainfall, soil factors such as soil type, and cultural factors such as cultivation method, plant spacing and quality of weed control in previous seasons. Large numbers of weed seeds may be introduced into a plot in poor quality composts or farmyard manure. The uncontrolled proliferation of weeds will inevitably produce serious plant losses.

Drainage (see Chapter 19) depends on a free flow of water along ditches. Dense growth of weeds such as chickweed may seriously reduce this flow and increase waterlogging of horticultural land.

Machinery such as mowing machines and harvesting equipment may be fouled by weeds, such as knotgrass, that have stringy stems

Poisonous plants. Ragwort (see Figure 13.2), sorrel and buttercups are eaten by herbivorous animals when more desirable food is scarce. Also, poisonous fruits of plants such as black nightshade may be attractive to children and also contaminate mechanically harvested crops such as blackcurrants and peas for freezing.

Figure 13.2 **Ragwort,** a poisonous weed

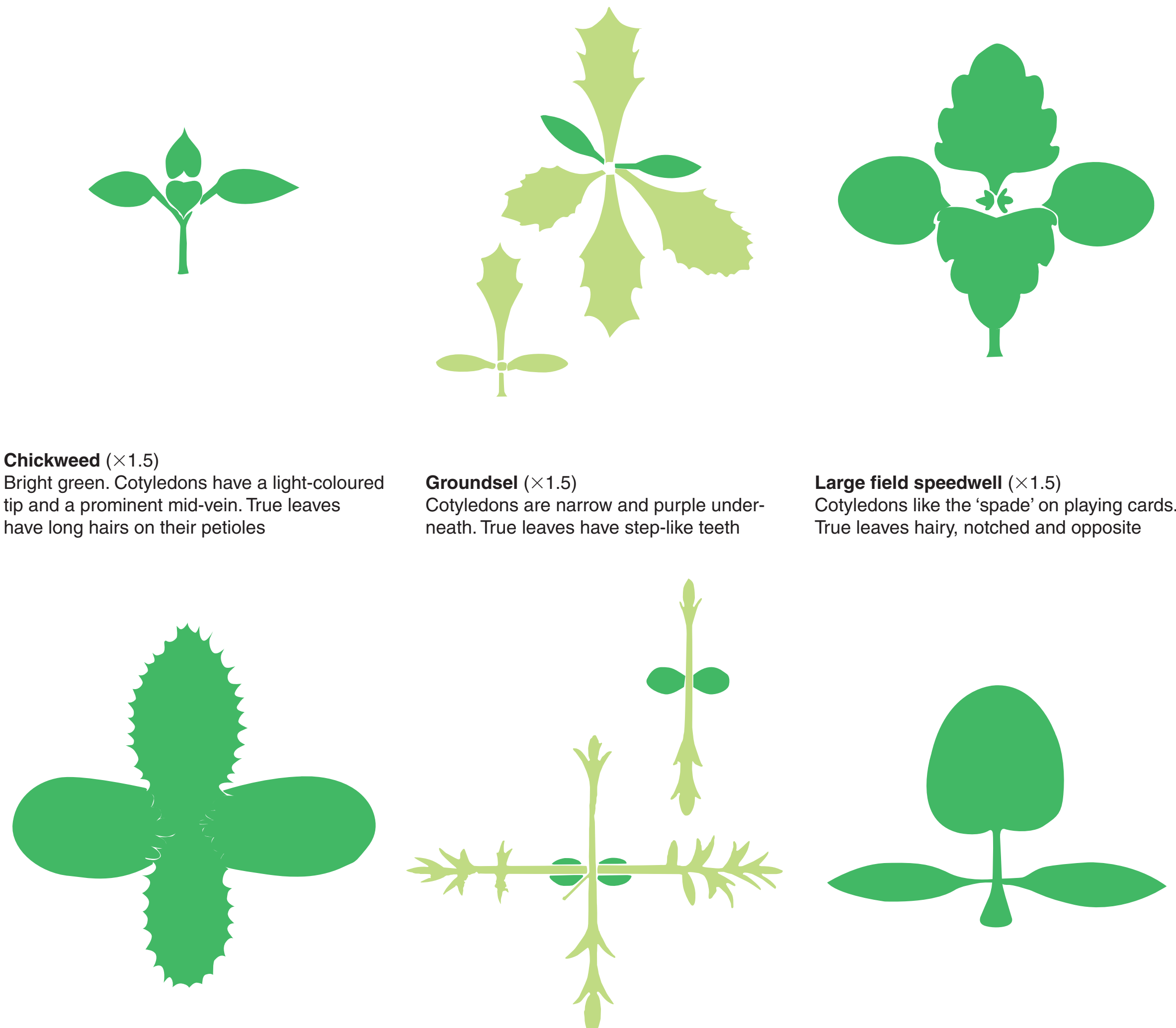
Seed quality is lowered by the presence of weed seeds. For example fat hen can contaminate batches of carrot seed.

Tidiness is important for a well-maintained garden. The amenity horticulturist may consider that any plant spoiling the appearance of plants in pots, borders, paths or lawns should be removed, even though the garden plants themselves are not affected.

Alternate hosts of pests and diseases. Pests and diseases are commonly harboured on weeds. Chickweed supports whitefly, red spider mite and cucumber mosaic virus in greenhouses. Sowthistles are commonly attacked by chrysanthemum leaf miner. Groundsel is everywhere infected by a rust which attacks cinerarias (see Figure15.9). Charlock may support levels of club root, a serious disease of brassica crops. Fat hen and docks allow early infestations of black bean aphid to build-up. Speedwells may be infested with stem and bulb nematodes.

Weed identification

As with any problem in horticulture, recognition and identification are essential before any reliable control measures can be attempted. The weed **seedling** causes little damage to a crop, but will quickly grow to be the damaging adult plant bearing seeds that will spread. The seedling stage is relatively **easy to control**, whether by physical or by chemical methods. Identification of this stage is therefore important and with a little practice the gardener or grower may learn to recognize the important weeds using such features as cotyledon and leaf shape, colour and hairiness of the cotyledons and first true leaves (see Figure 13.3).



Chickweed (×1.5)
Bright green. Cotyledons have a light-coloured tip and a prominent mid-vein. True leaves have long hairs on their petioles

Groundsel (×1.5)
Cotyledons are narrow and purple underneath. True leaves have step-like teeth

Large field speedwell (×1.5)
Cotyledons like the 'spade' on playing cards. True leaves hairy, notched and opposite

Creeping thistle (×1.5)
Cotyledons large and fleshy. True leaves have prickly margins

Yarrow (×1.5)
Small broad cotyledons. True leaves hairy and with pointed lateral lobes

Broad-leaved dock (×1.5)
Cotyledons narrow. First leaves often crimson, rounded with small lobes at the bottom

Figure 13.3 Seedlings of common weeds. Notice the difference between cotyledons and true leaves. (Reproduced by permission of Blackwell Scientific Publications)

Within any crop or bedding display, a range of different weed species will be observed. Changes in the weed flora may occur because of environmental factors such as reduced pH, because of new crops that may encourage different weeds to develop, or because repeated use of one herbicide selectively encourages certain weeds, e.g. groundsel in lettuce crops or annual meadow grass in turf. Horticulturists must watch carefully for these changes so that their chemical control may be adjusted. The mature weeds may be identified using an **illustrated flora** book, which shows details of leaf and flower characters.

Weed biology

Three types of weed

An **ephemeral weed** is a weed that has several life cycles in a growing season.

An **annual weed** is a weed that completes its life cycle in a growing season.

A **perennial weed** is a weed that lives through several growing seasons.

The range of weed species includes algae, mosses, liverworts, ferns and flowering plants. These species display one or more special features of their life cycle which enable them to compete as **successful weeds** against the crop, and cause problems for the horticulturist.

- **Ephemeral weeds**, such as groundsel and chickweed, produce seeds through much of the year. Weed seeds often germinate more quickly than crop seeds and thus emerge from the soil to crowd out the developing plants. Their seeds germinate throughout the year. Their roots are often quite shallow.
- **Annual weeds**, such as speedwells, annual meadow grass and fat hen, are similar to the ephemerals in their all-year round seed production. Their seeds take longer to ripen those of ephemerals. They may develop deeper roots than ephemerals.
- **Perennial weeds**, such as creeping thistle, couch-grass, yarrow and docks, have long-lived root system. Each species has an underground organ that is difficult to control. The creeping thistle has long lateral roots; couch has long lateral rhizomes; yarrow has long lateral roots and docks have deep, swollen roots.

  Whilst seed production may be high, especially in the last three of the four above-mentioned species, it is the spreading underground organs that present the main problems to horticulturalists. The large quantities of food stored in their vegetative organs enable these species to emerge quickly from the soil in spring, often from considerable depths if they have been ploughed in. The fragmentation of underground organs by cultivation machinery often enables these species to propagate vegetatively and increase their numbers in disturbed soils.

Spread of weeds

Weeds may be spread in a number of ways:

- fruits such as those in Himalayan balsam discharge seeds **explosively** to a considerable distance;
- seeds of species from the Asteraceae family such as groundsel, thistles, and dandelion, are carried along in the **wind** by a seed ‘parachute’;
- seeds of chickweed and dandelion may be spread by the moving **water** in ditches;
- fruits of the cleavers weed (see Figure 13.4) **stick** to clothes and hair of humans and animals in a manner similar to ‘Velcro’. Chickweed seed is held in a similar way;
- groundsel and annual meadow grass seeds **become sticky** in damp conditions and are able to stick to boots and machinery wheels;
- a proportion of the seeds of groundsel, annual meadow grass, yarrow and dock survive digestion in the guts of **birds**;

Figure 13.4 ***Young cleavers***. Seeds on older plants stick to the fur of animals

- chickweed and annual meadow grass seed is also able to survive **mammal** digestive systems;
- cut stems of slender speedwell are moved by **grass mowers**;
- **ants** carry around the seeds of speedwell;
- underground horizontal **roots**, **stolons** and **rhizomes** of perennial weeds such as thistle, yarrow and couch respectively slowly spread the weed from its point of origin;
- ploughs and rotavators move around **cut underground fragments** of thistles, yarrow, dandelion, and couch;
- commercial **seed stocks** can be contaminated with seeds of weeds such as speedwells and couch.

Other aspects of weed biology

Particular **soil conditions** may favour certain weeds. Sheep's sorrel (*Rumex acetosella*) prefers acid conditions. Mosses are found in badly drained soils. Knapweed (*Centaurea scabiosa*) competes well in dry soils. Common sorrel (*Rumex acetosa*) survives well on phosphate-deficient land. Yorkshire fog grass (*Holcus lanatus*) invades poorly fertilized turf. Nettle and chickweed prefer highly fertile soils.

The **growth habit** of a weed may influence its success. Chickweed and slender speedwell produce horizontal (prostrate) stems bearing numerous leaves that prevent light reaching emergent crop seedlings. Groundsel and fat hen have an upright habit that competes less for light in the early period of weed growth. Perennial weeds such as bindweed, cleavers and nightshades are able to grow alongside and climb up woody plants, such as cane fruit and border shrubs, making control difficult.

Annual **seed production** may be high in certain species. A scentless may-weed plant (perennial) may produce 300 000 seeds, fat hen (annual) 70 000 and groundsel (annual) 1000. A dormancy period is seen in many weed species. In this way, seed germination commonly continues over a period of 4 or 5 years after seed dispersal, presenting the grower with a continual problem. Groundsel is something of an exception, since many of its seeds germinate in the first year.

Perennial weeds with swollen underground organs provide the greatest problems to the horticulturist in long-term crops such as soft fruit and turf because foliage-acting and residual herbicides may have little effect.

Fragmentation of above-ground parts may be important. A lawnmower used on turf containing the slender speedwell weed cuts and spreads the delicate stems that, under damp conditions, establish (like cuttings) in other parts of the lawn.

Greenhouse production generally suffers less from weed problems because composts and border soils are regularly sterilized.

Some important horticultural weeds

Specific descriptions of identification, damage, biology and control measures are given for each weed species. Detailed discussion of **weed control** measures (cultural, chemical and legislative) is presented in Chapter 16.

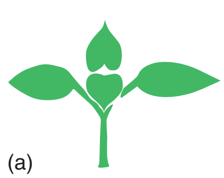
Ephemeral weeds

Chickweed (*Stellaria media*). Plant family – Caryophyllaceae

Damage. This species is found in many horticultural situations as a weed of flowerbeds, vegetables, soft fruit and greenhouse plantings. It has a wide distribution throughout Britain, grows on land up to altitudes of 700 m, and is most important on rich, heavy soils.

Life cycle. The seedling cotyledons are pointed with a light-coloured tip while its true leaves have hairy petioles (see Figure 13.5). The adult plant has a characteristic lush appearance and grows in a prostrate manner over the surface of the soil; in some cases it covers an area of 0.1 square metres, its leafy stems crowding out young plants as it increases in size. Small white, five-petalled flowers are produced throughout the year, the flowering response being indifferent to day length. The flowers are self-fertile.

An average of 2500 disc-like seeds (1 mm in diameter) may result from the oblong fruit capsules produced by one plant. Since the first seed may be dispersed within 6 weeks of the plant germinating and the plant continues to produce seed for several months, it can be seen just how



(a)

(b)

Figure 13.5 (a) Chickweed seedling (b) Chickweed plant prolific the species is. The large numbers of seed (up to 14 million/ha) are most commonly found in the top 7 cm of the soil where, under conditions of light, fluctuating temperatures and nitrate ions, they may overcome the dormancy mechanism and germinate to form the seedling. Many seeds, however, survive up to the second, third and occasionally fourth years. Figure 13.6 shows that germination can occur at any time of the year, with April and September as peak periods. Chickweed is an alternate host for many aphid transmitted viruses (e.g. cucumber mosaic), and the stem and bulb nematode.

Spread. The seeds are normally released as the fruit capsule opens during dry weather; they survive digestion by animals and birds and may thus be dispersed over large distances. Irrigation water may carry them into channels and ditches.

Control. This weed is controlled by a combination of methods. Physical controls include partial sterilization of soil in greenhouses while hoeing in the spring and autumn periods prevents the seedling from developing and flowering. Mulching is effective against germinating weeds.

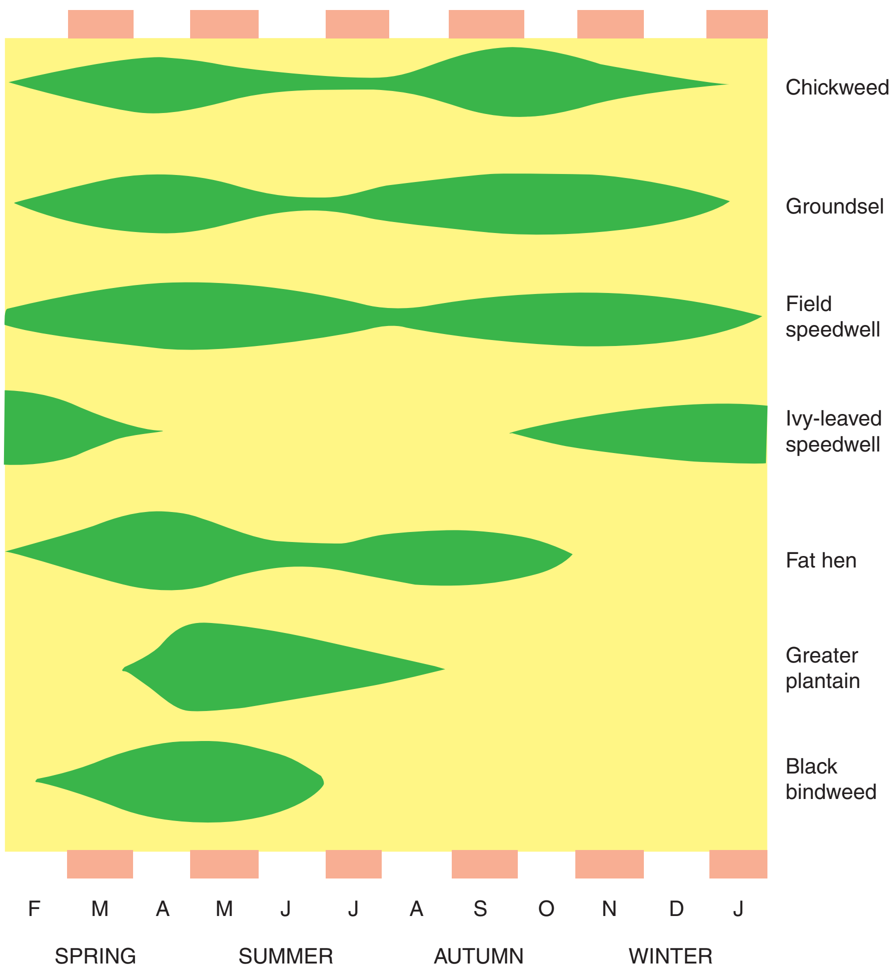


Figure 13.6 **Annual and perennial weeds**: periods of seed germination. Note that chickweed, groundsel and field speedwell seeds germinate throughout the year. Many other species are more limited. (Reproduced by permission of Blackwell Scientific Publications)