

BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

# Water management for sustainable agriculture

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# Introduction

There is increasing competition for water resources between various sectors in the face of supply shortages and declining reserves associated with climate change. At the same time poor water management is damaging agricultural systems, with problems such as salinization, waterlogging and erosion. This volume synthesises and summarises the wealth of research on understanding and better management of water resources for agriculture. It provides a comprehensive review of the range of water resources, from groundwater and surface water to rainwater, floodwater and waste water. The volume also discusses advances in irrigation techniques, from surface irrigation and sprinkler systems to micro/drip irrigation and fertigation, and assesses methods for optimising agricultural water use in rainfed and other systems.

## Part 1 Fundamentals

The first part of the volume reviews issues fundamental to water management, such as plant water use and soil water retention. The focus of Chapter 1 is understanding and measuring plant water use. The chapter examines the fundamentals of plant-water relations and ways of measuring them, before outlining the nature of evapotranspiration and modern measurement techniques for evapotranspiration fluxes. Finally, the chapter considers the issue of plant water use in the context of sustainable agriculture.

Chapter 2 moves on to analyse the dynamics of water storage and water retention in soil. Soil water storage and retention is one of the most important ecological and agricultural properties of soil, since soil is the main water reservoir for most plants, especially in rainfed systems. The chapter discusses different ways of defining, measuring and modelling soil water retention capacity, which varies according to the physical features of the soil. The chapter includes a detailed case study demonstrating how territorial patterns of soil water retention can be mapped and analysed. Given the time and labour-consuming nature of such methods, the chapter shows how readily available soil-water data can be used to estimate the water retention characteristics of large areas such as catchments. Finally, the chapter reviews the main types of water loss and factors affecting water retention, evapotranspiration and runoff.

Complementing the focus of the two preceding chapters on plant water use and retention of water in soil, Chapter 3 discusses the relationship between climate change and water resources for agriculture. Population dynamics, growing demand for water, pollution, land use changes and other factors frequently result in the failure of some water supply systems. Climate change is expected to aggravate these already existing pressures on water resources. The chapter presents an introduction to the effects of climate change on water resources and analyses their impacts on agriculture. The chapter focuses on several major challenges: the estimation of climate changes impacts on rainfed agriculture and water resources, the analysis of current and future water availability, guidelines for climate change adaptation policies in agriculture and water resources and the selection of climate change adaptation options. The chapter also includes a detailed case study analysing water availability for several Southern European basins.

Concluding Part 1, Chapter 4 brings together insights gained from agriculture around the world to examine an integrated approach to estimating crop water requirements

based on soil, plant and atmospheric measurements. Measuring crop water requirements is an essential part of managing agricultural water in crop fields. The chapter proposes a research approach for determining crop water requirements that integrates soil, plant and atmospheric measurements. The chapter discusses selected methods for estimating crop water requirements (lysimetry, atmospheric, plant- and soil-based methods), their spatial scale and time frequency, and their applicability. The chapter includes a case study from South Africa, where atmospheric (eddy covariance system), plant (sap flow) and soil water content measurements (time domain reflectometry) were used to determine seasonal evapotranspiration (ET) and crop water requirements, transpiration and the extent of over-irrigation (deep percolation). Splitting ET into crop transpiration and soil evaporation makes it possible to determine basal crop coefficients ( $K_{cb}$ ), which are more transferable than the  $K_c$  crop coefficients and less dependent on management practices.

## Part 2 Sustainable use of groundwater and surface water for irrigation

The second part of the volume discusses ways of mapping and monitoring groundwater and surface water resources. Chapter 5 concentrates on the economics of groundwater development and governance. The last century has seen a dramatic increase in the demand for groundwater, first as a source of drinking water, and more recently for agricultural use in arid and semi-arid regions. This sudden surge in demand can be explained by several attractive properties of this resource: it is free, available on demand, suitable for precision irrigation, and typically outlasts surface water stocks in times of drought. However, unregulated over-development of this resource poses a threat to its sustainability. The chapter presents a number of different approaches to groundwater governance: the idea of a public monopoly, direct governance, a contingency approach, and the possibility of collective action. Socioeconomic theory is used to evaluate the appropriateness of these approaches in different contexts. The chapter concludes that there is no universal method of governing groundwater economies; the appropriate approach will depend on both the nature of the society and the nature of the aquifer.

Moving from economic factors to the practical dimension of water management, Chapter 6 focusses on managing surface water for irrigation. As the world's population increases, so does the pressure on water resources to ensure that agriculture continues to meet global food demand. One way of coping with this increased pressure is to improve the management of surface water resources for irrigation, for instance by reducing water losses in large canal systems. The chapter presents a number of different strategies for improving and securing surface water irrigation systems. If irrigation schemes are to be sustainable, factors such as stakeholder commitment, sound design and efficient operation and maintenance must be ensured. Advanced irrigation technologies such as sprinklers and drip irrigation systems must be considered, along with decision support tools to assist farmers and managers in optimizing water allocation to different crops. The capacity of water institutions must be enhanced in order to solve entitlement, pricing and regulatory issues. The chapter concludes that reforms should aim at solving the underlying management issues, as well as delivering benefits to people.

## Part 3 Other sources of water for irrigation

The next group of chapters covers other water sources, such as rain and floodwater, waste and brackish water. Chapter 7 considers the use of rainwater and floodwater harvesting for crop irrigation. Rainwater and floodwater harvesting are environmentally-friendly ways to utilize rainwater and surface runoff for irrigation, water storage and groundwater recharge. Water harvesting (WH) can also reduce flooding and soil erosion risk and can diminish impacts of climate change. The chapter discusses the role of rainwater harvesting, methods for rainwater harvesting and their application, as well as the water storage and floodwater harvesting systems. The chapter also examines the socio-economic and environmental aspects of rainwater and floodwater harvesting.

Moving on from rainwater and floodwater, Chapter 8 looks at the use of treated wastewater for crop irrigation. The reuse of treated wastewater for crop irrigation is important in the effective use of scarce water resources, in ensuring a stable supply and in recovery of nutrients. The chapter explains the composition of wastewater and the characteristics of treated effluents, methods for treatment and guidelines for re-use for crop irrigation, including crop types and irrigation techniques. The final chapter in the section, Chapter 9, considers the use of brackish and marginal-quality water for irrigation in water scarce areas. The chapter explores the key issues and developments in the use of brackish/marginal water for irrigation, and includes a detailed case study as well as dealing with the application of methods for the treatment and use of brackish water in various countries.

## Part 4 Irrigation techniques

The fourth part of the volume covers developments in irrigation techniques and practices such as drip irrigation and fertigation. The focus of Chapter 10 is on developments in surface irrigation techniques. Surface irrigation has long been and still the main system for farmers use. The chapter reviews the development of surface irrigation techniques, providing a brief historical overview, and considering in detail the development of furrow, basin and border irrigation. The chapter examines irrigation scheduling and efficiency, and then reviews the many factors which play into the choice of an irrigation system. Finally, the chapter looks at modelling of surface irrigation systems.

Complementing the preceding chapter's focus on surface irrigation, Chapter 11 deals with trickle/drip irrigation systems. Trickle irrigation is the practice of applying water to crops at very low rates, using outlets placed close to the plant to ensure targeted application into the root zone. Since the 1950s, trickle irrigation has become increasingly advanced and widespread, and promises to become still more important with the depletion of existing water resources and the long-term effects of climate change. The chapter presents a summary of the basic components of the system, before discussing its main advantages and disadvantages. Trickle irrigation is a highly efficient water use practice, in that it avoids typical causes of water loss and allows poorer-quality water to be used. However, trickle irrigation systems are costly to install and challenging to maintain. There is a need to develop cheaper, small-scale trickle irrigation systems that are better suited to smallholder needs.

Moving from an above ground to a below ground context, Chapter 12 provides an overview of subsurface irrigation techniques. The chapter reviews four key subsurface irrigation techniques: traditional clay pot (pitcher) irrigation systems, auto-regulative subsurface pipes, subsurface drip irrigation (SDI) and porous pipe irrigation. The chapter presents the advantages and disadvantages for each technique as well as appropriate case studies. Finally, the chapter discusses subsurface irrigation with treated waste water and ways of modelling the design of these types of irrigation system.

Complementing the previous chapters' focus on irrigation, Chapter 13 moves on to examine how fertigation (application of nutrients through irrigation water) can be applied so as to achieve more efficient water and nutrient use in agriculture. The chapter describes how fertigation provides a powerful and efficient tool to optimize the use of both water and nutrients. The chapter examines advantages and limitations of fertigation, the prerequisites for successful and efficient fertigation, and the equipment available for fertilizer injection. The chapter also covers fertigation under greenhouse conditions and how fertigation can contribute to the principles of the 4R nutrient stewardship. Finally, the chapter addresses monitoring of soil, plant and water under fertigation.

## Part 5 Managing water on the farm

The fifth section of the volume concentrates on improving the use and management of water in on-farm contexts. The subject of Chapter 14 is modelling water use on farms. The chapter presents ways of modelling crop water use and irrigation water requirements, and discusses concepts of water use performance and productivity. The chapter also describes the main features of soil water balance and irrigation scheduling models. It focuses on the SIMDualKc model, which accurately partitions evapotranspiration into actual crop transpiration and soil evaporation. The chapter includes examples of the application of modelling in horticulture, field crops, olive orchards and vineyards as well as in intercropping.

Continuing the theme of efficient water use, Chapter 15 concentrates on improving water productivity in rainfed agriculture, looking especially at the challenges and opportunities for small-scale farmers in dry lands. It examines concepts, methods, constraints and examples drawn from both developing and developed countries, with a particular emphasis on small-scale farmers in the drylands of sub-Saharan Africa (SSA), and West Asia and North Africa (WANA). The chapter includes several detailed case studies.

Moving from dry lands to tropical areas, Chapter 16 examines the challenge of improving water use in tropical rain-fed systems, with particular reference to the situation in India. The quantity of available water and land has not increased globally since 1950, but the availability of water and land per capita has declined significantly due to an increased global human population. Global food security for this growing population requires careful management of water resources. The chapter analyses the current status of agricultural water use in tropical rain-fed areas, assesses the potential for improvement, and then proposes a new paradigm to manage agricultural water efficiently by adopting various land, water, nutrient and crop management technologies.

Homing in on specific techniques for reducing water usage, Chapter 17 looks at deficit irrigation and site-specific irrigation scheduling techniques to minimize water use. Today more than ever, efficient use of water by the agricultural sector is critical to sustaining

national and global food security in both irrigated and rainfed regions. Implementing deficit irrigation strategies and site-specific irrigation management can improve crop water productivity without significantly reducing yield. Under some conditions, these management practices can also result in water conservation, while advanced technologies can facilitate environmental stewardship. The chapter describes the main deficit irrigation (DI) strategies used in agriculture and reports on results from current studies using DI strategies, as well as the status for site-specific irrigation management and its role in minimizing agricultural water use.

Concluding the section, Chapter 18 tackles the issue of drainage systems to support sustainable water use. In arid and semi-arid regions of the world, rainfall is supplemented by irrigation, and drainage is needed to prevent irrigation-induced waterlogging and soil salinization. The chapter provides an overview of agricultural drainage systems, explains in detail the need for drainage and its benefits, and explores in some depth the challenges of making drainage work, including the construction of drainage infrastructure and ways of dealing with drainage effluent.

## Part 6 Managing water resources

The sixth and final section of the volume addresses ways in which water resources can be better managed regionally. Chapter 19 provides an overview of the challenge of increasing water productivity in agriculture. There is good evidence that improvements in crop productivity have come from increases in yield rather than from decreases in total water use. In irrigated agriculture, there are increasing attempts to decrease the unproductive losses of water from storage, through distribution systems and onto fields. The chapter defines the meaning and implications of increased water productivity and then systematically considers the limits and opportunities for improvement. Water productivity is considered in the context of both rain dependent (often called 'dryland') and irrigated agricultural production. The chapter acknowledges that many agricultural systems have animals as part of food and fiber production, and argues that efforts to increase water productivity need to consider whole agricultural systems.

Moving from an overview to look at needs specific to localities, the focus of Chapter 20 is regional strategies in sustainable water management for irrigation. The chapter addresses a variety of challenges associated with regional water management, including the resolution of conflicts between sectors in order to resolve the 'demand versus availability' equation, and the symbiosis needed between agronomy and engineering in order to optimize the performance of irrigation networks. The chapter explores the adoption of the eco-efficiency approach as a modern management concept and indicator of sustainable water use, and presents a case study to demonstrate how the eco-efficiency approach has been applied over a large irrigation district located in the Puglia region of Southern Italy.

Chapter 21 looks at the specific challenge of sustainable water resources management under conditions of water scarcity. Historically, water control developments were mostly small-scale, locally-managed and hydrologically-independent, with annual rainfall, runoff and recharge setting the limits to annual use. In recent decades, the vast expansion of irrigation (the largest water user with about 70% withdrawal worldwide) has resulted in dramatic increases in water consumption. The escalation of water scarcity, further impacted by climate change, is posing huge challenges for sustainable water resources

management. A solution, which has prominently influenced the agenda of planners, policymakers and financial institutions, has been improvement of irrigation technology, replacing traditional 'inefficient' techniques with 'modern' irrigation systems, assuming that significant amounts of water can be saved and released for other uses. The chapter describes case studies which demonstrate that, most of the time, water consumption increases with 'modernization' of irrigation. The chapter argues that restoring a balance between sustainable supply and consumption of water requires physical control of water allocation and consumption as an initial priority.

The final chapter in the volume, Chapter 22, examines the challenges of assessing the cost of supplying water for agriculture, and looks at the implementation of a food supply cost curve. As part of a 'Regional Initiative on Water Scarcity in the Near East and North Africa (NENA) Region', the UN Food and Agriculture Organization (FAO) has been proposing a practical tool for the assessment of investment projects called the Food Supply Cost Curve (FSCC). The chapter describes the concept of the Food Supply Cost Curve, and outlines which steps need to be taken to practically implement an FSCC evaluation exercise. It concludes by commenting on some preliminary findings obtained at the FAO when the FSCC has been employed in some countries in the Near East and North Africa.

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