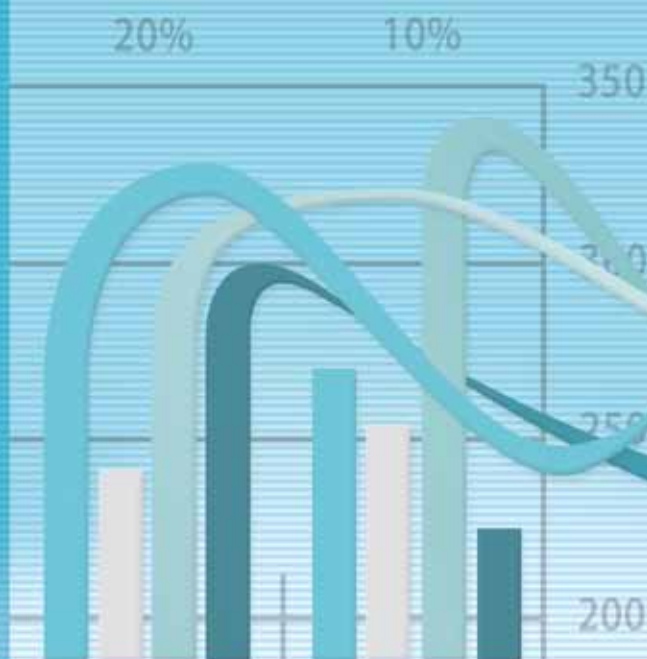


# LOOKING AHEAD IN WORLD FOOD AND AGRICULTURE: Perspectives to 2050

Edited by **Piero Conforti**



**AGRICULTURAL DEVELOPMENT ECONOMICS DIVISION  
ECONOMIC AND SOCIAL DEVELOPMENT DEPARTMENT**



# **LOOKING AHEAD IN WORLD FOOD AND AGRICULTURE: Perspectives to 2050**

*Edited by Piero Conforti*

**Food and Agriculture Organization of the  
United Nations, 2011**

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## FOREWORD

Anticipating future developments in global agriculture is by no means a simple exercise. In the last few years, many of the acute phenomena observed have complicated further the formulation of long-term prospects. The turbulence of world agricultural markets, the price spikes of 2008 and 2011, the wide climate variability experienced in important production regions, and the enhanced linkage among agriculture and other markets such as the energy and the financial markets have propelled interest in revisiting the relations among agriculture, its natural resource basis, economic development, food security and population growth. Discussions of the relationships among these phenomena are lively, as are those on what can be done to prevent the onset of more frequent and more critical conditions in the coming decades.

Given its various fields of expertise, FAO is at the centre of the technical debate on these themes. In 2009, FAO organized an expert meeting and forum around the question of “How to feed the world in 2050”. This initiative was supported by papers authored by world-class experts. This work has been revisited, and is now presented in this volume.

Several aspects of the perspectives for global agriculture are analysed. FAO’s last global projection exercise to 2050 indicates that agricultural and food demand is expected to slow over the next decades, following slowing population growth and raising incomes. However, population will still grow considerably in the coming decades, and require world agricultural production to increase substantially by 2050. The macroeconomic outlook indicates that economic growth may bring significant reductions in poverty in the 2050 horizon, but climate change may impose additional constraints, particularly through increased pressures on land and water resources. Biofuel development may be another source of stress for markets, depending on the ability of technology to reduce the overlap between energy feedstock and food products.

Other areas explored in the volume are natural resources – notably land and water – as well as capital, investment and technology. Regarding natural resources, the amounts of land and water available at the global level are most

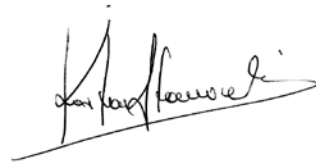
probably sufficient to support the projected production increases. By 2050, the FAO baseline points to some net expansion of arable land, all in developing countries. However, the bulk of production increase will need to be generated through increased yields.

Technically, there seems to be considerable scope for pushing the agricultural technology frontier outwards. But much could also be done by simply applying existing technologies. To this end, farmers and other stakeholders along value chains need to receive the correct scarcity signals from markets to be able to access appropriate inputs and to invest. Global fixed capital stock in agriculture has been growing steadily over the last three decades, although at declining rates. Research is shown to be among the most productive investments for supporting agriculture, together with education, infrastructure and input credits. The concluding part of this volume takes stock of areas where consensus seems to emerge and those where controversies loom large. It identifies areas in which more information and analytical work are required and, last but not least, it provides insights into the strategies and policies to be enacted in support of global agriculture in the 2050 perspective.

In publishing this volume, FAO aims to keep the debate alive. The various chapters bring to the fore not only what we know about the long-term future of global agriculture, but also what we do not know, and the weaknesses of the methodologies used to make projections.



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## ACRONYMS

ACIAR	Australian Centre for International Agricultural Research
ACS	agricultural capital stock
AEZ	Agro-Ecological Zone (model)
AGVP/PC	agricultural gross value of production per capita
AKST	agricultural knowledge, science and technology
ARI	agricultural research intensity ratio
AR4	Fourth Assessment Report (IPCC)
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
ASTI	Agricultural Science and Technology Indicators
AY	attainable yield
AYa	attainable yield under current economics
AYb	attainable yield under efficient institutions and markets
CAADP	Comprehensive Africa Agriculture Development Programme
CARD	Centre for Agriculture and Rural Development
CARDI	Caribbean Agricultural Research and Development Institute
CATIE	Tropical Agricultural Research and Higher Education Center
CBS	country balance sheet(s)
CDM	Clean Development Mechanism
CGE	computable general equilibrium (model)
CGIAR	Consultative Group on International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Center
CIRAD	International Cooperation Centre of Agricultural Research for Development
CO <sub>2</sub>	carbon dioxide
CSIRO	Commonwealth Science and Industrial Organization
CV	coefficient of variation
DEA	data envelopment analysis
DSSAT	Decision Support System for Agrotechnology Transfer
EM	expert meeting

ENVISAGE	ENVironmental Impact and Sustainability Applied General Equilibrium (model)
EU	European Union
FAPRI	Food and Agricultural Policy Research Institute
FBS	food balance sheet(s)
FDI	foreign direct investment
FT	Fischer-Tropsch (diesel)
FTE	full-time equivalent
FY	farm yield
GAEZ	Global Agroecological Zones Study
GCM	general circulation model
GDP	gross domestic product
GEO	Global Environmental Outlook
GHG	greenhouse gas
GIDD	Global Income Distribution Dynamics
GIS	Geographic Information System
GMC	global middle class
GTAP	Global Trade Analysis Project
HGCA	Home Grown Cereal Authority
HI	harvest index
HIC	high-income country
IAASTD	International Assessment of Agricultural Science and Technology for Development
ICOR	incremental capital output ratio
ICP	International Comparison Project
ICRISAT	International Crop Research Institute for the Semi-Arid Tropics
IEA	International Energy Agency
IF	International Futures (model)
IFPRI	International Food Policy Research Institute
IIASA	International Institute for Applied Systems Analysis
IITA	International Institute of Tropical Agriculture
IMF	International Monetary Fund
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IP	intellectual property
IPCC	Intergovernmental Panel on Climate Change

IR	Interim Report
IRD	Institute of Research for Development
IRRI	International Rice Research Institute
JIRCAS	Japan International Research Center for Agricultural Sciences
K	potassium
LMY	low and middle-income country
LUT	land utilization type
MARS	marker-assisted recurrent selection
MAS	marker-assisted selection
MDER	minimum daily/dietary energy requirement
MDG	Millennium Development Goal
MEA	Millennium Ecosystem Assessment
MIROC	Model for Interdisciplinary Research on Climate
MUV	Manufacturing Unit Value index
MV	modern varieties
N	nitrogen
NARS	National Agricultural Research Systems
NCAR	National Center for Atmospheric Research
NCD	non-communicable disease
NEPAD	New Partnership for Africa's Development
NUE	nitrogen use efficiency
ODA	official development assistance
OECD	Organisation for Economic Co-operation and Development
OFID	OPEC Fund for International Development
OPEC	Organization of the Petroleum Exporting Countries
P	phosphorus
PAR	photosynthetically active radiation
ppm	parts per million
PPP	purchasing power parity
PWT	Penn World Tables
PY	potential yield
PY <sub>w</sub>	water-limited potential yield
R&D	research and development
ReSAKSS	Regional Strategic Analysis and Knowledge Support System
RUE	radiation use efficiency



SAP	standard accounting procedure
SAR	Special Administrative Region
SME	small and medium enterprise
SNS	sensitivity (scenario)
SOFI	The State of Food Insecurity in the World
SRES	Special Report on Emissions Scenarios
SUA	supply utilization account
TAR	target (scenario)
TDW	total above-ground dry weight
TE	transpiration efficiency
TFP	total factor productivity
TOE	tonne(s) of oil equivalent
TV	traditional varieties
UN	United Nations
UNEP	United Nations Environment Programme
USDA	United States Department of Agriculture
WEO	World Energy Outlook
WFS	World Food System (model)
WTO	World Trade Organization

## INTRODUCTION

Piero Conforti

The last few years have witnessed a revamping of the debate on the relations among agriculture, natural resources, population growth and economic development. Various events, taking place within a short time span, have driven such renewed interest. Weather variability has seemed to accelerate, deeply affecting agricultural production around the world. Food and energy prices have shown large swings, while the biofuel industry has been expanding rapidly in some countries. Financial investment in agricultural commodity-based derivatives has grown at a fast pace, while large international investments in land, especially targeting developing countries, have gained the newspaper headlines.

These phenomena, and the relations among them, are complex in nature and enmeshed in a wide technical debate involving a host of different subjects and fields of expertise. Controversies loom large, but consensus seems to be emerging, at least around a few facts. For instance, the fact that agriculture has been neglected in many developing countries, and that this has at least accentuated the negative consequences of the events of recent years; and the fact that the phenomena observed – such as the 2008 spike in agricultural prices and the peak in 2011 – are acute symptoms generated by the combination of several causes. Beyond these facts there are no simple answers or solutions to the many questions and problems posed by current events. Some experts and commentators stress the finite dimension of natural resources available on the planet. Global population is growing at a decreasing pace, but is expected to continue growing over the next decades. And in certain regions the pressure on natural resources is already approaching critical levels.

Information and discussion on what is to be expected in the coming decades seem to be in high demand. How are the evolution of demand and supply in the next decades going to shape agricultural markets? How are long-term growth prospects and the expected evolution of per capita income going to affect agriculture and food production? Are the natural resources available, such as land and water,

sufficient to feed a growing population? What role can economic incentives and technical change play in shaping supply? And what are the priority areas where investment and research should be directed? How may the use of agricultural products in biofuel production affect markets? How can climate change affect production possibilities, and hence markets? Projections and impact analyses of these phenomena are subject to a wide debate; some figures point to catastrophic outcomes, albeit with attached probability values that are, fortunately, smaller than one.

In such a context, it is imperative to attempt to gain a better understanding of how these perspective events may interact. All of them directly affect food security, and especially the ability of vulnerable population groups to express an effective demand on the market, to produce enough food sustainably, and to earn a viable income. Agriculture plays a notoriously vital role in the dynamic of poverty, given that a large share of the poor make their living directly or indirectly from this sector.

In 2009, FAO's Economic and Social Development Department organized an expert meeting and high-level expert forum around the question of "How to feed the world in 2050". The scientific basis of this initiative was provided by world-class experts, who analysed key aspects of the matter, including population, poverty and macroeconomic developments; investment and technology; and markets and price development, the connection between food and energy markets, and the impact of climate change.

This volume follows up on these events in two ways. First, the volume proposes a selection of revised and updated results – which in some cases resulted from the interaction of experts after the 2009 expert meeting – and takes stock of the conclusions reached, highlighting areas where there is fundamental consensus, and those where more information and analytical work are required. Second, the results form the basis of discussion of the strategies and policies that can be considered to prepare global agriculture for the 2050 perspective.

Needless to say, the volume is far from exhaustive on all of these issues, and some of them are almost absent. Environmental issues and related policies are hardly emphasized, but contributions are made to the debate on resources and their availability for agricultural production. The debate surrounding the volatility of food prices, its causes, consequences and related policies is also outside the domain of this volume, along with the debate on the relation between agriculture and financial markets, and discussion of the dynamics of foreign direct investment.

Many of the contributions to the 2009 expert meeting collected in this volume report on projection exercises. It is worth emphasizing that these are not meant to be speculations on the future; rather, they aim to fuel a discussion

of how the phenomena observed today may evolve and combine in the future. Their ultimate goal is to offer insights into what can be done today to shape some underlying trends. In so doing, projections also help to identify which of the many phenomena observed today may be long-lasting and may produce significant impacts in the future.

The volume is divided into four main parts. The first part, The global agriculture outlook, reports the results of three fairly comprehensive projection exercises produced by FAO, the International Food Policy Research Institute (IFPRI) and the International Institute for Applied Systems Analysis (IIASA).

Chapter 1, by N. Alexandratos, analyses the perspectives of global agriculture to 2050, using as a starting point the base period 1999 to 2001. Alexandratos works around the latest global projection exercise produced by FAO (2006), known and quoted as the “Interim Report”, whose main results are summarized in an Annex at the end of the chapter. Alexandratos validates the results of the 2006 exercise. First he analyses how projections compare with recent developments observed in world agricultural markets. Second, the chapter looks at how the projections in the FAO (2006) report compare with those formulated three years later for the Organisation for Economic Co-operation and Development (OECD)/FAO Outlook. These are based on more recent information – the 2008 price spike had already occurred – and for the period from 2009 to 2018. This part of the validation also looks at the market impact of the increased use of crops by the biofuel industry. The chapter revisits food consumption projections formulated on the 1999/2001 base, and projections of the number of undernourished people in developing countries. Over the last years, food consumption data have been considerably revised, as have the parameters used to compute numbers of undernourished and population projections. The results presented by Alexandratos are not based on a single equilibrium model; rather, they are generated through an accounting system that projects demand and supply for 110 countries and 34 agricultural products using a wealth of econometric technical parameters and geo-referenced data.

A different approach is taken by the second projection exercise presented in this part of the volume, prepared by S. Msangi and M. Rosegrant. Contrary to Alexandratos, these authors base their projections on intensive modelling, using the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), developed by IFPRI. This model has been extensively used to project long-term global food supply and demand and food security. A set of counterfactual scenarios are analysed to gain insights into the impact that market drivers such as income and population have on world food prices, production and food security. Another set of simulations focus on three specific aspects:

the development of the biofuel industry, which is deemed to have significantly affected world prices in 2008; the potential role of technical change in world markets, particularly yield-increasing innovations, and their impact on food security; and climate change, which is assumed to have a significant impact on markets in the coming decades. Scenarios are run also to understand how increases in agricultural production and productivity may offset the increased use of feedstocks in the bioenergy industry, in terms of world prices and changes in the nutrition status of vulnerable population groups. The chapter concludes with a discussion of the prospects for food security, and some policy implications.

The last projection exercise included in the first part of this volume is authored by G. Fischer. This chapter focuses mainly on the development of biofuels and the impact of climate change. The analysis is deeply rooted in geo-referenced data, coupled with an economic equilibrium model. Geo-referenced data are drawn from the FAO/IIASA Agro-Ecological Zone (AEZ) model, while the economic equilibrium model used is the IIASA World Food System (WFS) model. Concerning climate change, Fischer starts from country-level assumptions of gross domestic product (GDP) growth and their likely impact on main environmental variables, particularly greenhouse gas emissions and atmospheric concentrations of carbon dioxide (CO<sub>2</sub>). The impacts of the resulting climate change scenarios are analysed on the basis of geo-referenced data, to understand how the potential for agriculture and food production may change over the coming decades. This allows the computation of projected changes in yields. In building biofuel development scenarios, Fischer draws on the 2008 World Energy Outlook (WEO), which reports projections on energy uses. This same source is employed to derive assumptions on future shares of biofuels in total energy. Simulations also analyse the uncertainty about technical change, by specifying alternative patterns of diffusion and reduction in the use of traditional feedstocks, such as sugar and maize. The consequences of alternative scenarios are analysed mainly in terms of relative prices, production, consumption, trade and number of people at risk of hunger.

The second part of the volume, Growth, poverty and macroeconomic prospects, discusses the evolution of macro variables and income distribution. Growth plays a key role in shaping the economic environment in which agriculture is expected to operate. At the same time, in several countries, the macroeconomic framework is directly affected by what happens in agriculture. This is particularly the case for poorer countries, where agriculture is still the backbone of the economy, and the agriculture sector's performance is more closely related to food insecurity. This second part of the volume consists of two chapters.

The first, by E. Hillebrand, analyses the outlook for growth, poverty and inequality. The author starts from the observation that global poverty rates have

fallen in the last 50 years, while income inequality has increased, as shown by the growing distance between OECD countries and the rest of the world. Hillebrand applies an accounting procedure to forecast poverty levels based on exogenous GDP projections, assuming constant income distribution and a constant ratio of consumption to income. Reduced-form equations are employed to compute an elasticity of the poverty headcount ratio to income growth. The chapter analyses two main scenarios. The first, called “market first”, is optimistic, and implies fast growth and the tendency for poor countries to converge rapidly towards OECD ones. The second scenario, “trend growth”, is more pessimistic. It assumes that countries continue to evolve along the paths observed over the last 25 years, which means continued fast growth in some countries, such as China and India, and more mixed outcomes in Latin America, the Near East and Africa. Projections of poverty turn out to be sensitive to assumptions on population growth and the resource outlook. Projections also turn out to be quite sensitive to the assumption, embedded in all scenarios, that technical change can address the limitations imposed by finite resource availability. The author correctly notes that a number of common assumptions in forecast exercises are highly questionable: technology is not necessarily a residual, as in Solow-type models; and catching up is not a necessary outcome, especially if institutions and investment are not adequate.

On related themes, the second contribution in this part of the volume is the chapter by D. van der Mensbrugge, I. Osorio-Rodarte, A. Burns and J. Baffes. Focus here is on the linkage between poverty and commodity markets. The analysis is wide, and dwells on a number of aspects, starting from experience of the 2008 and 2010/2011 price spikes and their causes. The chapter analyses how commodity price formation can be affected in the future by growth prospects, and the related expansion of consumption, which is expected to take place mostly in developing countries and emerging economies. The impact of climate change, particularly on production and trade, is also analysed, along with the increased interdependence between energy and non-energy markets. The interaction among macro variables, the environment and commodity markets is studied through the World Bank general equilibrium global model called ENVIRONMENTAL Impact and Sustainability Applied General Equilibrium Model (ENVISAGE). This is a so-called “integrated assessment model”, which specifies the relations among economic activity, greenhouse gas emissions and temperatures up to 2100. Scenarios analysed concern climate change, the evolution of agricultural productivity, and its potential impact on agricultural commodity prices, with special reference to developing countries. Prospects for poverty to 2050 are analysed with the World Bank’s Global Income Distribution Dynamics (GIDD) model.

The third part of the volume is titled Land, water and capital requirements, and is made up of three chapters that propose, respectively, quantifications of natural resources, human-made capital, and investment to satisfy agricultural and food demand projected in 2050.

Chapter 6, by J. Bruinsma, discusses the outlook for natural resources to 2050, and deals with the *vexata quaestio* of whether resources available on the planet are sufficient to support the population expected in 2050. As the starting point, the author takes the FAO baseline projections to 2050, partially revised with updated information for recent years, and analyses the implications of the expected size of demand and supply in terms of land use, water use and crop intensification. Consistent with the FAO approach to long-term projections, the analysis is not based on alternative scenarios. Similar to Fischer's work in Chapter 3, it relies on the FAO-IIASA AEZ database. For land, Bruinsma starts from overall potential, and works out an amount of surface that could potentially be converted into arable land, taking into account the constraints to expansion, such as those arising from environmental concerns, the need to protect fragile ecologies, and the lack of infrastructure. Projections on water use rely on the FAO ACQUASTAT database, and a wealth of scattered information for specific countries. The author projects the likely expansion of areas equipped for irrigation, water use efficiency and a measure of pressure on water resources.

The following two chapters of this third part discuss agricultural capital stock, its evolution over the last decades, and its likely evolution to 2050, given the requirements in terms of predicted agricultural supply. Chapter 7, by S. von Cramon-Taubadel, G. Anriquez, H. de Haen and O. Nivyeviskyi, start by estimating the evolution of capital stocks and investment in agriculture over the last four decades. Two approaches to measuring agricultural capital stocks are proposed, implemented and compared. The first is based on national accounts; it is more comprehensive and allows the capture of a wide set of farming assets, but the necessary data are available for only a few countries. The second method is based on physical inventories reported in FAOSTAT. This information is available for a large set of countries over a long time series, but it covers only a small set of fixed assets in farming; hence this second method is less comprehensive. The relations among capital, investment, agricultural productivity and food insecurity are subsequently analysed in this chapter, and estimates of changes in agricultural TFP are presented. The chapter also explores the role that public expenditure on agriculture has played in encouraging the growth of agricultural capital stock and factor productivity.

Investment requirements to 2050 are analysed in Chapter 8, by J. Schmidhuber, J. Bruinsma and G. Boedeker, with reference to developing countries. The authors

compute the amount of capital required to produce crops and livestock products projected in FAO's long-term outlook to 2050. The idea is that given the technical parameters, projected production quantities can be used to infer the required input use; in other words, given the amount of a certain crop expected to be produced in 2050, the requirements are computed for that production in terms of hectares of land, amount of irrigation, machinery, livestock herds, hand tools, etc. The authors also consider investment in production chains that strictly speaking go beyond primary production, such as those in storage, processing and marketing. No distinction is made between private and public investment.

The fourth and last main part of the volume, *Raising productivity: research and technology*, discusses how research and development (R&D) can contribute to increasing productivity in agriculture, the role of public expenditure and the specific types of technologies that should be emphasized. This part includes two chapters: the first analyses past trends and the current situation, while the second looks at the 2050 perspective.

Chapter 9 is by N. Beintema and H. Elliott and relies extensively on the Agricultural Science and Technology Indicators (ASTI) database, supported by IFPRI. The authors review past trends of investments in agricultural R&D, considering both public and private resources for agriculture. Underinvestment in agriculture is then analysed in three ways: by comparing the rate of return on agricultural research relative to the social rate of return; by considering trends in productivity growth; and by looking at the inability to attain political commitments, such as the Millennium Development Goals (MDGs). The agricultural research intensity ratio (ARI) – the ratio of agricultural R&D investments to agricultural GDP – is computed for a large sample of developing and middle-income countries. The authors analyse ARIs through four components: i) the share of agricultural research in total agricultural expenditure; ii) the share of public expenditure on agriculture in total public expenditure; iii) the share of public revenue and expenditure in GDP; and iv) the inverse of agriculture's share in GDP. The chapter also discusses emerging challenges for agricultural research, such as adaptation to climate change, increasing weather variability and water scarcity.

The following and last chapter in this part, authored by T.R.A. Fischer, D. Byerlee and G.O. Edmeades, discusses the possibility of technology achieving the level of agricultural intensification required to meet expected demand in 2050. Specifically, the chapter discusses yield prospects for three key staple crops – wheat, rice and maize – which are the basis for many consumption patterns around the world. Actual farm yields, attainable yields and potential yields are analysed, along with the constraints that can undermine intensification, ranging from inadequate infrastructure and institutions to farmers' skills and attitude



towards technology. Incentives are also considered among the elements that can affect technology adoption by farmers as well as technology development. The technical possibilities for increasing potential yields are also discussed, including through the use of biotechnology.

The concluding part of the volume also contains two chapters. Chapter 11, by N. Alexandratos, presents a critical review of the projection exercises, highlighting the main messages that can be derived from the previous chapters, the information gaps and inconsistencies, and the methodological differences that lead to different results. Alexandratos organizes his review around five topics: i) the expected behaviour of world food prices; ii) the impact of climate change; iii) the impact of biofuel development on world agricultural markets; iv) the outlook for GDP and global inequality and poverty; and v) the projections for sub-Saharan Africa, which is undoubtedly the most sensitive area, both today and in perspective.

The insights provided by Alexandratos serve as a useful introduction to the following and last chapter, by P. Conforti and A. Sarris. Chapter 12 gives a broad overview on the results, the challenges that they pose in the 2050 perspective, and the policy directions that can be derived from them. A brief discussion of the major areas in which more information and analysis would be useful is also included. The need to shape policy action is one of the main reasons for taking an interest in long-term projections and for attempting to distinguish what are likely to be short-lived phenomena from what are likely to continue having an impact on the world agriculture and food system into the coming decades. The discussion of policy directions is organized around three pillars: measures affecting the demand side of the global food system; measures affecting its supply side; and measures aimed at producing global public goods related to agriculture.

The book seeks to contribute to maintaining the debate on the future of the global agricultural and food economy. Its content was designed to interest both a technical audience and a wider range of professionals working around the world in areas related to agriculture and food security, in both public and private institutions.

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Fuelled by the turbulence of world agricultural markets, the debate on relations among agriculture, food security, natural resources, population growth and economic development has been revamped over the last few years. How are growth prospects and the expected evolution of per capita income in the long term going to affect the agricultural and food economy? Are the natural resources available, such as land and water, sufficient to feed a growing population? What role can economic incentives and technical change play in shaping resource use and supply? What are the priority areas where investment and research should be directed? How may the use of agricultural products in biofuel production affect markets? And how can climate change affect production possibilities and markets? Around these questions, in 2009, FAO's Economic and Social Development Department organized a forum and a high-level expert meeting on How to Feed the World in 2050. This volume follows up on that initiative, by gathering updated versions of technical materials prepared for the occasion, along with further work. The book seeks to sustain the debate on the future of the global agricultural and food economy. Its contents were designed to interest both a technical audience and a wider range of professionals working around the world in areas related to agriculture, in both public and private institutions.



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