

Advances in Irrigation Agronomy

Fruit Crops

As global pressure on water resources intensifies, it is essential that scientists understand the role that water plays in the development of crops, and how such knowledge can be applied to improve water productivity. Linking crop physiology, agronomy and irrigation practices, this book focuses on eleven key fruit crops upon which millions of people in the tropics and subtropics depend for their livelihoods (avocado, cashew, *Citrus* spp., date palm, lychee, macadamia, mango, olive, papaya, passion fruit and pineapple).

Each chapter reviews international irrigation research on an individual fruit crop, identifying opportunities for improving the effectiveness of water allocation and encouraging readers to link scientific knowledge with practical applications. Clearly written and well illustrated, this is an ideal resource for engineers, agronomists and researchers concerned with how the productivity of irrigated agriculture can be improved, in the context of climate change, and the need for growers to demonstrate good irrigation practices.

Mike Carr is Emeritus Professor of agricultural water management at Cranfield University, UK. He has over forty-five years of experience in the management and delivery of international research, education, training and consultancy in agriculture and natural resource management. He is the author of *Advances in Irrigation Agronomy: Plantation Crops* (Cambridge, 2012) and former Editor in Chief of the Cambridge University Press journal *Experimental Agriculture*.

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M. K. V. Carr

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Fruit Crops

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**This book is dedicated to my wife:
Dr Susan Carr
for putting up with me for so long!**

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Foreword

The last decade has witnessed a partial reversal of the sharp decline in investments in agriculture that occurred all over the world during the previous two decades, due to a false perception among policy-makers that no new investments in food and agriculture were needed. Particularly, since the dramatic increases in the price of food in 2008, agriculture is back on the global agenda and will remain there for years to come. Population growth and economic development are the driving forces behind demands for increased food production and for a more diversified diet. World production of fruits and vegetables has proportionally increased from 18 to 23% of the total agricultural output over the last nine years. Driven by efficient transport systems and by the advances in post-harvest technologies, and facilitated by globalisation, the diversity of fruits now being offered to consumers in world markets has expanded enormously. Barriers of space and time no longer exist for accessing fresh fruits at any season, and the only limits are imposed by economics. Growing high-quality fruits successfully is at the starting point of this new development in the diversification of the human diet.

Modern advances in agriculture have been founded on agricultural research, and fruit production is no exception. However, much of the research has been carried out on temperate species such as the apple, and much less effort has been devoted to study the performance of fruit crops grown in subtropical and tropical environments. The increased popularity of exotic fruits demands that much more attention is paid to tropical fruit crops and their production processes. Water management is essential for stability of production in such environments and this book represents an important effort towards optimising the agronomy of irrigation in these species. The book is second in a series on irrigation agronomy, the first having focused on plantation crops.

The author of both books, Professor Mike Carr, has had an extensive career, first in the tropics for many years and, subsequently as professor of agricultural water management at Cranfield University, UK. Plucking through the ever-expanding body of literature (a term commonly used in tea harvesting, his favourite crop), Professor Carr has selected the best 'sprouts' (among a vast sea of literature of varied relevance) to produce a superb synthesis of what is known on irrigation and water relations of the principal subtropical and tropical fruit crops. He has also managed to identify the major gaps in knowledge (and the duplication of efforts in some cases), providing insight into what research will be needed in the future. There is a unifying line of thought throughout the book, as the author aims at connecting the fundamental knowledge to the relevant applications in irrigation management, with the goal of providing the

necessary elements that field practitioners need for precision irrigation. Mike Carr has produced a book that will have a significant influence on the development of the tropical fruit industry, as well as among a new generation of irrigation scientists, which is badly needed to meet the challenges that irrigation will be facing in the future.

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Preface

This is the second book in a series published by Cambridge University Press under the generic title ‘Advances in Irrigation Agronomy’. The first focused on the water requirements and water productivity of nine plantation crops grown in the tropics or subtropics on which millions of people from around the world depend for their livelihoods. They included several tree crops, such as rubber, cocoa, coffee and tea, two palms (oil palm and coconut), a giant herb (banana), a succulent xerophyte (sisal) and a grass (sugar cane). This diverse range of crops has an equally diverse range of useful products from latex to sucrose, to oil, to fibre, to leaves, to fruit, to seed.

When the book was completed someone immediately said ‘why didn’t you include *Citrus* spp., after all they are plantation crops too?’. That question immediately raised another question; where are the boundaries between orchard crops and plantation crops? After all, two fruit crops, banana and coconut, had been included, and the useful products of two others, oil palm and cocoa, come essentially from fruits. To build on what had gone before, and to fill some gaps, the next book in this series had to be about fruit crops. So this book is about fruit crops that are grown commercially in the tropics and subtropics (broadly defined), for export, as well as for local consumption. Following improvements in post-harvest storage and transport systems, there is now an increasing international demand for exotic fruits. One reviewer asked another fundamental question: ‘how was it decided which crops to include (or to exclude)?’. Since there was an element of subjectivity in making that choice, depending in part on the geographic and other limits that were set, this was not an easy question to answer. Hopefully you will find that the selected crops are representative of the major fruits produced in the tropics and subtropics. But, inevitably, not all the important, or potentially important, crops could be included. This issue is considered further in Chapter 1.

On a personal note, after graduating from Nottingham University in the UK, I had three rewarding, and overlapping, roles as a university teacher, a researcher and an adviser in agriculture, with irrigation water management as a common theme. Each one of these roles took me overseas, with professional visits to over 30 countries in the tropics and subtropics. These included Tanzania and Kenya, where we lived for five years, other countries in east, west and southern Africa, at both low (Nigeria) and high altitudes (Uganda), the Indian subcontinent, from Sri Lanka to Bangladesh, Central America (Mexico), South-east Asia (Indonesia and Malaysia); the far east (Japan), western Asia (Israel, Iraq, Jordan), western and southern states in the USA and deserts

(in Israel and Nigeria), as well as Mediterranean basin areas and temperate regions throughout Europe. Since retiring, I have been able to extend my international experience with visits to Australia, New Zealand and China.

My birth certificate describes me as the son of a smallholder. Growing up on a farm provided me with an understanding of the day-to-day challenges faced by families relying on the land to provide their livelihoods, and their dependency for survival on the weather. The common theme in my career has been to try to facilitate effective communication of the outcomes from research to the stakeholders, whoever they are and whatever status they occupy. I have been privileged to live, visit and work in some beautiful places alongside committed and talented people from whom I have learnt a lot. I have witnessed crops of all types being grown in diverse farming systems, from the very primitive to the very sophisticated, in areas receiving less than 200 mm of rain annually to those with more than 2500 mm, from small-scale, labour-intensive irrigation of individual trees with water from a bucket, to large-scale, automated centre-pivots applying water to more than 60 ha in one rotation.

This, therefore, is the background from which I have come and from which this book has evolved. Each of the 11 core chapters covers one fruit crop. These are grown by smallholders as individual trees, or in small orchards, as well as by commercial companies in large-scale plantations. As background information, each chapter begins with a description of the centre of origin of the crop, and the most recent (at the time of writing) production figures. This is followed by a summary of the development stages of the plant in the context of water availability, fundamental plant–water relations, crop water requirements and water productivity, and finally irrigation systems and scheduling (where appropriate). Each chapter is designed to contribute towards converting science into practice by bringing together and interpreting information from a diverse range of sources (over 600 references have been accessed and cited). All the chapters follow a common format, and include interim summaries, together with recommendations on the outstanding researchable issues. In addition to the core chapters, there is an introductory chapter at the beginning of the book, and a synthesis at the end.

Each chapter is based on a paper that has already been published in *Experimental Agriculture* (or is in press), an established refereed journal published by Cambridge University Press. The crops covered are avocado, cashew, citrus, date palm, lychee, macadamia, mango, olive, papaya, passion fruit and pineapple. Cross-references are made, where appropriate, to the reviews of banana and coconut published in Volume 1. My hope is that people from a wide range of backgrounds will find this book as useful and as interesting as I found it to research and write.

Acknowledgements

Once again I have had the help and support of many people whilst compiling this book. I begin by thanking my wife, Susan, for tolerating my self-indulgence over many months, and for reading and constructively editing each chapter with great skill.

Each of the core chapters is based on a paper that has been published in the Cambridge University Press's international journal *Experimental Agriculture*. I acknowledge with thanks the skill with which the editor, Dr David Harris, handled the peer-review process. Anonymous referees provided helpful feedback. This is a thankless, unrewarded but essential task that underpins the reputation of academic journals. I cannot think of any other profession that would undertake such a task without demanding payment.

Individuals, who are recognised as leaders in their fields also helped by reading and providing expert advice on how to improve draft versions of each chapter. These include: Professor Ahmed Al-Amoud (date palm), Dr Duane Bartholomew (pineapple), Professor Elias Fereres (olive), Dr Wayne Hancock (macadamia, mango and papaya), Dr Emi Lahav (avocado), Dr Rob Lockwood (citrus and macadamia), Dr Chris Menzel (co-author of Chapter 6, lychee), Professor Robert Paull and Peter Rigden (passion fruit), Dr Russ Stephenson (macadamia) and Dr Clive Topper (cashew). General advice was always available from Dr Hereward Corley, Melvyn Kay, Dr Rob Lockwood and Dr David Midmore. But, needless to say, any mistakes are all mine!

Professor Elias Fereres, Editor-in-Chief of *Irrigation Science*, kindly wrote the Foreword. I first met Elias in a peach orchard in Davis, California in 1978, when we were both much younger!

Photographs came from a number of sources. Many were selected from the collection of slides belonging to the late Professor Don Tindall, previously a colleague of mine at Cranfield University, UK. I am sure that he would be pleased that his slides have been retained and put to good use. Don's pictures are labeled HDT in the text. Photographs have also been generously provided by Richard Carter (RCC), Colin Congdon (TCEC), Elias Fereres (EF), Susan Hayden (SH), Luiz Mirisola (LM), Raffi Stern (RS) and myself (MKVC). John Shepherd kindly prepared some of the images for publication.

Staff of the Cambridge University Press were supportive throughout the publication process, particularly Megan Waddington (Editor – Life Sciences) and Dominic Lewis (Commissioning Editor – Life Sciences). I thank them both. Jo Tyszka was an excellent copy-editor.