1 Introduction

The introduction is divided into three sections: in Part I, *Background*, the reasons for writing this book, and the purposes it is intended to serve are described. The geographic areas in which fruit crops are grown are defined and the reasons for the selection of particular crops to be reviewed are explained, including their origins and centres of production. The principal farming systems in which fruit production is a component are briefly summarised, with a focus on the continuing intensification of crop management practices. Finally, the role that irrigation of fruit crops can play in the sustainable production of high-quality fruit is outlined, providing enough water is made available for irrigation in water-scarce areas of the world. Part II provides a synopsis of the basic science behind *Understanding Crop Productivity*, including measurement techniques. In order to provide a comprehensive account within this book, it largely repeats the corresponding section in Volume 1.[1] Topics covered include crop development stages, plant–water relations, crop water requirements, and water productivity. Finally, Part III provides a description of the main *Irrigation Systems* used to irrigate fruit crops, and the principal methods recommended to growers on how best to schedule irrigation.

PART I: BACKGROUND

There are few easily identifiable or accessible sources where the results of international irrigation research have been brought together and interpreted in coherent and useful ways for individual crops. This is in part due to the diversity of sources, and also to the difficulty of reconciling the results of research conducted in contrasting situations, often with insufficient supporting information to allow the results to be extrapolated to new situations with confidence.

A scientific understanding of the role that water plays in the growth and development of crops is essential, but this knowledge needs to be interpreted and presented as practical advice in a language that can assist planners, irrigation engineers, horticulturalists and producers to allocate and use water, whether from rainfall or irrigation, effectively and profitably. Communication between the professions attempting to improve irrigation water management for the benefit of the commercial producer and the wider community can always be improved. Field experiments must be well designed and managed to quantify with precision the (marketable) yield responses of crops to water (Carr, 2000). Adequate supporting measurements need to be taken to enable the results to be interpreted and applied with confidence to other locations, or at other times, where the climate, weather and/or soils may be different. Site-specific, single-discipline, empirical studies should normally be avoided. *But, to minimise duplication of effort, existing information on the water relations and irrigation needs of individual crops first needs to be collated and interpreted in practically useful ways*. This is especially true for orchard crops having international commercial importance. This is what this book sets out to achieve. It follows the first book in this series, which was devoted to plantation crops. Fruit crops, in particular those grown in warmer regions of the world, tend to be neglected in review books. For example, in the comprehensive reference text *Irrigation of Agricultural Crops* only deciduous trees were included (Stewart and Nielsen, 1990), and only three evergreen subtropical fruit crops (avocado, citrus and olive) were reviewed in the FAO Irrigation and Drainage Paper 66 *Crop Yield Response to Water* (Steduto *et al*., 2012).

Reasons for writing this book

Average yields of all orchard crops, and even the best commercial yields, are often still far below the potential yields. Water is just one of many limiting factors, but in some locations it is the major one. One purpose of this book is to collate all the published information on the water relations of the important orchard crops in order to quantify, where possible, the yield losses due to water stress or, where appropriate, the likely benefits from irrigation or other approaches to drought mitigation as an aid to planning. Another purpose is to provide an entry point for researchers wishing to build on what is already known and avoid duplication of effort. A third purpose is to compare and contrast different orchard crops since, because of specialisation and regional diversity, there is often limited cross-fertilisation of knowledge about other crops among researchers and producers. A fourth purpose is to make a contribution to the need, frequently stated, to use water more productively in the face of increasing competition for a scarce resource (Perry *et al*., 2009; Perry, 2011). The uncertainties associated with climate change make water productivity even more of an imperative (Corley, 2012). Finally the book is intended to be a source of reference for students wishing to know more about tropical and subtropical horticulture and its continuing but rewarding challenges.

Definitions

Sampson (2003) defined fruit growing simply as ‘the cultivation of edible fruits that are consumed either fresh or processed’. A fruit is the structure that develops from individual flowers or from inflorescences, usually after fertilisation. In most cases the marketed fruit consists only of the developed ovary, but it may include other parts of the flower such as the receptacle (part of the flower stem; e.g. *apple*). A *pineapple* is formed from a cluster of flowers that have fused together; it is known as a multiple or aggregate

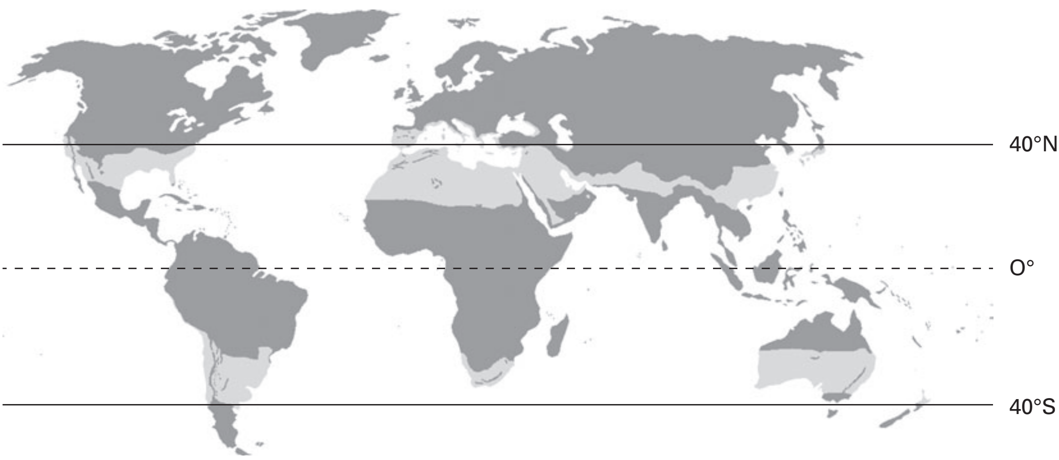

Figure 1.1 World map showing the official limits of the tropics and subtropics, including the Mediterranean-type areas.

fruit. Some fruits are eaten as vegetables (e.g. tomato), but most are normally eaten fresh and out of the hand, although there are many exceptions. A nut is a type of fruit.

Although fruit crops are often divided into those that are grown in the tropics, the subtropics and the temperate regions of the Earth, it is not always easy to make this distinction. There is a great deal of overlap in the geographic areas where these crops are grown commercially. This classification is unrelated to the regions of the world in which individual crops are believed to have originated. The boundaries between the Tropics of Cancer and Capricorn (23°27’ north and south of the Equator) are too rigid to be a useful guide to the areas suitable for growing tropical fruit, as they contain high-altitude areas, where crops considered to be best suited to the subtropics or even to temperate regions can be grown successfully. Similarly, there are areas beyond these boundaries that have local or regional climates where crops associated with the tropics can be grown. The subtropics officially refer to the regions beyond the boundaries of the two tropics up to about 40°N and 40°S latitude (Figure 1.1). In addition there are areas with what is known as a Mediterranean-type climate, which can also be described as subtropical (Anonymous, 2012).

The Mediterranean Basin has long been a site of subtropical and temperate fruit production. It embraces southern Europe, northern Africa and parts of Western Asia. Similar climates are also found elsewhere in the world, for example, in much of California, in parts of Western and South Australia and northern New Zealand, in south-west South Africa, sections of Central Asia and in parts of central, coastal Chile. The reason for these similarities in climate across diverse areas of the Earth’s surface is due to their association with five, large subtropical high-pressure cells linked to the oceans.[2]

The tropics, subtropics, Mediterranean and temperate areas differ climatically in terms of temperature (absolute level, variability during the year, and differences between night and day), the dryness (saturation deficit) of the air, incoming solar radiation levels, hours of daylight, and total rainfall and its seasonal variability. In the low-altitude humid *tropics*, there are usually two rainy seasons separated by two dry, or less wet, periods. Here there may be a need in some years to supplement rainfall with irrigation. Temperatures vary little during the year, averaging about 27 °C. In semi-arid, *subtropical* areas, there is usually a short rainy season, followed by a long dry season when supplementary irrigation of fruit crops may be necessary or even essential depending on the crop, the season and the amount of rainfall and its timing. Here the summers are hotter and the winters colder than in the humid tropics. The subtropics are bounded by the 10 °C isotherm in the coldest month. In the *Mediterranean-Basin-type climate areas*, there is rain during the mild to cool winter whilst the summers are warm to hot, and dry. Crops that are not irrigated usually survive the summer on the surplus winter rainfall stored in the soil. In the extreme climate conditions that are associated with *deserts*, irrigation (or a high water-table) is essential for any form of crop production. But irrigation does not always substitute for rainfall. For example, dry air can inhibit crop growth processes even when the soil is wet (although high levels of solar radiation in the dry season may more than compensate for the adverse effects of dry air) (Figure 1.2).

The *temperate areas* extend from about 40°N and S to 66°N and S and can be divided into *maritime regions* (temperatures stabilised by the proximity of the oceans) and *continental regions* (more extreme winter and summer temperatures) that can be semi-arid or arid. In maritime regions, rainfall can be expected throughout the year, but there is great variability from day to day, from month to month and from year to year. Here irrigation is supplementary to the rainfall, providing stability in production.

Figure 1.2 An oasis in north-east Nigeria bordering Niger. The date palm (*Phoenix dactylifera* L.) (together with the branched doum palm (*Hyphaene thebaica* L. Mart)) relies on a shallow water table (or irrigation) for survival in these arid areas (MKVC). See also colour plates section.

Which fruit crops to review?

In the tropics, the most important perennial fruit crops, based on quantities harvested, are *banana* (with *plantain*), *mango*, *coconut*, *papaya* and *pineapple*. They are all well known in both local and international markets. Those of lesser international importance, such as *passion fruit* and *cashew* nuts, are now attracting more attention and expanding in importance. Most of these crops are trees, the exceptions being *banana*/*plantain* and *papaya* (large herbs), *pineapple* (herb) and *passion fruit* (vine). Extending into the subtropics are *orange* (*citrus*), *lychee*, *avocado* and *macadamia*. With the exception of *banana* and *coconut*, all these crops were chosen for inclusion in this book in part because of their biological diversity as well as their popularity. *Banana* and *coconut* were covered in Volume one of this series on plantation crops, but are considered here alongside the other fruit crops in the Synthesis (Chapter 13) (Figure 1.3). There are of course many other tropical fruits of considerable economic importance in their respective regional markets, but of lesser international importance. These include *carambola*, *rambutan* and *mango-steen*, seedlings of which may take 15 years to produce a profitable crop (Figures 1.4, 1.5 and 1.6) and the unusual *jackfruit* (Figure 1.7). All of these are indigenous to South-East Asia. There is also the *pejibaye* palm, about which little is known outside northern South America and Central America. All of these crops are under-researched, and that is one of the reasons that they are not reviewed here (NAS, 1975; Wickens *et al*., 1989).

Olive, *peach* and *apricot* (all of which are trees) are fruit crops that are normally associated with a subtropical Mediterranean-type climate. Of these, only the *olive*, an

Figure 1.3 Coconut (*Cocos nucifera* L.): an inflorescence is initiated up to 44 months before the fruit is harvested – Tanzania (MKVC).

Figure 1.4 Carambola (also known as star fruit) is the fruit of *Averrhoa carambola* L., a species of tree native to the Philippines, Indonesia, Malaysia, Indonesia, India and Sri Lanka – Malaysia (MKVC).

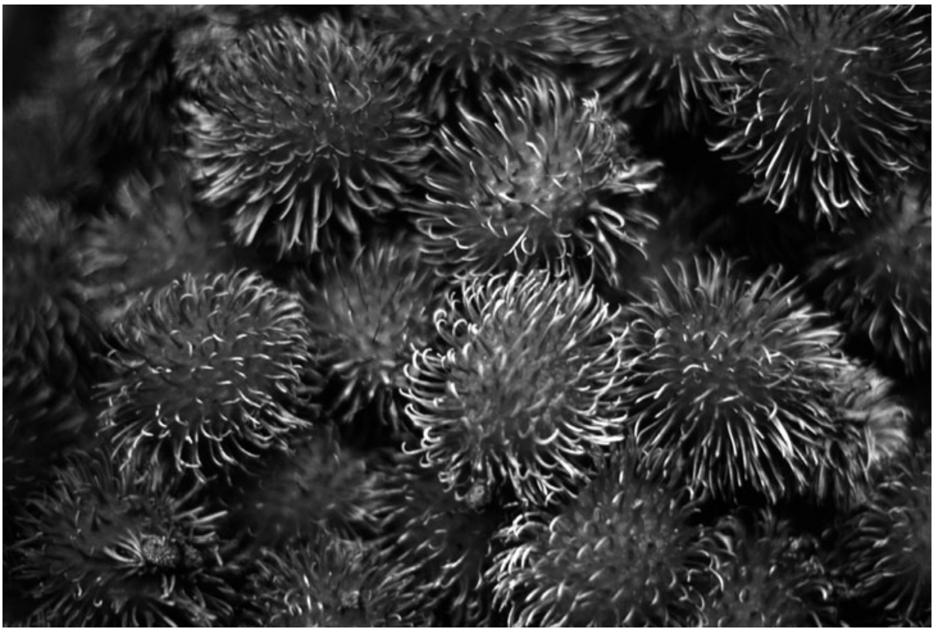

Figure 1.5 Rambutan (*Nephelium lappaceum* L.) is native to Indonesia and Malaysia, and is a relatively common crop in South-east Asia The word ‘rambut’ refers to the spiky rind. Rambutan is related to the lychee (Chapter 6) – Thailand (HDT). See also colour plates section.

Figure 1.6 The purple mangosteen (*Garcinia mangostana* L.) is a tropical evergreen fruit tree believed to have originated in the islands of Indonesia. It is grown principally in South-east Asia and more recently it has been introduced into South America – Thailand (HDT). See also colour plates section.

example of a well-researched crop grown extensively (and now intensively) in southern Europe, is reviewed here. Also reviewed is the *date palm*, a crop that is linked with the unique oasis farming systems found in North Africa and West Asia on the opposite shores of the Mediterranean Sea.

Well-known temperate crops include *apple*, *pear*, *apricot*, *quince* (all of which are trees), together with the *grape*, a traditional source of wine, and the *kiwi*, a twentieth-century crop (both vines) (Figure 1.8). No temperate crop is included here. Small fruits such as *strawberry*, *raspberry* and *currant* are also not covered.

The tropical and subtropical crops described are all evergreen (senescing leaves are continuously replaced), although *avocado* is strictly classified as winter-green because the longevity of the leaves is no more than 12 months, and the entire leaf canopy is replaced in two to three weeks during the renewal spring growth that comes after flowering. By contrast, some Mediterranean-type and most temperate crops, including *peach*, *grape* and *apple*, are deciduous (Figures 1.9 and 1.10). Deciduous crops begin to shed their leaves in the autumn as temperatures fall. The buds then enter a state of dormancy (known as a 'rest period'). Dormancy is broken and refoliation begins after the buds have experienced a period of cold weather. One method used to calculate this 'winter chilling requirement' is to count the number of hours that the air temperature is at or below, for example, 7 °C. Another consideration affecting where a crop can be grown is the level of frost it can withstand, and its susceptibility to water stress. Most of the crops described here are mesophytes

Figure 1.7 Individual fruits of jackfruit can weigh up to 30 kg and a productive tree can produce up to 200 fruits a year – Uganda (RCC). See also colour plates section.

(adapted to average moisture conditions), but three xerophytes (adapted to dry conditions) are also included: *date palm*, *olive* and *pineapple*.

Galán Saúco *et al.* (2012) have highlighted the difficulty of formally differentiating subtropical fruit crops from those predominantly grown in the tropics. Indeed they have argued that more tropical crops could be grown in the subtropics, given sufficient research effort. For example, *avocado*, *lychee* and *mango* have already become important commercial crops in many subtropical countries after many years of research and the effort of growers. Other potential examples include *banana*, *guava*, *passion fruit* and *carambola*. Galán Saúco *et al.* (2012) suggest that there are a number of advantages to be gained by growing tropical crops in the subtropics. These include: less vigorous vegetative growth due to cooler conditions (at least in winter) would mean easier canopy management and tree training, which in turn could mean higher planting densities, with larger initial yields; proximity to the market (cost saving, reduced carbon

Figure 1.8 Kiwifruit is the edible berry of a woody vine (*Actinidia chinensis* Planch.). It is native to southern China, and was introduced into New Zealand in the early twentieth century, where it was developed into a commercial crop. It is now grown in more than ten countries, principally Italy, New Zealand, Chile and Greece – Thailand (HDT).

Figure 1.9 Peach (*Prunus persica* L. Batch.) is a deciduous fruit tree native to China. It sheds its leaves in the autumn and flowers early in the spring before re-foliating. Fruit are produced during the summer – Israel (MKVC).

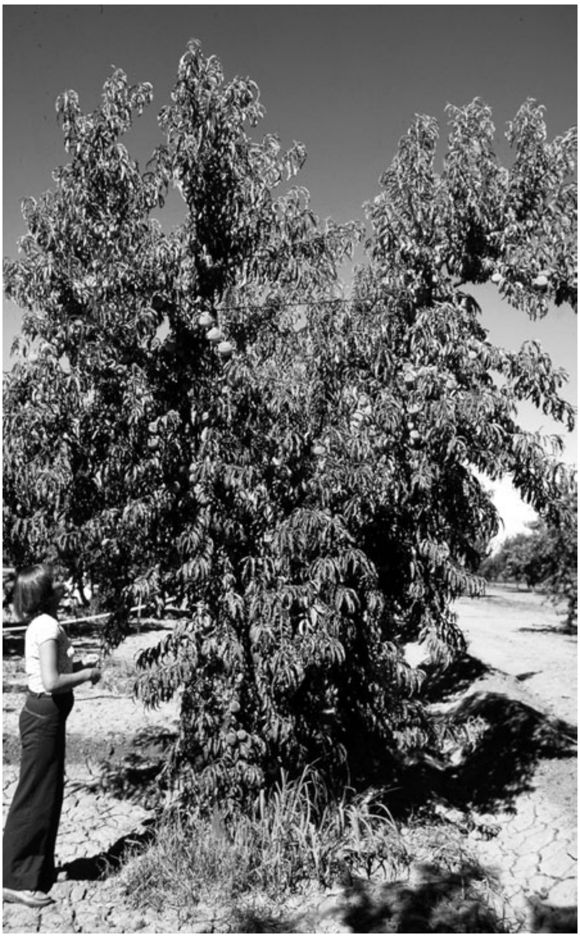

Figure 1.10 A fully foliated peach tree with fruit in California (MKVC).

footprint) and reduced risk of pests due to constraints of low temperatures in winter. Disadvantages include: pest and disease risks (e.g. weever borer and Fusarium wilt in banana) and damage by low temperatures.

These land-use changes are already taking place in the Mediterranean Basin. For example, in one small but representative watershed in south-east Spain, many of the long-established rain-fed orchards have largely disappeared. Over a 30-year period (1978–2007), traditional hand-cut terraces, built of stone, producing rain-fed crops (in 1978: 64% of the area was *almond*, 7% *vines* and 2% *olive*, plus 25% fallow) had become mechanically constructed, reverse-slope bench irrigated terraces producing tropical/subtropical crops (in 2007:19% *avocado*, 17% *almond*, 4% *mango*, 2.4% *loquat*, 1% *cherimoya* and 0.6% *vines*; in addition, 55% of the land had been effectively abandoned). This shift towards intensively grown, subtropical crops may or may not be sustainable (Zuazo *et al*., 2011a). Similar changes are happening in Israel.