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Achieving sustainable cultivation of wheat

Volume 2: Cultivation techniques

Edited by Professor Peter Langridge
University of Adelaide, Australia

WHEAT INITIATIVE

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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.

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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

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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

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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

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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

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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.

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