Achieving sustainable cultivation of wheat

Volume 2: Cultivation techniques

Edited by Professor Peter Langridge
University of Adelaide, Australia
Contents

Series list ix
Introduction xiii
Key priorities in wheat research: the Wheat Initiative’s Strategic Research Agenda xix

Part 1 Wheat cultivation techniques

1 Variety selection in wheat cultivation 3
   Arun Kumar Joshi, International Maize and Wheat Improvement Center (CIMMYT); Vinod Kumar Mishra, Banaras Hindu University, India; and Simanchal Sahu, Orissa University of Agriculture and Technology, India
   1 Introduction 3
   2 Wheat variety selection methods: natural and traditional selection 4
   3 Wheat variety selection methods: modern molecular breeding 8
   4 Variety selection by plant breeders 12
   5 Variety selection by farmers 17
   6 Conclusion 18
   7 Where to look for further information 18
   8 References 18

2 Establishment and root development in wheat crops 25
   Peter J. Gregory and Christina K. Clarke, University of Reading, UK
   1 Introduction 25
   2 Root development and growth during establishment 26
   3 Crop establishment practices 28
   4 Case study: the effects of embryo size and seed mass on early vigour 33
   5 Research contributions to improved wheat establishment and production 35
   6 Future trends in research 36
   7 Where to look for further information 38
   8 Acknowledgements 38
   9 References 38

3 Conservation tillage for sustainable wheat intensification: the example of South Asia 41
   Vijesh Krishna, Georg-August University of Göttingen, Germany; Alwin Keil, International Maize and Wheat Improvement Center (CIMMYT), India; Sreejith Aravindakshan, Wageningen University, The Netherlands; and Mukesh Meena, Indian Institute of Soil and Water Conservation, India
   1 Introduction 41
   2 Factors affecting the diffusion of CT wheat in South Asia 43
   3 Recent evidence of the agronomic and economic impacts of CT wheat in South Asia 45

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<table>
<thead>
<tr>
<th>4</th>
<th>Constraints to the diffusion of CT practices in wheat in South Asia</th>
<th>49</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Recent developments in CT wheat</td>
<td>53</td>
</tr>
<tr>
<td>6</td>
<td>Concluding remarks</td>
<td>55</td>
</tr>
<tr>
<td>7</td>
<td>Where to look for further information</td>
<td>56</td>
</tr>
<tr>
<td>8</td>
<td>Acknowledgements</td>
<td>56</td>
</tr>
<tr>
<td>9</td>
<td>References</td>
<td>56</td>
</tr>
<tr>
<td>4</td>
<td>Improving water management in winter wheat</td>
<td>63</td>
</tr>
<tr>
<td>Q. Xue, J. Rudd, J. Bell, T. Marek and S. Liu, Texas A&amp;M AgriLife Research and Extension Center at Amarillo, USA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Introduction</td>
<td>63</td>
</tr>
<tr>
<td>2</td>
<td>Winter wheat yield</td>
<td>68</td>
</tr>
<tr>
<td>3</td>
<td>Yield determination under water-limited conditions</td>
<td>69</td>
</tr>
<tr>
<td>4</td>
<td>The role of measuring evapotranspiration (ET)</td>
<td>70</td>
</tr>
<tr>
<td>5</td>
<td>Water-use efficiency</td>
<td>70</td>
</tr>
<tr>
<td>6</td>
<td>Wheat yield, evapotranspiration (ET) and water-use efficiency (WUE) relationships</td>
<td>71</td>
</tr>
<tr>
<td>7</td>
<td>Case studies</td>
<td>73</td>
</tr>
<tr>
<td>8</td>
<td>Future trends and conclusion</td>
<td>80</td>
</tr>
<tr>
<td>9</td>
<td>Where to look for further information</td>
<td>80</td>
</tr>
<tr>
<td>10</td>
<td>References</td>
<td>81</td>
</tr>
<tr>
<td>5</td>
<td>Post-harvest wheat losses in Africa: an Ethiopian case study</td>
<td>85</td>
</tr>
<tr>
<td>Tadesse Dessalegn, Tesfaye Solomon, Tesfaye Gebre Kristos, Abiy Solomon, Shure Seboka and Yazie Chane, Ethiopian Institute of Agricultural Research, Ethiopia; Bhadriraju Subramanyam and Kamala A. Roberts, Kansas State University, USA; and Fetien Abay and Rizana Mahroof, South Carolina State University, USA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Introduction</td>
<td>85</td>
</tr>
<tr>
<td>2</td>
<td>Methods</td>
<td>88</td>
</tr>
<tr>
<td>3</td>
<td>Demographics</td>
<td>88</td>
</tr>
<tr>
<td>4</td>
<td>Crop production information</td>
<td>90</td>
</tr>
<tr>
<td>5</td>
<td>Post-harvest issues</td>
<td>91</td>
</tr>
<tr>
<td>6</td>
<td>Preventing post-harvest losses</td>
<td>99</td>
</tr>
<tr>
<td>7</td>
<td>Information flow and training requirements</td>
<td>99</td>
</tr>
<tr>
<td>8</td>
<td>Gender and food security issues</td>
<td>100</td>
</tr>
<tr>
<td>9</td>
<td>Conclusion</td>
<td>101</td>
</tr>
<tr>
<td>10</td>
<td>Acknowledgements</td>
<td>101</td>
</tr>
<tr>
<td>11</td>
<td>Where to look for further information</td>
<td>102</td>
</tr>
<tr>
<td>12</td>
<td>References</td>
<td>102</td>
</tr>
</tbody>
</table>

Part 2 Wheat crop management

<p>| 6 | Wheat crop modelling to improve yields | 107 |
| J. R. Guarin and S. Asseng, University of Florida, USA |  |
| 1 | Introduction | 107 |
| 2 | Extrapolation from crop models in time and space | 111 |</p>
<table>
<thead>
<tr>
<th>Contents</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Experiments for testing crop models</td>
<td>114</td>
</tr>
<tr>
<td>4 Adapting crop models for climate change impact</td>
<td>117</td>
</tr>
<tr>
<td>5 Natural resource management</td>
<td>121</td>
</tr>
<tr>
<td>6 Managing seasonal variability</td>
<td>124</td>
</tr>
<tr>
<td>7 Decision support for farmers</td>
<td>126</td>
</tr>
<tr>
<td>8 Future trends</td>
<td>127</td>
</tr>
<tr>
<td>9 Conclusion</td>
<td>129</td>
</tr>
<tr>
<td>10 Where to look for further information</td>
<td>130</td>
</tr>
<tr>
<td>11 Acknowledgements</td>
<td>130</td>
</tr>
<tr>
<td>12 References</td>
<td>130</td>
</tr>
<tr>
<td>7 Integrated crop management of wheat</td>
<td>143</td>
</tr>
<tr>
<td>Brian L. Beres, Reem Aboukhaddour and Haley Catton, Agriculture and Agri-Food Canada, Lethbridge Research and Development Centre, Canada</td>
<td>143</td>
</tr>
<tr>
<td>1 Introduction</td>
<td>143</td>
</tr>
<tr>
<td>2 Impact of agronomists on agriculture</td>
<td>145</td>
</tr>
<tr>
<td>3 Case study: ICM for wheat stem sawfly (Cephus cinctus Norton)</td>
<td>153</td>
</tr>
<tr>
<td>4 Future trends and conclusion</td>
<td>159</td>
</tr>
<tr>
<td>5 Where to look for further information</td>
<td>160</td>
</tr>
<tr>
<td>6 References</td>
<td>160</td>
</tr>
<tr>
<td>8 Organic production of wheat and spelt</td>
<td>167</td>
</tr>
<tr>
<td>T. F. Döring, Humboldt-Universität zu Berlin, Germany</td>
<td>167</td>
</tr>
<tr>
<td>1 Introduction</td>
<td>167</td>
</tr>
<tr>
<td>2 Wheat in organic rotations</td>
<td>169</td>
</tr>
<tr>
<td>3 Organic wheat in species mixtures</td>
<td>179</td>
</tr>
<tr>
<td>4 Diversification of organic wheat at the genetic level</td>
<td>182</td>
</tr>
<tr>
<td>5 Organic wheat and farm biodiversity</td>
<td>187</td>
</tr>
<tr>
<td>6 Future trends and conclusion</td>
<td>189</td>
</tr>
<tr>
<td>7 Where to look for further information</td>
<td>189</td>
</tr>
<tr>
<td>8 Acknowledgements</td>
<td>190</td>
</tr>
<tr>
<td>9 References</td>
<td>190</td>
</tr>
<tr>
<td>9 Durum wheat: production, challenges and opportunities</td>
<td>199</td>
</tr>
<tr>
<td>J. M. Clarke, K. Nilsen, D. Khitiri, X. Lin and C. J. Pozniak, University of Saskatchewan, Canada; and K. Ammar, International Maize and Wheat Improvement Center (CIMMYT), Mexico</td>
<td>199</td>
</tr>
<tr>
<td>1 Introduction</td>
<td>199</td>
</tr>
<tr>
<td>2 Durum wheat yield and agronomic traits</td>
<td>200</td>
</tr>
<tr>
<td>3 Abiotic stresses on durum wheat</td>
<td>202</td>
</tr>
<tr>
<td>4 Major diseases of durum wheat</td>
<td>205</td>
</tr>
<tr>
<td>5 Insect pests of durum wheat</td>
<td>210</td>
</tr>
<tr>
<td>6 End-use quality of durum wheat</td>
<td>212</td>
</tr>
<tr>
<td>7 Durum wheat breeding technologies</td>
<td>215</td>
</tr>
<tr>
<td>8 Future trends and conclusion</td>
<td>218</td>
</tr>
<tr>
<td>9 Where to look for further information</td>
<td>220</td>
</tr>
<tr>
<td>10 References</td>
<td>220</td>
</tr>
</tbody>
</table>
### Part 3 Improving wheat cultivation in the developing world

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Supporting smallholders in improving wheat cultivation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tinashe Chiurugwi, Simon Kerr, Ian Midgley and Lesley Boyd, National Institute of Agricultural Botany (NIAB), UK; Johnson Kamwaga, Food Crops Research Centre – Njoro, Kenya; Peter Njau, Highlands Agri-consult Services Ltd, Kenya; Terry van Gevelt, University of Cambridge, UK; and Claudia Canales and Max Marcheselli, the Malaysian Commonwealth Studies Centre (MCSC) and the Cambridge Malaysian Education and Development Trust (CMEDT), UK</td>
<td>237</td>
</tr>
<tr>
<td></td>
<td>1 Introduction: smallholder wheat cultivation</td>
<td>237</td>
</tr>
<tr>
<td></td>
<td>2 Limitations to smallholder wheat cultivation</td>
<td>242</td>
</tr>
<tr>
<td></td>
<td>3 How research addresses limitations to smallholder wheat cultivation</td>
<td>246</td>
</tr>
<tr>
<td></td>
<td>4 Case study: Agri-transfer</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>5 Future trends</td>
<td>253</td>
</tr>
<tr>
<td></td>
<td>6 Where to look for further information</td>
<td>254</td>
</tr>
<tr>
<td></td>
<td>7 References</td>
<td>255</td>
</tr>
<tr>
<td>11</td>
<td>Improving wheat cultivation in Asia</td>
<td>261</td>
</tr>
<tr>
<td></td>
<td>Rajiv Kumar Sharma, Global Wheat Improvement Program – CIMMYT, India</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 Introduction</td>
<td>261</td>
</tr>
<tr>
<td></td>
<td>2 Improving and exploiting genetic diversity</td>
<td>262</td>
</tr>
<tr>
<td></td>
<td>3 Improving breeding techniques</td>
<td>264</td>
</tr>
<tr>
<td></td>
<td>4 Dealing with biotic stresses</td>
<td>266</td>
</tr>
<tr>
<td></td>
<td>5 Dealing with abiotic stresses</td>
<td>267</td>
</tr>
<tr>
<td></td>
<td>6 Improving aspects of quality</td>
<td>269</td>
</tr>
<tr>
<td></td>
<td>7 Improving cultivation practices</td>
<td>270</td>
</tr>
<tr>
<td></td>
<td>8 Case study: improving cultivation in India</td>
<td>271</td>
</tr>
<tr>
<td></td>
<td>9 Summary</td>
<td>274</td>
</tr>
<tr>
<td></td>
<td>10 Where to look for further information</td>
<td>274</td>
</tr>
<tr>
<td></td>
<td>11 References</td>
<td>275</td>
</tr>
<tr>
<td>12</td>
<td>Improving wheat production in the Central and West Asia and North Africa (CWANA) region</td>
<td>287</td>
</tr>
<tr>
<td></td>
<td>W. Tadesse, A. Amri, M. Sanchez-Garcia, M. El-Bouhssini, M. Karrou, S. Patil, F. Bassi and M. Baum, International Center for Agricultural Research in the Dry Areas, Morocco; and T. Oweis, International Center for Agricultural Research in the Dry Areas, Jordan</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 Introduction</td>
<td>287</td>
</tr>
<tr>
<td></td>
<td>2 Major wheat production environments</td>
<td>290</td>
</tr>
<tr>
<td></td>
<td>3 Challenges to wheat production</td>
<td>291</td>
</tr>
<tr>
<td></td>
<td>4 Improved technologies to enhance wheat production</td>
<td>292</td>
</tr>
<tr>
<td></td>
<td>5 Intensification of wheat technologies</td>
<td>301</td>
</tr>
<tr>
<td></td>
<td>6 Future trends</td>
<td>303</td>
</tr>
<tr>
<td></td>
<td>7 Where to look for further information</td>
<td>305</td>
</tr>
<tr>
<td></td>
<td>8 References</td>
<td>305</td>
</tr>
</tbody>
</table>

Index 309

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Introduction

The chapters in this volume, *Achieving sustainable cultivation of wheat Volume 2: Cultivation techniques*, pick up on the core themes identified in the Wheat Initiative’s Strategic Research Agenda:

- Core theme 1: increase wheat field potential
- Core theme 2: protect yield potential
- Core theme 3: protect the environment and increase the sustainability of wheat production systems
- Core theme 4: ensure the supply of high quality, safe wheat

They cover key issues such as improvements in individual cultivation techniques to make wheat production more resource efficient and sustainable, as well as the best ways of combining such techniques in systems such as integrated or organic crop management. The book also reviews research on the key challenges in adopting new varieties, methods and technologies in practice in the developing world.

Part 1 Wheat cultivation techniques

Chapter 1 provides an overview of key issue in wheat variety selection. It looks first at relevant developments in breeding, including pedigree, modified bulk, selected bulk, non-selected bulk and back cross selection methods, before discussing more recent developments such as marker-assisted selection, genomic selection and next generation phenotyping. It then focuses on key criteria for breeders in selecting new varieties, from targeting a particular set of environmental conditions or mix of crop management methods to addressing specific biotic or abiotic stresses, or focusing on quality requirements for end users. The chapter compares these with farmer requirements which may differ from those of breeders. As an example, hybrid varieties may only be suitable for farmers who have access to funds or credit to purchase hybrid seed every year and are able to practice high input agriculture to obtain a sufficient return. Small-scale subsistence farmers often rely on seeds saved by farmers the previous years and thus prefer pure line varieties, which can be grown for a number of years from the same seed source. The chapter shows how breeder and farmer objectives can be better aligned through techniques such as participatory varietal selection (PVS).

Chapter 2 reviews recent research on wheat crop establishment, the period encompassing plant development and growth prior to the elongation of the main stem. As the chapter points out, good establishment lays the foundations for wheat yield. The chapter describes current research on how the seedling root system establishes and then outlines how key agronomic practices (time and depth of sowing, seeding rate and soil moisture conditions) affect the initial growth of the plant. The chapter includes a case study from Australia on how embryo size affects seed mass which affects early growth, and concludes with some recent ideas as to how root systems might be optimised in different soils to increase production.
Chapter 3 explores the use of conservation agriculture techniques for sustainable wheat intensification. Conservation agriculture emphasises the importance of soil health through minimal soil disturbance, residue retention and permanent soil cover, combined with crop rotations to enhance soil moisture and nutrition. A key element is conservation tillage (CT) which encompass zero-tillage, reduced-tillage, and ridge-tillage practices in wheat production. CT has been seen as an important way of addressing stagnant wheat yields in regions such as the Indo-Gangetic Plains of South Asia. The chapter reviews factors affecting the diffusion of CT in South Asia and the latest evidence of its agronomic and economic impact. It also assesses constraints to the diffusion of conservation tillage practices in wheat, taking India as a case study. The chapter shows the benefits of CT in reducing energy, fertilizer and especially irrigation input costs whilst maintaining yields, but shows that its diffusion has been variable, particularly amongst smallholders. The chapter identifies problems such as insufficient support networks for CT wheat technology, variation of yield impacts across some farming systems and locations, and the fact that tractor and CT drill ownership is unaffordable for many poorer smallholders. To improve adoption, it argues for developments such as customised hiring services to reduce transaction costs for small farms, farmer group- or cooperative-based investments in CT machinery, and the development and deployment of more location-specific and scale-appropriate machinery.

Chapter 3 emphasised the role of conservation agriculture in increasing soil water retention. Chapter 4 looks in more detail at improving water management in wheat cultivation, focussing on winter wheat. Globally, winter wheat is mainly grown in Eurasia, China, Iran, and the USA. Drought stress can significantly reduce winter wheat yields, even in high precipitation environments. Since water is the most important factor affecting crop production, development of crop management practices to conserve and optimize water use and improve crop water use efficiency (WUE) becomes essential, particularly under changing climate conditions. Chapter 4 reviews progress in winter wheat water management and WUE, drawing on long-term field experiments in the USA's southern Great Plains (which have a long history of winter wheat research). The chapter discusses yield determination under water-limited conditions, as well as the relationships between yield, evapotranspiration and WUE. It also summarises best management practices based on case studies. These practices range from soil and water conservation techniques (such as no-till, residue mulching and rotation associated with conservation agriculture), irrigation scheduling and deficit irrigation, to genetic improvement of drought tolerance.

According to estimates provided by the African Postharvest Losses Information System (APHLIS), physical grain losses range from 10-20%. It has been estimated that overall post-harvest grain losses for sub-Saharan Africa could be as high as US$4 billion/year, around 15% of total production. This compares to the findings reported for post-harvest losses of wheat in Ethiopia discussed in Chapter 5. These suggest high average losses of around 17%, with losses ranging from 14 to as high as 23%. Chapter 5 explores the range of issues underlying post-harvest losses through a case study highlighting the problem in Ethiopia. It emphasises the importance of investigating the experience and views of farmers themselves. Farmers indicated post-harvest losses to be greatest at harvest and during storage, primarily due to insects, molds, and vertebrate pests, especially rodents. Rain during harvest also greatly increased post-harvest losses.

To resolve these problems, farmers identified the need for more information about weather conditions (particularly during the harvest period), better moisture measurement, better storage techniques (including using pesticides during storage), and better market
information. Storage methods can be improved by using hermetic storage or polypropylene bags (such as Purdue Improved Cowpea Storage (PICS) bags), metal or plastic drums, or metal silos. It is also important that storage methods are cost effective and accessible to remote or poor households. Finally, providing continued training on post-harvest loss mitigation methods will help greatly reduce post-harvest losses and increase food security of Ethiopian wheat farmers.

Part 2 Wheat crop management

Crop simulation models are robust tools for scientists, farmers, and policymakers that can be used to develop practices and strategies to increase agricultural productivity and sustainability on a local, regional, or global scale under conditions and treatments difficult or impossible to test using solely field experimentation. Crop models are increasingly being used to explore solutions to issues such as global food security, climate change impact assessment and adaptation, nitrogen fertilization, irrigation, and seasonal variability management.

Chapter 6 examines the experimental datasets, dynamic modeling processes, validation and fundamental applications of current wheat crop models. It reviews research on ways of using crop models, for example in responding to the challenge of climate change by modelling the effects of changing temperatures and rainfall patterns. As an example, it refers to studies that show where changing weather patterns could make new regions suitable for wheat cropping. Models can also highlight ways of balancing yield improvement with more efficient and sustainable use of inputs whilst conserving natural resources. Crop modeling also enables exploration of the benefits from seasonal forecasts to manage seasonal variability to improve efficiency and profitability. One way to manage the increased risks of less predictable weather is through the use of in-season decision support systems that incorporate crop models, such as Yield Prophet, Crop Prophet or AgroClimate. Yield Prophet, for example, is a web interface and mobile application built around the APSIM crop modeling system that produces a comprehensive crop report based on simulated growing conditions using farm location, cultivar details, soil data, hundred-year weather data, and seasonal climate forecasts. This crop report gives the latest seasonal weather forecasts and estimated impacts on crop yields, including updates on growth stage, yield potential, available soil water and nitrogen, water and nitrogen stress indices, and risks of exposure to heat or frost stress at critical crop developmental stages. This allows farmers to make more informed decisions about the timing, placing and amount of irrigation to apply, for example.

As Chapter 7 explains, integrated crop management (ICM) is the practice of using multiple agronomic and pest control methods to maximize yield and net returns, minimize inputs while maintaining economic and environmental sustainability. ICM is a holistic framework concerned with optimally and sustainably managing abiotic and biotic production components to allow actual crop yield to approach the genetic yield potential. This is accomplished by maximizing potential yield through improved crop breeding, mitigating production losses by optimizing nutrients, moisture and agronomic practices, and using integrated pest management to reduce losses from weeds, diseases and insects. This chapter describes the role of agronomists in developing ICM strategies. It also shows how ICM principles can be applied. As an example, adoption of no-till and preservation
of crop residues can result in colder and often wetter soils at planting, which can also delay seedling emergence. Integration of crop protection inputs such as dual fungicide and insecticide seed treatments can help offset weak systems vulnerable to poor stand establishment and low yield performance. The chapter provides a detailed case study of the use of ICM to control the wheat pest wheat stem sawfly (WSS), combining pre-crop strategies to reduce the local number of adult female WSS available to lay eggs; planting and in-crop strategies to reduce the number of eggs and to reduce egg or larval survival prior to the cutting stage; and harvest management strategies to reduce or prevent damage from cutting and to enhance biocontrol of WSS.

Wheat plays a major role in organic agriculture around the globe. Chapter 8 reviews the current state of organic cultivation of wheat and its close relative, spelt, with a focus on crop diversification, through rotational design, use of species mixtures containing wheat, and diversification at the genetic level, for example through variety mixtures. The chapter shows that there are constraints associated with diversification in organic wheat cultivation systems. Diversifying rotations may dilute wheat production within the rotation; intercrops containing wheat are often characterised by unpredictability and technical difficulties; and diversification of wheat through evolving crop populations may be hampered by seed-borne diseases. The chapter concludes that optimization of organic wheat cultivation systems across the world through diversification depends on a continuous and reliable, systematic and comprehensive collection of agronomic data under conditions of increased crop diversity.

Durum wheat is principally used for the manufacture of pasta, couscous and, to a lesser extent, in the production of bulgur and bread. Chapter 9 explores the challenges and opportunities of durum wheat production in the twenty-first century. After discussing research on durum wheat yields, it covers the major abiotic stresses facing durum wheat cultivation, as well as the principal diseases and insect pests. It describes approaches used to mitigate production constraints and the progress realized through these approaches in breeding in recent years. The chapter also examines end use quality of durum wheat and future trends in the form of emerging breeding technologies.

Part 3 Improving wheat cultivation in the developing world

Chapters 10 to 12 review ways of improving cultivation in the developing, including case studies from Africa, Central and South Asia. It has been estimated that just over half of global wheat production comes from about 150 million hectares cultivated in 75 low and middle income countries, mainly in South, South East and West Asia, North Africa, Middle East, sub-Saharan Africa and Latin America. Wheat production in these regions is mainly carried out by smallholder farmers. Chapter 10 summarises some of the main problems that constrain smallholder wheat cultivation and discuss ways in which these can be addressed. It reviews the key research on the range of constraints facing smallholders, from biophysical constraints to socioeconomic limitations. There is a particular focus on women given their central role in smallholder farming. It reviews how each of these constraints can be overcome. To illustrate what this means in practice, it includes a case study from Kenya. As the chapter points out, new, improved and disease-resistant wheat varieties developed by the Kenya Agricultural & Livestock Research Organisation (KALRO) do not
always find their way into the fields of smallholder farmers. Part of the problem is: a lack of awareness and understanding by smallholder farmers on how to grow a good wheat crop, poor access to affordable, genuine, certified seed, and inadequate dissemination platforms to educate and engage smallholder farmers. It describes the two-year Agri-Transfer technology transfer project. This has used measures such as farmer-managed trials and demonstrations, a wheat production handbook and farmer-managed certified seed production schemes to improve adoption rates.

Wheat is the principal staple food in most countries of the Central and West Asia and North Africa (CWANA) region, accounting for 45% of the region’s per capita calorie intake with an average wheat consumption of about 200 kg/capita/year. Wheat production in the region has increased in recent decades but most of the countries in the region are still unable to meet their national demand. After reviewing the major wheat production environments in the region, Chapter 11 reviews the main challenges of wheat production, the available wheat production technologies and the ways forward to improve wheat production while conserving the natural resource base in the region. Areas for improvement discussed include the use of: modern varieties (MV), sustainable nutrient and water management, crop rotation systems and other conservation agriculture techniques as well as integrated pest management.

The chapter then shows how these techniques were effectively deployed in sustainable intensification programmes. Different approaches were followed in each country to disseminate improved wheat packages (including improved varieties, fertilizers, irrigation frequency and raised-bed management). Yield results of participating farmers in all countries showed that increases under all production systems (i.e. irrigated, supplementary irrigated or rain-fed) were achievable through the use of improved technologies as compared to the use of farmers’ own practices. An average increase of 27% over a five year period was achieved in the fields of participating farmers across all countries involved.

It has been estimated that wheat production in South Asia needs to grow at the rate of 2–2.5% annually until the middle of 21st century to feed its population. As Chapter 12 points out, China exemplifies both the successes and the continuing challenges of improving wheat yields. Chinese wheat production experienced rapid growth after the beginning of hybridization. However, more intensive cultivation has led recently to serious problems such as decline in soil fertility, environmental pollution and concerns about remaining water resources. These problems have resulted in significant yield variations and slowing yield improvement. The chapter reviews a number of key ways of addressing these challenges and improving cultivation in Asia. These include: enhancing and exploiting genetic diversity, improving breeding techniques, methods for dealing with biotic and abiotic stresses, improving aspects of grain quality and developing more efficient and sustainable cultivation techniques such as the use of conservation agriculture (a theme also highlighted in Chapter 3). The chapter includes a case study showing how improvements have been implemented in India.

Summary

The chapters in Volume 2 summarise a wealth of research on ways of improving wheat cultivation. They discuss a range of individual techniques from variety selection, tillage and planting through to water management and reducing post-harvest losses. They also
show the broader systems which make it possible to select, combine and apply individual techniques, from crop modelling to conservation agriculture (CA). They also show how a holistic approach, as advocated in integrated crop management, can be used, for example, to offset problems in applying CA techniques in certain conditions. Finally, the chapters highlight how important it is to understand the often complex web of constraints which prevent smallholders from adopting new varieties, methods and technologies and deploying them successfully. They highlight the key importance of engaging with farmers and involving them from the start, for example in participatory breeding programmes, if initiatives to support them are to be appropriate, and innovations designed to help them are to be understood, accepted and adopted.
Abiotic stresses
on durum wheat 202–204
and wheat cultivation, in Asia 267–269
and wheat production, in CWANA 291
and wheat variety selection 15–16
AGFACE. see Australian Grains FACE (AGFACE)
Agri-transfer
farmer-managed certified seed production 252
farmer-managed trials and demonstrations 251–252
overview 250–251
wheat production handbook 252
Agronomists, and ICM challenges 151–153
conservation agriculture 145–148
genotype, environment and management (GxExM) 148–151
APSIM crop modelling system 126
Asia, wheat cultivation in
and abiotic stresses 267–269
and biotic stresses 266–267
and genetic improvement 262–264
improving breeding techniques 264–266
improving cultivation practices 270–271
improving quality aspects 269–270
in India 271–274
overview 261–262
Australian Grains FACE (AGFACE) 115–116
Biophysical limitations, and wheat cultivation addressing 246–248
climatic issues 242
pests and diseases 243
soil fertility 242–243
varieties and seeds 243–244
Biotic stresses
and wheat cultivation, in Asia 266–267
and wheat production, in CWANA 291
and wheat variety selection 15–16
BMS. see Breeding Management System (BMS)
Breeding
for drought tolerance 293
of durum wheat
doubled haploids 215–216
marker-assisted selection (MAS) 216–218
for quality 296
Breeding Management System (BMS) 127
CA. see Conservation agriculture (CA)
Central and West Asia and North Africa (CWANA), wheat production in
adaptive genes from genetic resources 303
challenges to
abiotic and biotic stresses 291
limited availability and high price of inputs 291–292
yield gap 292
climate-smart wheat technologies 303
conservation agriculture (CA) 298–299
and grain quality segregation 304
integrated pest management (IPM) 300–301, 304
intensification of 301–303
major 290–291
modern varieties (MVs)
breeding for drought tolerance 293
breeding for quality 296
high-yielding and disease-resistant wheat varieties 293–295
overview 292–293
seed production and distribution 296–297
overview 287–290
policies and working environments 304–305
regional and international networks 305
seed delivery systems 304
sustainable crop rotation systems 297–298
sustainable nutrient management 297
wheat water management 299–300
Climate change, and wheat crop modelling
global climate models (GCMs) 117–118
other impact factors 120–121
rainfall 118–119
scaling 118
temperature 119–120
Climate-smart wheat technologies 303
Conservation agriculture (CA) 145–148, 298–299
Conservation tillage (CT) wheat
agronomic and economic impacts of 45–49
constraints to
developments in 53–55
heterogeneous technology impacts 50–51
institutional and policy hurdles 51–53
limited information availability and access 49
diffusion, factors affecting 43–45
overview 41–43
Consumer demand, and wheat variety selection 16–17
Conventional wheat vs. organic wheat 187–188
Crop establishment, and root development
elongation and growth 27
embryo size and seed mass 33–35
overview 25–26
research contributions to 35–36
resource acquisition and yield  28
root system architecture  28
seed rate  31
semenial and nodal root axes  26–27
and sowing
  depth of  31–33
  time  28–30
  wetness and dryness  33
Crop management, and wheat variety selection  14–15
Crop rotations
  organic wheat and spelt
    concentration  169–170
    conditions of cultivation  178–179
    importance of  169
    reducing pests, diseases and weeds  170–172
    for supplying nutrients  172–174
    types of  174–178
Cultivars and traits  122
Domestication, and wheat variety selection  5
Doubled haploids  215–216
Drought tolerance, and WUE  78–79
Durum wheat
  abiotic stresses on  202–204
  breeding technologies
    doubled haploids  215–216
    marker-assisted selection (MAS)  216–218
  diseases of
    Fusarium head blight (FHB)  208–210
    leaf spotting complex  207–208
    wheat rusts  205–207
    end-use quality of  212–215
    insect pests of  210–212
    overview  199–200
  yield and agronomic traits  200–202
Embryo size and seed mass  33–35
End-use quality, of durum wheat  212–215
ET. see Evapotranspiration (ET)
Evapotranspiration (ET)  70
Extrapolation, and wheat crop modelling
  field  111–113
  global scale  113–114
  region  113
  time  111
  treatments  111
FACE. see Free-air carbon dioxide enrichment (FACE)
Farm biodiversity, and organic wheat
  vs. conventional wheat  187–188
  vs. other organic crops  188
  wheat management  188–189
Farmer(s)
  -managed certified seed production  252
  -managed trials and demonstrations  251–252
and wheat crop modelling  126–127
wheat variety selection by participatory varietal selection (PVS)  17–18
seed cost  18
Farm machinery and labour  244
FHB. see Fusarium head blight (FHB)
Free-air carbon dioxide enrichment (FACE)  115
Fusarium head blight (FHB)  208–210
GCMs. see Global climate models (GCMs)
Gender and food security  100–101
Genetic improvement, and wheat cultivation  262–264
Genomic selection  10–11
Genotype, environment and management (GxExM)  148–151
Global climate models (GCMs)  117–118
Grain quality segregation, and wheat production  304
GxExM. see Genotype, environment and management (GxExM)
Hot serial cereal (HSC)  116
HSC. see Hot serial cereal (HSC)
India, wheat cultivation  271–274
Insect pests, of durum wheat  210–212
Integrated Breeding Platform  127
Integrated crop management (ICM) and agronomists
  challenges  151–153
  conservation agriculture  145–148
  genotype, environment and management (GxExM)  148–151
  overview  143–145
  for wheat stem sawfly (WSS)  153–158
  and decision support system  157–158
  harvest management strategies  156–157
  overview  153–155
  planting and in-crop strategies  156
  pre-crop strategies  155
Integrated pest management (IPM)  300–301, 304
Intensification, of wheat production  301–303
Intercropping, of organic wheat
  with combinable crops  179–181
  with forage crops  181–182
IPM. see Integrated pest management (IPM)
Irrigation
  deficit  76–78
  and drainage  124
  scheduling  75–76
Leaf spotting complex  207–208
Marker-assisted selection (MAS)  216–218
  and wheat variety selection  8–10

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Modern varieties (MVs)
  breeding for drought tolerance 293
  breeding for quality 296
  high-yielding and disease-resistant wheat varieties 293–295
  overview 292–293
  seed production and distribution 296–297

MVs. see Modern varieties (MVs)

Natural resource management (NRM)
  cultivars and traits 122
  irrigation and drainage 124
  managing seasonal variability 124–126
  nitrogen fertilization 122–123
  sowing 121
  spatial variability 124

Natural selection, of wheat variety 4

Nitrogen application rate 114–115

Nitrogen fertilization 122–123

NRM. see Natural resource management (NRM)

Organic wheat and spelt
  breeding and variety choice 182–183
  crop rotations
    concentration 169–170
    conditions of cultivation 178–179
    importance of 169
    reducing pests, diseases and weeds 170–172
    for supplying nutrients 172–174
    types of 174–178
    examples 184–187
  and farm biodiversity
    vs. conventional wheat 187–188
    vs. other organic crops 188
    wheat management 188–189
  intercropping
    with combinable crops 179–181
    with forage crops 181–182
    mixtures and populations 183–184
    overview 167–169

Participatory varietal selection (PVS) 17–18

Phenotyping 11–12

Plant breeders, and wheat variety selection
  biotic and abiotic stresses 15–16
  consumer demand 16–17
  crop management practices 14–15
  environment and location 12–14

Post-harvest wheat losses, in Africa
  crop production information 90–91
  description 91–98
  gender and food security 100–101
  information flow and training requirements 99–100
  methods 88
  overview 85–88
  prevention of 99

PVS. see Participatory varietal selection (PVS)

Rainfall, and wheat crop modelling 118–119

Resource acquisition and yield 28

Root system architecture 28

Scaling, and wheat crop modelling 118

Seasonal variability, managing 124–126

Seed cost, and wheat variety selection 18

Seed delivery systems 304

Seed mass and embryo size 33–35

Seed production and distribution 296–297

Seed rate 31

Seminal and nodal root axes 26–27

Smallholder wheat cultivation
  agri-transfer
    farmer-managed certified seed production 252
    farmer-managed trials and demonstrations 251–252
    overview 250–251

  wheat production handbook 252

  biophysical limitations
    addressing 246–248
    climatic issues 242
    pests and diseases 243
    soil fertility 242–243
    varieties and seeds 243–244
    overview 237–241

  socio-economic limitations
    addressing 248–249
    farm machinery and labour 244
    finance 245
    information and advice 244–245
    land 244
    post-harvest handling 244
    women in 245–246

  Socio-economic limitations, and wheat cultivation
    addressing 248–249
    farm machinery and labour 244
    finance 245
    information and advice 244–245
    land 244
    post-harvest handling 244

  Soil and water conservation 74–75

  Soil fertility 242–243

  Sowing 121
  and crop establishment
    depth of 31–33
    time 28–30

  Spatial variability 124

  SRA. see Strategic Research Agenda (SRA)

  Strategic Research Agenda (SRA) xix–xx

  themes of
    agronomy and crop management xxvi–xxvii
controlling wheat diseases and pests xxii–xxiii
enabling technologies and methods xxix–xxx
ensuring high quality and safe wheat supply xxviii–xxix
natural resource management (NRM) cultivars and traits 122
irrigation and drainage 124
managing seasonal variability 124–126
nutrient fertilization 122–123
sowing 121
spatial variability 124
overview 107–110
Sustainable crop rotation systems 297–298
Sustainable nutrient management 297

Temperature, and wheat crop modelling 119–120

Water management and evapotranspiration (ET) 70
irrigation deficit 76–78
and irrigation scheduling 75–76
overview 63–68
soil and water conservation 74–75
water-use efficiency (WUE) 70–71
and drought tolerance 78–79
wheat yield-ET relationship 71–73
winter wheat yield 68–69
yield determination 70
Water stress experiment 115
Water-use efficiency (WUE) 70–71
and drought tolerance 78–79
Wheat breeding for drought tolerance 293
durum doubled haploids 215–216
marker-assisted selection (MAS) 216–218
for quality 296
Wheat crop modelling and climate change
global climate models (GCMs) 117–118
other impact factors 120–121
rainfall 118–119
scaling 118
temperature 119–120
decision support for farmers 126–127
experiments for testing
Australian Grains FACE (AGFACE) 115–116
free-air carbon dioxide enrichment (FACE) 115
hot serial cereal (HSC) 116
nitrogen application rate 114–115
water stress experiment 115
extrapolation field 111–113
global scale 113–114
region 113
time 111
treatments 111
wheat field potential growth xx–xxi

The Wheat Initiative, xix–xx
Wheat management, and organic wheat 188–189

Wheat production, in CWANA
adaptive genes from genetic resources 303
challenges to abiotic and biotic stresses 291
limited availability and high price of inputs 291–292
yield gap 292
climate-smart wheat technologies 303
conservation agriculture (CA) 298–299
and grain quality segregation 304
integrated pest management (IPM) 300–301, 304
intensification of 301–303
major 290–291
modern varieties (MVs) breeding for drought tolerance 293
breeding for quality 296
high-yielding and disease-resistant wheat varieties 293–295
overview 292–293
seed production and distribution 296–297
overview 287–290
policies and working environments 304–305
regional and international networks 305
seed delivery systems 304
sustainable crop rotation systems 297–298
sustainable nutrient management 297
wheat water management 299–300
Wheat rusts 205–207
Wheat stem sawfly (WSS) and ICM 153–158
   and decision support system 157–158
   harvest management strategies 156–157
   overview 153–155
   planting and in-crop strategies 156
   pre-crop strategies 155
Wheat variety selection
   and domestication 5
   by farmers
      participatory varietal selection (PVS) 17–18
      seed cost 18
   genomic selection 10–11
   and marker-assisted selection (MAS) 8–10
   natural selection 4
overview 3
   and phenotyping 11–12
   by plant breeders
      biotic and abiotic stresses 15–16
      consumer demand 16–17
      crop management practices 14–15
      environment and location 12–14
      in post-Mendelian era 6–7
      in pre-Mendelian era 5–6
      selection by humans 4–5
Wheat water management 299–300
Winter wheat yield 68–69
WSS. see Wheat stem sawfly (WSS)
Yield/agronomic traits, of durum wheat 200–202
Yield Prophet 126