Food Security and Environmental Quality in the Developing World

Rattan Lal
David Hansen
Norman Uphoff
Steven Slack

LEWIS PUBLISHERS

Foreword by Lester R. Brown

Food Security and Environmental Quality in the Developing World

Rattan Lal
David Hansen
Norman Uphoff
Steven Slack

Foreword by Lester R. Brown

LEWIS PUBLISHERS

A CRC Press Company
Boca Raton London New York Washington, D.C.

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Version Date: 20131024

International Standard Book Number-13: 978-1-4200-3221-5 (eBook - PDF)

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

Foreword

The new century has begun with some of the lowest grain prices in recent memory. From an economist's vantage point, this is a sure sign of excess production capacity. However, there may be more here than meets the economist's eye.

Natural scientists, many of whom have contributed to this volume, see something very different. They see reason to be concerned about such issues as the overplowing of land and the overpumping of aquifers. They look at sustainable production and see a worrisome fraction of world food output being produced with the unsustainable use of land and water.

They see countries abandoning rapidly eroding cropland, much of it land that should never have been plowed. Kazakhstan, the site of the Soviet Union's virgin lands project in the 1950s, has abandoned half its grainland since 1980. In northwestern China, agriculture is retreating southward and eastward. In an effort to stem the encroachment of the desert on its cropland, Algeria is abandoning the production of grain on the southernmost 20% of its cropland, converting this land to orchard crops such as olive orchards and vineyards. To the south of the Sahara, Nigeria is losing 200 square miles of productive agricultural land each year.

The situation with water, the other basic resource used in food production, is no more encouraging. My Worldwatch colleague Sandra Postel, using data for China, India, the Middle East and the United States, estimates that we are overpumping aquifers by 160 billion tons of water per year. Using the rule of thumb of 1000 tons of water to produce 1 ton of grain, this suggests that 160 million tons of grain, or some 8% of the global harvest, are being produced with the unsustainable use of water. At the average world consumption level of a third of a ton of grain per person per year, this means that 480 million of the world's 6.1 billion people are being fed with grain that is produced with an unsustainable supply of water.

We've made impressive gains in raising world grainland productivity over the last half century, raising it from just over 1 ton of grain per hectare worldwide to nearly 3 tons per hectare today. We now need to think about systematically raising water productivity. Today it is water, not land, that is the principal constraint on our efforts to expand the world food supply. Just as India began to systematically raise land productivity with the new high-yielding wheats and rices 35 years ago, it must now devote similar energies to raising water productivity if it is to feed its 1 billion-plus people.

Over the last half century, the world added 3.4 billion people. During that period, we reduced the share of people in the world who were hungry, but the absolute number who were hungry increased. Now we are facing the addition of 3 billion more people over the next half-century. There is one difference, however, in that these 3 billion will all be added in developing countries, most of them already facing water shortages.

Given the dimension of the challenge the world faces on the food front, not only do we need this book for India, but many more like it if we are to keep focused on the effort to secure food supplies for all of humankind.

Lester R. Brown
President
Earth Policy Institute

Preface

The second half of the 20th century witnessed great advances in science and its application to enhance agricultural production in the world. Success in this endeavor is illustrated by the following data: the per capita cereal production in developed countries was 678 Kg/person/yr in 1980 and is expected to be 722 kg/person/yr in 2010. Per capita cereal production also increased in developing countries, but the total volume was less than one third of that in developed countries. Per capita cereal production in developing countries was 200 Kg/person/yr in 1980 and is projected to be 229 Kg/person/yr in 2010.

India is a microcosm of developing countries when considering biophysical, social, economic and political concerns. Per capita cereal production in India has increased steadily since the 1960s and achieved the level of 232 Kg/person/yr in 2000. Using 1980 as a baseline (1980 = 100 index), the relative index of agricultural production in India grew to 105 in 1982, 121 in 1984, 125 in 1986, 138 in 1988, 149 in 1990 and 160 in 1993. Comparable advances in total agricultural production were made in the 1990s. However, per capita cereal production remained either constant or increased at only a modest rate. While the increase in total food production was impressive, it was achieved at a high cost to environmental quality, reflected in severe soil degradation, widespread pollution and contamination of natural waters, deteriorating air quality in both rural and urban areas and increases in emissions of greenhouse gases into the atmosphere from the agricultural and industrial sectors.

Despite the impressive gains, about 300 million inhabitants of India are food insecure because of their low purchasing power. As the population of developing countries in general, and of India in particular, continues to grow, numerous relevant questions need to be addressed:

- Can developing countries meet the food requirements of their growing population without jeopardizing a natural resource base that is already stressed?
- Can the rate of food production achieved in the last two decades of the 20th century be sustained in the first 2 or 3 decades of the 21st century or until the population is stabilized?
- Can developing countries achieve freedom from hunger and malnutrition for all of their population (including children under 5 and nursing mothers)?
- How can food security be reconciled with environment quality in an industrialized society?

Food security and sustainability are interdependent. In fact, adoption of sustainable systems of agricultural production can minimize risks of soil and environmental degradation. Technological know-how to achieve food security and improve environmental quality exists, is scale-neutral, and can be adopted by resource-poor small landholders of developing countries. However, a need exists to validate and adopt such technology in the context of site-specific biophysical conditions, and socioeconomic, cultural and political factors.

The context reflected in the above discussion formed a background for a 1-day workshop that took place at The Ohio State University on 7 March 2001. The workshop was jointly organized by The Ohio State University and Cornell University. It was preceded by a public lecture by Dr. M.S. Swaminathan entitled Century of Hope. This volume represents the proceedings of this workshop. In addition to the papers presented, several authors were invited to write manuscripts on specific topics (e.g., biotechnology, energy use in agriculture, water harvesting, soil degradation, etc.).

The book is thematically divided into five sections. Section A, entitled Food Demand and Supply, contains eight chapters. As the title suggests, these chapters deal with the state of natural resources (e.g., soil, water, climate), fertilizer and energy needs and the importance of biotechnology. Section B, entitled Environment Quality consists of five chapters that address issues pertaining to water quality and the use of agricultural chemicals, and pesticide residues on food. Section C deals with Technological Options and contains eight chapters. It addresses issues related to water harvesting, post-harvest food losses, storage and processing of animal products, and sustainability and inequality issues. Section D, entitled Poverty and Equity, consists of five chapters and deals with issues of poverty alleviation, microfinance and gender equity. There are four chapters in Section E addressing policy issues and the role of the public sector. Emerging issues and priorities are discussed in the concluding chapter, which is found in Section F.

The organization of the symposium and publication of this volume were made possible by close cooperation between The Ohio State University and Cornell University. Funding support was received from the Ohio Agricultural Research and Development Center (OARDC) and the College of Food, Agriculture & Environmental Sciences (FAES) of The Ohio State University. The editors thank all authors for their outstanding efforts to document, organize and present pertinent information on topics of great concern related to the major theme of the workshop. Their efforts have contributed substantially to enhancing the overall understanding of issues pertaining to food security and environment quality in developing countries.

We offer a special vote of thanks to the staff of CRC Press for their timely efforts to publish this volume, thereby making the information contained herein available to the world community. We also recognize the invaluable contributions by numerous colleagues, graduate students and OSU staff. In particular, we thank Ms. Lynn Everett for her help in organizing the workshop and Ms. Patti Bockbrader for helping with the editorial process. We offer special thanks to Ms. Brenda Swank for her help in organizing the flow of the manuscripts from the authors and for her support in helping with all jobs related to preparing this volume for publication

The Editors

Editors

Rattan Lal is a professor of soil science in the School of Natural Resources at The Ohio State University. Prior to joining Ohio State in 1987, he served as a soil scientist for 18 years at the International Institute of Tropical Agriculture, Ibadan, Nigeria. In Africa, Professor Lal conducted long-term experiments on soil erosion processes as influenced by rainfall characteristics, soil properties, methods of deforestation, soil tillage and crop residue management, cropping systems including cover crops and agroforestry, and mixed or relay cropping methods. He also assessed the impact of soil erosion on crop yield and related erosion-induced changes in soil properties to crop growth and yield. Since joining The Ohio State University in 1987, he has continued research on erosion-induced changes in soil quality and developed a new project on soils and global warming. He has demonstrated that accelerated soil erosion is a major factor affecting emission of carbon from soil to the atmosphere. Soil erosion control and adoption of conservation-effective measures can lead to carbon sequestration and mitigation of the greenhouse effect.

Professor Lal is a fellow of the Soil Science Society of America, American Society of Agronomy, Third World Academy of Sciences, American Association for the Advancement of Sciences, Soil and Water Conservation Society and Indian Academy of Agricultural Sciences. He is the recipient of the International Soil Science Award, the Soil Science Applied Research Award of the Soil Science Society of America, the International Agronomy Award of the American Society of Agronomy, and the Hugh Hammond Bennett Award of the Soil and Water Conservation Society. He is the recipient of an honorary degree of Doctor of Science from Punjab Agricultural University, India. He received the Distinguished Scholar Award of the Ohio State University in 1994, Distinguished University Lecturer in 2000, and Distinguished Senior Faculty of OARDC in 2001. He is past president of the World Association of the Soil and Water Conservation and the International Soil Tillage Research Organization. He is a member of the U.S. National Committee on Soil Science of the National Academy of Sciences. He has served on the Panel on Sustainable Agriculture and the Environment in the Humid Tropics of the National Academy of Sciences. He has authored and co-authored about 1000 research publications.

David O. Hansen has worked in rural and institutional development for 35 years. His work has involved more than 10 years of overseas residence, including Peace Corps volunteer experience in Bolivia, research assignments in Costa Rica, Brazil and the Dominican Republic, long-term university Agency for International Development (A.I.D.) contract assignments in Brazil, short-term consulting A.I.D. assignments in the Dominican Republic, Bolivia, El Salvador, Peru, Brazil and Nicaragua; program development, administration and development experience in

India, China and Eastern and Southern Africa; and a 3-year Joint Career Corps assignment with A.I.D./Washington's Bureau for Science and Technology. His tenure with The Ohio State University includes extensive academic experience, including teaching of development-related courses, advising foreign graduate student thesis and dissertation research and Latin American field research. In addition, Dr. Hansen has had considerable experience with the administration of A.I.D., World Bank and other donor-sponsored university contracts, with administration of the Ohio State rural sociology graduate program, activities of the Rural Sociological Society, the International Rural Sociology Association, the Association for International Agriculture and Rural Development, and other national and international organizations impacting Third World development policies and programs.

Norman Uphoff is director of the Cornell International Institute for Food, Agriculture and Development (CIIFAD) and professor of government at Cornell University. He is also a member of the Steering Committee for Cornell University's Poverty and Inequality in Development Initiative. From 1970–1990, he served as chair of the Rural Development Committee in the Center for International Studies at Cornell and as a member of the Research Advisory Committee of USAID.

Having consulted for USAID, the World Bank, the Ford Foundation, FAO, the U.N., CARE and other organizations, most of Uphoff's research and outreach activities have centered on participatory approaches to development, particularly for agricultural innovation, irrigation improvement, and natural resource management. Geographically, his work has focused most on Ghana, Nepal, Sri Lanka, Indonesia and Madagascar, with current involvement in China and South Africa. His present writing and interests are in addressing agroecology, rice intensification and social capital.

Steven A. Slack has been at The Ohio State University since 1999 as associate vice president for agricultural administration and director of the Ohio Agricultural Research and Development Center. Dr. Slack received his B.S. and M.S. degrees from the University of Arkansas, Fayetteville and his Ph.D. from the University of California, Davis. In 1975, he joined the faculty of the Plant Pathology Department at the University of Wisconsin at Madison and in 1988 he joined the Cornell University faculty as the Henry and Mildred Uihlein Professor of Plant Pathology. He was department chair from 1995–1999. His major area of research interest has been seed potato pathology, especially the epidemiology of viral and bacterial diseases and tissue culture propagation techniques. He is a fellow and past president of the American Phytopathological Society, and is an honorary life member and past president of the Potato Association of America. In 1995, he and colleagues received a USDA Group Honor Award for Excellence for work on a nonpesticidal control strategy for the potato golden nematode. In 1996, he received the Outstanding Alumnus award from the Dale Bumpers College of Agricultural, Food and Life Sciences at the University of Arkansas.

Contributors

R.S. Antil
Department of Soil Science
CCS Haryana Agricultural University
Hisar, Haryana, India

Lopamudra Basu
Department of Animal Sciences
The Ohio State University
Columbus, Ohio

Nirali Bora
Cornell University

Courtney Carothers
Cornell University

Lester R. Brown
Earth Policy Institute
Washington, D.C.

S. K. De Datta
Office of International Research and Development
College of Agriculture and Life Sciences
Virginia Technological Institute
Blacksburg, Virgina

Rachel Doughty
Cornell University

Clive A. Edwards
Department of Entomology
The Ohio State University
Columbus, Ohio

Gary W. Frasier
USDA-ARS
Rangelands Resources Research Unit
Fort Collins, Colorado

Richard R. Harwood
Plant and Soil Science
Michigan State University
East Lansing, Michigan

David O. Hansen
International Programs
The Ohio State University
Columbus, Ohio

Poul Hansen
The Ohio State University
Columbus, Ohio

Peter Hazell
IFPRI
Washington, D.C.

Fred J. Hitzhusen
Agricultural Administration
The Ohio State University
Columbus, Ohio

Prem P. Jauhar
USDA-ARS
Northern Crop Science Laboratory
Fargo, North Dakota

Ramesh S. Kanwar
Department of Agricultural and Biosystems Engineering
Iowa State University
Ames, Iowa

Gurdev S. Khush
International Rice Research Institute
Manila, The Philippines

Laura R. Lacy
M.I.N.D. Institute Research Program
University of California
Davis, California

William Lacy
University Outreach and International Programs
University of California
Davis, California

Rattan Lal
School of Natural Resources
The Ohio State University
Columbus, Ohio

Sonja Lamberson
Cornell University

Katherine Lee
Cornell University

Richard L. Meyer
Agricultural Administration
The Ohio State University
Columbus, Ohio

Judith A. Narvhus
Department of Food Science
Agricultural University of Norway
Aas, Norway

R.P. Narwal
Department of Soil Science
CCS Haryana Agricultural University
Hisar, Haryana, India

Herbert W. Ockerman
Department of Animal Sciences
The Ohio State University
Columbus, Ohio

David Pimentel
College of Agriculture and Life Sciences
Cornell University
Ithaca, New York

K.V. Raman
Deptartment of Plant Breeding
Cornell University
Ithaca, New York

Alan Randall
Agricultural Administration
The Ohio State University
Columbus, Ohio

Paul Robbins
Department of Geography
The Ohio State University
Columbus, Ohio

Amit H. Roy
International Fertilizer Development Co.
Muscle Shoals, Alabama

G. Edward Schuh
HHH Institute of Public Affairs
University of Minnesota
Minneapolis, Minnesota

Sara J. Scherr
Agricultural and Resource Economics Department
University of Maryland
College Park, Maryland

Ashok Seth
Headley, Bordon
Hampshire, U.K.

Shahla Shapouri
USDA-ERS
Washington, D.C.

B.R. Singh
Department of Soil and Water Sciences
Agricultural University of Norway
Aas, Norway

Steve Slack
Ohio Agricultural Research and Development Center
Wooster, Ohio

M.S. Swaminathan
M.S. Swaminathan Research Foundation
Madras, India

Luther Tweeten
Agricultural Administration
The Ohio State University
Columbus, Ohio

Dina Umali-Deininger
World Bank
Washington, D.C.

Norman Uphoff
Cornell University
Ithaca, New York

Gurneeta Vasudeva
Tata Energy and Resources Institute
Arlington, Virginia

Contents

Part I
Food Demand and Supply

Chapter 1 The Century of Hope 1

M.S. Swaminathan

Chapter 2 Natural Resources of India 13

Rattan Lal

Chapter 3 Food Security: Is India at Risk? 31

Dina Umali-Deininger and Shahla Shapouri

Chapter 4 Fertilizer Needs to Enhance Production
— Challenges Facing India 53

Amil H. Roy

Chapter 5 Economic Impacts of Agricultural Soil Degradation in Asia 69

Sara J. Scherr

Chapter 6 Soil Degradation as a Threat to Food Security 89

R.P. Narwal, B.R.Singh and R.S. Antil

Chapter 7 Importance of Biotechnology in Global Food Security 107

Prem P. Jauhar and Gurdev S. Khush

Chapter 8 Energy Inputs in Crop Production in Developing
and Developed Countries 129

*David Pimentel, Rachel Doughty, Courtney Carothers, S. Lamberson,
N. Bora and K. Lee*

PART II
Environment Quality

Chapter 9 Environmental Conflict and Agricultural Intensification in India 155

Gurneeta Vasudeva

Chapter 10 Water Quality and Agricultural Chemicals 169

Ramesh S. Kanwar

Chapter 11 Environmental Quality: Factors Influencing Environmental Degradation and Pollution in India 193

Clive A. Edwards

Chapter 12 Agricultural Chemicals and the Environment 205

David Pimentel

Chapter 13 Applying Grades and Standards for Reducing Pesticide Residues to Access Global Markets 215

K.V. Raman

Chapter 14 Reconciling Food Security and Environment Quality Through Strategic Interventions for Poverty Reduction 229

Ashok Seth

PART III
Technological Options

Chapter 15 Ensuring Food Security and Environmental Stewardship in the 21st Century 237

S.K. De Datta

Chapter 16 Water Harvesting and Management to Alleviate Drought Stress 245

Gary W. Frasier

Chapter 17 Postharvest Food Losses to Pests in India 261

David Pimentel and K.V. Raman

Chapter 18 Storage and Processing of Agricultural Products............................269

Judith A. Narvhus

Chapter 19 Postharvest Food Technology for Village Operations 277

Poul M.T. Hansen and Judith A. Narvhus

Chapter 20 Reconciling Animal Food Products With Security and Environmental Quality in Industrializing India........................287

Herbert W. Ockerman and Lopamudra Basu

Chapter 21 Sustainable Agriculture on a Populous and Industrialized Landscape: Building Ecosystem Vitality and Productivity.............305

Richard R. Harwood

PART IV
Poverty and Equity

Chapter 22 Global Food Security, Environmental Sustainability and Poverty Alleviation: Complementary or Contradictory Goals? 319

William B. Lacy, Laura R. Lacy and David O. Hansen

Chapter 23 Poverty and Inequality: A Life Chances Perspective 331

Norman Uphoff

Chapter 24 Microfinance, Poverty Alleviation and Improving Food Security: Implications for India 347

Richard L. Meyer

Chapter 25 Poverty and Gender in Indian Food Security: Assessing Measures of Inequity...369

Paul Robbins

PART V
Policy Issues

Chapter 26 Priorities for Policy Reform in Indian Agriculture 385

Peter Hazell

Chapter 27 The Role of the Public Sector in Achieving Food Security............393

G. Edward Schuh

Chapter 28 Global Food Supply and Demand Projections
and Implications for Indian Agricultural Policy..............................405

Luther Tweeten

Chapter 29 Context, Concepts and Policy on Poverty and Inequality...............419

Fred J. Hitzhusen

Chapter 30 Sustainable Development: Some Economic Considerations...........431

Alan Randall

PART VI
Issues and Priorities

Chapter 31 Reconciling Food Security with Environmental Quality
in the 21st Century..443

Norman Uphoff

Index..449

Part One

Food Demand and Supply

1 The Century of Hope

M.S. Swaminathan

CONTENTS

Introduction....3
Basis of Optimism....4
An Evergreen Revolution....8
Reaching the Small-Scale Farmer....9
The Biovillage....10
Conclusions....12
References....12

INTRODUCTION

The content of this chapter is based on a book I wrote 2 years ago, also titled *The Century of Hope.* During the same time frame, I also wrote a book about hope's becoming despair. First I will deal with despair and say why there are people who feel that this century will not be a bright one, and then discuss why I believe the reverse will happen. I will use the terms "despair" and "hope" as they relate to the food security front, i.e., sustainable food security. This chapter will be confined to sustainable food security and the prospects of eliminating hunger from this planet, as there are many other aspects of hope or despair. People like Lester Brown, centers such as the Worldwatch Institute, and books like *Who Will Feed China,* reiterate the wide concern regarding the future prospects of sustainable food security.

We can identify numerous global issues that, if ignored, will affect whether we can achieve sustainable food security. First is the issue of continued population growth. China alone has a population of 1.25 billion and India a population of 1 billion, with many other developing countries still having high growth rates. Second, there is environmental degradation as good soil and fertile arable land are removed from agricultural use. Third, there is the problem of water pollution, with groundwater being overexploited and aquifers rapidly disappearing, making water a critical constraint. Biodiversity is also vanishing, largely because of habitat destruction; as Dr. Wilson of Harvard said, "We have entered an era of mass extinctions. Then there are issues such as global climate change. These are all elements that contribute to environmental degradation. Soil, water, climate, biodiversity and forests are the ecological foundations essential for sustainable advances in agriculture. The president of Maldives says, "We talk about endangered species but not about endangered

1-5667-0594-0/02/$0.00+$1.50

nations. The island I reside on would go down and our nation, Maldives, would cease to exist if the sea level rises by a meter or so." There seems to be distinct prospects of this occurring.

Then, of course, there are serious social needs to be addressed, both in terms of inequity and poverty. The cover page of the United Nations Development Programme (UNDP) human development report shows a champagne glass, its top representing a small percentage of people who have more and more income, and the bottom of the glass representing the large proportion that is being squeezed more and more. According to the World Bank, 1.3 billion people live on $1.00 a day or less. Poverty is increasing in the world along with overall unemployment or jobless economic growth, i.e., there is more economic growth, but the numbers of jobs are not growing commensurately. Although the U.S. is not currently experiencing this problem, many European countries are. Then, too, there is the question of proprietorship in science, exclusivity at a time when we need to be inclusive, either in terms of society or knowledge. We classify everything as "my" intellectual property right, and consider that everything developed requires a "patent." To indigenous communities, also known as tribal societies, the concept of intellectual property is quite alien; they do not understand what this means. They believe, as I do, that knowledge is something that comes down from earlier generations, and therefore, must be shared. The gene revolution is covered by proprietary science, while the Green Revolution was public research largely funded by public money and by philanthropic foundations.

BASIS OF OPTIMISM

Why then, in the midst of all these problems, do I consider this a century of hope? First, science is fortunately advancing very fast. The new frontiers of science include biotechnology, space technology and even weather forecasting. Who ever thought we could have such accurate weather forecasting? Even in India, the weatherman used to be the butt of all ridicule, but today everyone trusts the weatherman because of modern tools and technology, which have made it possible to predict short- and long-term weather conditions. Space technology has many other applications, such as information and communication technology; reaching the unreachable is possible today. It is not necessary to be exclusive; you can include the excluded in terms of information and knowledge empowerment. New kinds of virtual colleges involving U.S. and Indian institutions can be established where the latest developments in the U.S. can immediately be transferred across long distances to the poorest of the poor in the villages across the world.

The new frontiers of science include biotechnology, genomics or functions of genomics, proteomics, biochips, the Internet and nanotechnology. Many of these emerging concepts are as yet unfamiliar; new concepts are emerging every day and new technologies are going into what we call the new biovision for agriculture. What role that biovision and other new technologies are going to play, we still do not know; we are still investigating them and some controversy about them remains. In the next few years, there will be a new biovision that is backed by completely new biotechnologies — not only conventional genomics, but a whole sea of biotechnologies. For example, there is genetic enhancement for salinity tolerance in development of transgenic tobacco, brassica, vigna and rice brought about by the "gene revolution." There are designer potatoes and golden rice for better nutrition. The total projected population of India in 2001 is 1011 million, of which the rice-eating population is 366 million, or roughly 37%. Therefore, development of rice rich in micronutrients has a tremendous potential in the Indian scenario.

For these reasons, I have some confidence in the 21st century. Especially in the 1950s and '60s, the last century was considered to be a hopeless century as far as food production was concerned. In fact, as early as the 1960s, Paul and William Paddock wrote a book called *Famine 1975* in which they completely wrote off my country, India, and others as hopeless, never capable of feeding themselves. In *The Population Bomb* (1968), the much respected population experts Paul and Anne Erlich stated that, unless a nuclear bomb controls population, the population–food supply equation is hopeless. They believed that the ability to produce food for the increasing human numbers just did not exist.

But then things changed. We had new plant types: Nobel Peace Prize winner Norman Borlaug and Dr. Orville Vogel, along with others, developed new varieties. There were numerous other genetic and agronomic discoveries and major developments in the whole area of engineering. The start of the Green Revolution in 1968 initiated an era of hope on the food front. "Green" refers to the color of chlorophyll, and the name was coined to describe new plant types' ability to harvest more sunlight rather than as a reference to environmental consequences. Many people think the Green Revolution was environmentally disastrous, and there are clearly some problems that need to be addressed. Nevertheless, we had such progress in food production that today, in a country like mine, where the population has more than tripled since 1947 (from 300 million to over a billion today), the government has so much grain that it is not sure where to store it. As much as 60 million tons of food grains are available in the stores (although there continues to be a large number of people going to bed hungry as they do not have the purchasing power, but that is another challenge that will not be addressed here).

The second reason I consider this a hopeful century is that, by and large, democratic institutions and culture are spreading across the world. Dictatorships are vanishing, and this is a good thing. When all is said and done, in democracies people have the right to say what they want to say, there is a free debate and the media is free. Whether we like what they say or not, the fact remains that everyone can discuss and debate. Democracy provides a mechanism for resolution of conflict, not through arms but through negotiation, through words and dialogues. In India, for example, one reason we collaborate with The Ohio State University (OSU) in the sustainable management of major soil types is that we feel confident that whatever scientific work we do can be spread largely because there are the democratic institutional structures at the local level. Every village has an elected government of its own called *Panchyat*. At least one third of each village governing council must be women, so there is gender balance, not a divide, with both sides working together. Therefore, there are opportunities through democratic institutions. On the contrary, in the last 20–30 years, many African countries have experienced famine that was not due to grain food shortage per se (although the Sahelian drought of the '80s did cause food shortages), but to civil wars and lack of peace and security in the region.

The third reason I consider this a century of hope is the possibility of reaching the heretofore unreachable. Modern information and communication technologies are bridging the digital divide. These are very important mechanisms for knowledge and skill empowerment of the poor. People can reach each other quickly, and there are excellent opportunities today for spreading new information and converting general knowledge into location-specific knowledge. Often, general knowledge is not needed in sustainable agriculture but rather location-specific knowledge in relation to the soils, microenvironment, etc. It is important to have methodologies by which this can be achieved. Wisdom lies in knowing that one does not know. Numerous opportunities await to enhance wisdom through development of user-controlled and demand-driven knowledge centers. Rural computer-aided knowledge centers for all age groups are also needed. These centers could help convert generic into location-specific information and advice; provide information related to health, livelihoods, weather and market; and enhance knowledge and skill empowerment.

In India, the last century can be divided into three phases. Phase one lasted from 1900–1950. Population was low, death rates were high, birth rates were high but infant mortality rates were also high and, at the time of independence in India, the average life span was 28 years. During this period, many illnesses that we now consider to be minor ailments were then great killers. Everything was a killer: malaria, smallpox (which has been nearly eradicated today), and numerous other diseases. This was the era prior to the discovery of antibiotics and the whole system of preventive and curative medicine. The growth rate of agriculture was 0.01% in food crops. In other words, during the British days, the growth rate in food supply was nil except in plantation crops and some of the commercial crops, which is why, in the early part of India's independence, wheat was imported as a cushion or many people would have died from hunger.

The second, or institution-building phase, lasted from 1950–1965. We are grateful for OSU's involvement at this time, particularly at the Punjab Agricultural University, which has been on the forefront of the Green Revolution movement. In the institution-building phase, arrangements were made to provide more irrigation, fertilizer factories were built, etc. However, the food deficit remained a problem even during the second phase (see Figure 1.1). Food security is a function of three factors: (1) availability, (2) access, and (3) absorption. Availability is a function of production, access is a function of purchasing power, and absorption a function of clean drinking water and environmental hygiene. Improvement has to be made in all three factors to enhance food security. In fact, in 1966, nearly 10 million tons of wheat was imported under the PL-480 program. Consequently, some started describing India as a country with "ship-to-mouth" existence.

The third phase, from 1966–2000, is the era of the Green Revolution. In 1968, Dr. William Gaud of the U.S. coined the term "Green Revolution" to indicate that, not only in the case of wheat, but in rice, corn, sorghum and many other crops, new opportunities had been opened up for a radical increase in growth rates. Formerly a small incremental pathway, evolution could now occur at revolutionary speed. Consider that wheat cultivation in India has a recorded history of over 4000 years. From those early days until 1950, total production had reached the level of 7 million tons. But between 1964 and 1968, another 7 million tons was added; in other words, 4000 years of wheat-production evolution was condensed into 4 years.

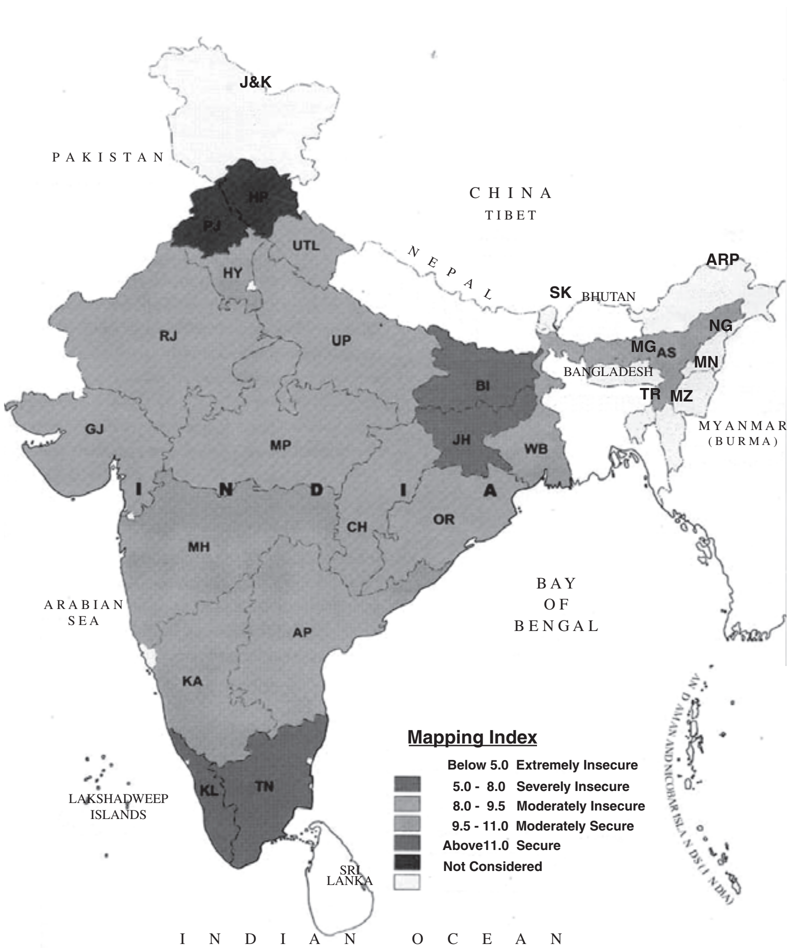

FIGURE 1.1 Food insecurity situation in India.

It is now clear that this revolution has its own problems. Social scientists say that the Green Revolution only makes the rich richer and the poor poorer, because inputs like seeds, fertilizer and water are needed for output; those who don't have the access or purchasing power for these inputs cannot benefit. Of these inputs, the availability of water is particularly important in India because of a large proportion of dry farming areas. When you don't have enough water, production is low unless water management is very good. Judicious water management is crucial to obtaining high yields. "Fertigation" and producing more yield or income per drop of water are important strategies. India receives most of its rainfall in just 100 hours out of 8760 hours in a year. If this water is not captured or stored (see Figure 1.2), there is no water for the rest of the year. Effectively captured and conserved, 100 mm of

FIGURE 1.2 Community water harvesting and cultivation of high-value, low-water-requirement crops (grain legumes).

rainfall falling on a 1-hectare plot can yield up to 1 million liters of water. Therefore, monsoon management is crucial. In addition, the Green Revolution also relied heavily on the use of pesticides. However, an excessive and indiscriminate use of pesticides can lead to the killing of pests' natural enemies, groundwater contamination, nitrate pollution and a whole series of environmental problems.

AN EVERGREEN REVOLUTION

The desire to solve these problems led to the development of the term "sustainable agriculture" during the last quarter of the 20th century. It refers to technology that is environmentally sustainable, economically viable and also socially acceptable. I coined the term "Evergreen Revolution" some years ago to indicate these kinds of sustainable advances in productivity, because the Green Revolution involves increased production through productivity improvement or yield per unit area. There are three basic steps toward achieving an Evergreen Revolution: (1) defending the gains already made, (2) extending the gains to additional areas and farming systems, and (3) achieving new gains in farming systems through intensification, diversification and value addition. Agricultural intensification, increasing yield per unit area, is an important strategy. For example, the average per capita arable land in India even today, with one billion people, is 0.15 hectare. The per capita arable land in China is even lower, less than 0.1hectare. Obviously, with increasing urbanization and industrialization, land is going to go out of agriculture use. Therefore, there will be alternating demands on land and no option will exist except to produce more from diminishing land resources. This is what is called a vertical growth in productivity, in contrast to

FIGURE 1.3 Wheat production in India.

a horizontal expansion in area. The latter option is not open to us unless the remaining few forests are also to be lost. We have no option except to produce more from less land and less water, but produce it without the associated ecological or social concerns. This is what I defined as an "Evergreen Revolution," and that is why my book is called *The Century of Hope.* There is a prospect today for sustainable agriculture or an Evergreen Revolution based on productivity improvement per unit of water, per unit of land, and per unit of labor. At the same time, we should be able to increase the income of the farmer, because the smaller the holding, the greater the need for marketable surplus.

The Evergreen Revolution concept is especially relevant to production of wheat and rice in India. Wheat production in India now occupies the second position in the world (shown in experimental plots in Figure 1.3). However, the demand for wheat in India will increase by 40% between 2000 and 2020. There are opportunities to develop hybrid wheat, super-wheat with spikes that contain 50% more grains, wheat with high nutritional value (vitamin A, Fe and Zn contents), resistance to pests and improved physiological performance. New semi-dwarf varieties of wheat can produce 89 Kg of grains/ha/day. Similarly, hybrid rice has a vast yield potential (shown in Figure 1.4).

REACHING THE SMALL-SCALE FARMER

Advances in agriculture have been the most powerful instrument for poverty eradication in India because they touch the lives of so many people. In 1947, 80% of 300 million people in India were in farming; today, 70% of India's population of 1 billion still remain in farming. In other words, in absolute numbers, those who have to live by agriculture have increased enormously. If I am a farmer producing 1 ton of rice per hectare, then I have 200 kilograms to sell, but if I produce 5 tons of rice on the same land, then I have more than 4 tons to sell. The smaller the farm,

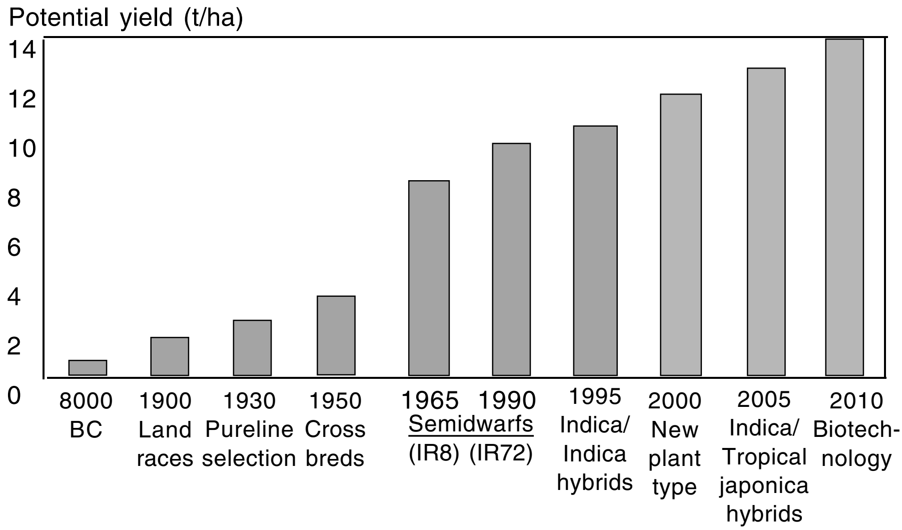

FIGURE 1.4 Progress in the yield potential of rice.

the greater the need for productivity improvement, largely because, unless there is cash flow, there is no marketable surplus. Small farmers require institutional structures to support them, like the soil management study between MSSRF (M.S. Swaminathan Research Foundation) and OSU. Success depends not only on the accumulation of scientific knowledge but also the ability to spread it around, which requires social engineering and the necessary mechanisms.

For instance, India is now the largest producer of milk in the world, having surpassed the U.S. We now produce 80 million tons of milk annually, while the U.S. produces only 72–73 million tons. The main difference is that milk in the U.S. is probably produced by only 200,000–300,000 farms, while India's 80 million tons of milk is produced by 50 million women farmers. How did they achieve the power of scale required both at the production site and the marketing site? In this particular case, the small producers formed into dairy cooperatives that had a single-window service system. This is a prime example of socially sustainable, economically viable and environmentally friendly small-scale agriculture. Enhancing the self-esteem of socially and economically underprivileged people and developing symbiotic linkages between knowledge providers and seekers (laboratory to land, and land to laboratory) are important strategies.

THE BIOVILLAGE

This term denotes a village where human development occupies a place of pride. *Bios* means life; *biovillage* implies human-centered development in which people are the decision makers. Their needs and feelings are ascertained through participatory rural surveys. The beneficial approach of development based on patronage gives way to an approach that regards rural people as producers, innovators and entrepreneurs. The enterprises are identified based on market studies and economic, environmental and social sustainability.

This concept is very relevant to eco-farming. In the 1st century BC, Varro, a Roman farmer, wrote, “Agriculture is a science which teaches us what crops should be planted in each kind of soil, and what operations are to be carried out, in order that the land may produce the highest yields in perpetuity.” To achieve this, there is a specific three-step biovillage methodology: (1) microlevel planning, possibly based on geographic information system (GIS) mapping, (2) micro-enterprises based on markets, and (3) microcredit based on management by rural families.

There are numerous important applications of the concept to sustainable management of natural resources. Specific components include:

- Conservation of arable land
- Enhancement of soil quality
- Conservation and management of water
- Integrated gene management
- Integrated pest management
- Integrated nutrient management
- Minimizing post-harvest losses
- Development of integrated natural resources management committees at the local body level

Much of ecological farming requires a focused approach, whether it is watershed management, water conservation, saving water and sharing it, or integrated pest management (IPM). Writers have stated that IPM in the U.S. is not merely innovative technology but is also a question of social organization. If that is true in this country’s larger farms, you can understand its significance for the small farms of India. Unless people can work together, new ecologically friendly technologies cannot be widely adopted. This is why the spread of democratic systems of governments at the grassroots level is an important and powerful ally in the movement for spreading eco-friendly and cost-effective technologies. We want to reduce the cost of production while increasing the income.

Apart from proprietary science, a separate world trade agreement on agriculture has been adopted for the first time since 1994. Previously, we had only bilateral agreements. The agreement is called AOA or Agreement on Agriculture. It is based on Ricardo’s Principle of Comparative Advantage, which, in turn, was based on the observation that the differing fertility of land in different locales yielded unequal profits to the capital and labor applied to it. So, where can we produce most efficiently? Small-scale agriculture can have a lot of accountability, but today lacks the infrastructure, particularly the postharvest technology, sanitary and phytosanitary measures required by the western world.

In matters relating to quality, we should be concerned not only about exports but also about the food eaten at home. We should take the same precautions: *E-coli* and dysentery should become household words everywhere, and everyone should understand clearly what these terms mean. While we are working on the technological aspects of sustainable soil and water management, we should not forget the welfare of human beings. It is important also that the institutional structures and various methods by which people work together coalesce. In small-scale-farming conditions (whether in aquaculture, dairy or crop husbandry), it is very important to give farmers the power of scale; this makes ecologically friendly farming possible at the production site and provides more bargaining power at the marketing site. It also provides for the institution of some common facilities for sanitary and phytosanitary measures.

CONCLUSIONS

Achieving food security in India requires development and implementation of an integrated approach. The community food and water security system involves four components:

1. Gene bank or the *in situ* on-farm conservation of germ plasm
2. Seed bank or the formulation of *ex situ* seed bank as seed security reserve
3. Water bank or *in situ* conservation of rain, ground and surface waters
4. Grain bank or grain storage facilities where losses are minimal and reserves can be made available to cater to emergencies

This is an era of hope. Hope or despair is a state of mind. There are those people who are born optimists and those who are born pessimists. There is no use in being optimistic, though, without action. Therefore, I hope that this Century of Hope will give us the necessary impetus to work together and address the issues facing humankind. If we harness the power of partnership wisely, achieving a hunger-free world need not remain a dream.

REFERENCES

Mann, C. 1997. Reseeding the Green Revolution, *Science,* v. 277 (5329), p. 1038-1039 and 1041-1043.

Swaminathan, M.S. 2001. *Century of Hope: Harmony with Nature and Freedom from Hunger.* East-West Books, Chennai, India, 154 pp.

2 Natural Resources of India

Rattan Lal

CONTENTS

Introduction 13
Land 14
Agricultural Production in India 22
Soil Degradation 22
Water Pollution 25
Air Pollution 26
Conclusions 28
References 28

INTRODUCTION

Food grain production in India increased from 50 million tonnes (Mg = megagram = 1 metric ton) in 1947 to more than 200 million Mg in 2000. The Green Revolution — the use of high-yielding varieties along with intensive use of fertilizers on irrigated soils — enhanced agronomic production at a rate faster than that of the population growth. While these advances in production saved millions from starvation, some problems relevant to food security remain and new ones have emerged. Despite the large grain reserves, food is not accessible to a large proportion of the poor because of the lack of purchasing power. Further, expected food demand of 300 million tonnes of grains by the year 2050 will jeopardize natural resources already under great stress. The per capita availability of arable land and renewable fresh water are declining because of the increase in population. These resources are also being diminished by severe degradation of soil and pollution contamination of surface and groundwaters. Thus, there is an urgent need to develop strategies of sustainable management of natural resources while addressing the socioeconomic and political issues of equality, poverty, and postharvest losses due to lack of storage and processing facilities. There is little potential for further expansion of irrigation. Therefore, emphasis needs to be given to rain-fed agriculture. The Green Revolution strategies, as important a breakthrough as they were, need to be revisited in terms of the important issues pertaining to biophysical, socioeconomic and policy issues.

1-5667-0594-0/02/$0.00+$1.50

TABLE 2.1
Dynamics of India's Population

Period	Population at the end of the period (millions)	Annual average growth rate (%/year)
1901–1911	252	0.56
1911–1921	251	–0.03
1921–1931	279	1.04
1931–1941	319	1.33
1941–1951	361	1.25
1951–1961	439	1.96
1961–1971	548	2.20
1971–1981	683	2.22
1981–1991	846	2.16
1991–2001	1001	1.85

Source: Adapted from Pachauri and Sridharan (1999; FAO (1998).

India is home to about 17% of the world population; its land area represents 2.9% of the world's total land mass. India's population increased from 252 million in 1900 to 1 billion in 2000, and is presently increasing at the rate of 1.85%/yr (Table 2.1). The country is endowed with a wide range of ecoregions, ranging from extreme heat to glaciers and from arid regions to those that receive more than 10 meters of rain every year. India has made outstanding progress in increased foodgrain production, which has more than quadrupled over the five decades since independence. Currently, India has in excess of 50 million tons of food grains in reserves. Per capita dietary energy supply increased from 1980 cals in 1961 to 2267 cals in 1990 and 2415 cals in 1996 (Siamwalla, 2000). The present per capita food supply of about 2500 cals is adequate to meet the needs of its burgeoning population. Yet, more than 200 million people are undernourished, and infant mortality rates are among the highest in the world (Table 2.2). The malnutrition was 66% for children under age 5 for the period 1950–96 (Siamwalla, 2000). Poor composed 36% of the population in 1993 and 26% in 1999, while the literacy rate increased from 52% in 1991 to 65% in 2001 (*The Economist*, 2001).

Food security is a complex issue that is governed by a range of interacting biophysical, socioeconomic and policy variables. Food supply depends to a large extent on biophysical factors, but food availability is governed by complex socioeconomic and policy considerations. In this chapter, food supply aspects related to resources such as soils, water availability and forest reserves are discussed.

LAND

India has diverse climates and ecoregions related to its large size. Rainfall averages range from less than 125 mm in the Thar Desert to 11,000 mm in Cherrapunji. Temperature, too, ranges widely, with a mean annual temperature of <4.5°C in Dras Kashmir to >45°C in Ganganagar, Rajasthan. India's climate is influenced by the

TABLE 2.2
Estimates of Hunger in India and Other Regions (Bread for the World Institute, 2000)

Country/region	Population (10^6) 1999	Population (10^6) 2025	Percent increase	% population with access to safe water (1990–1997)	Mortality rate under 5 per 1000 live births 1960	Mortality rate under 5 per 1000 live births 1997	Percent decrease	Per capita dietary energy supply (cals)	Undernourished people 1995–97 (10^6)
India	998.1	1330.4	33.3	81	131	108	17.6	2495.6	204.4
South Asia	1340.3	1971.7	47.1	80	135	116	14.1	2448.8	296.6
Sub-Saharan Africa	596.7	1244.1	108.5	50	--	170	—	2182.8	179.6
Latin America & the Caribbean	511.3	696.7	36.3	77	53	41	22.6	2798.1	53.4
Developing countries	4793.2	6608.8	37.9	--	104	96	7.7	2650.0	791.4
World	5978.4	7823.7	30.9	72	94	87	7.4	2720.0	824.6

Source: From Bread of the World Institute, *Hunger 2000: A Program to End Hunger*, Silver Spring, MD, with permission.

Himalayan range in the north and by the Indian Ocean, Arabian Sea and Bay of Bengal, which surround the peninsula.

1. Rainfall: Depending on the geographic location, rainfall is highly site-specific and variable. Based on annual rainfall, India can be divided into the following regions: (a) the northeastern regions, neighboring areas and the west coast, which receives more than 2500 mm/yr; (b) the plains of the central and eastern upper peninsula, Bihar and West Bengal, which receive between 1250 and 1875 mm rainfall; (c) the region east of 79°E longitude and the west coast, which receive more than 1000 mm; (d) the northern plains between the northwest desert and the Brahmaputra Valley and the peninsula, excluding the coastal belt, which receive 500 to 750 mm rainfall; and (e) the northwestern region, which receives less than 250 mm of rainfall. About 70 to 80% of the rainfall occurs during the monsoon season from June to September.

TABLE 2.3
Land Use in India

	Area (Mha)					
Land use	**1950**	**1960**	**1970**	**1980**	**1990**	**1998**
Gross usable area	284	298	304	304	305	304
Not available for cultivation	48	51	45	40	41	—
Other cultivated land including fallow land	49	38	35	32	31	—
Fallow land	28	23	20	25	23	—
Total cropped area (gross)	132	153	166	173	185	—
Net area cropped	119	133	140	140	142	57
Net irrigated area	21	25	31	39	47	—
Cropping intensity	111	115	119	124	130	—

Source: From Ministry of Agriculture (1994) Annual Report, New Delhi, India; Pachauri and Sridharan (1999) *Looking Back to Think Ahead: Green India*, TERI, New Delhi, India; FAO (1998) Production Yearbook, Rome. With permission.

2. Land use: India has a large land area, much of which is suitable for cultivation. The gross cropped area, including land used to produce more than one crop per year, increased from 132 million hectares (Mha) in 1950 to 185 Mha in 1990 (Table 2.3). The corresponding net cropped area increased from 119 Mha in 1950 to 142 Mha in 1990. Net cropped area has stabilized around 140 Mha since 1970. The area under food grain in India changed little from 1977 to 1997 (Table 2.4). The net irrigated area increased substantially from 21 Mha in 1970 (17.6% of the net cropped area) to 47 Mha in 1990 (33.1% of the net cropped area). Irrigated land area in 1998 represented 57 Mha and contributed substantially to food grain production. Indeed, irrigation has played a major role in enhancing

TABLE 2.4
Area Under Food Grains in India

	Area			
	Mha		% of total	
Particular	1977	1997	1977	1997
Food grains	122.6	125.5	67.2	58.9
Others	59.7	87.4	32.8	41.1

Source: From Kaosa-ard and Rerkasem (2000), *Growth and Sustainability of Agriculture in Asia,* Oxford University Press, New York, with permission.

TABLE 2.5
Forest Resources of India, 1995

Particulars	Area
Total land area	297.3 Mha
Total forest area	65.0 Mha
% of land under forest	21.9%
Per capita forest area in 1995	0.065 ha
Natural forest	50.4 Mha
Plantation	14.6 Mha

Source: From Kaosa-ard and Rerkasem (2000), *Growth and Sustainability of Agriculture in Asia,* Oxford University Press, New York, with permission.

food grain production. Total per capita land area, including irrigated area, is progressively declining due to population increases and its conversion to other land uses (Lal, 2000). The per capita arable land area in India is estimated to have decreased from 0.35 ha in 1960 to 0.07 ha in 2025 (Engelman and LeRoy, 1995).

3. Forests: In addition to agriculture, vast forest resources cover 21.9% of the total land area (Table 2.5). Natural forests cover 50.4 Mha and plantation forests cover 14.6 Mha. The quality of forest resources is highly variable. Further, there are differences between the recorded forest area and the actual forest area (Table 2.6). Dense forest with a crown density of >40% represents merely 60% of the total area under forest. The remaining 40% of the area with a low crown density has little biomass. In addition, protected areas represent about 15 Mha (Table 2.7) and include world heritage and wetlands areas.
4. Soils of India: The distribution of major soil types in India is shown in Table 2.8. The most productive soils, those of alluvial origin, are found in the flood plains of Indo-Gangetic and Brahmaputra basins and along

TABLE 2.6
Forest Resources of India

Category	Forest area (Mha) 1982	1989	1991	1993	1995	2000
Recorded forest area	75.1	75.9	77.0	77.0	76.5	75.0
Actual forest area	64.2	64.0	63.9	64.0	64.0	
(i) dense forest	361	37.9	38.5	38.6	38.6	
(ii) open forest	27.7	25.7	25.0	25.0	24.9	
(iii) mangroves	0.4	0.4	0.4	0.4	0.5	
(iv) scrub land	7.7	6.6	6.0	5.9	6.1	
(v) uninterpreted	1.2	0.4	1.9	0.0	0.0	
Nonforest area	255.7	257.8	256.9	258.8	258.7	

Dense forest = crown density > 40%
Open forest = crown density = 10-40%
Scrub land = crown density < 10%
Forest survey of India (1988, 1990, 1992, 1994)

Source: From Pachauri and Sridharan (1999), *Looking Back to Think Ahead: Green India*, TERI, New Delhi, India, with permission; FAO (2000).

TABLE 2.7
Protected Area in India

Particular	No.	Protected area (Mha)
National	344	14.3
International		
(i) world heritage	5	0.3
(ii) wetlands	6	0.2

Note: Number of malnourished children under 5 years of age in India was 76 million in 1993 and 59 million in 2010 (Rosegrant and Hazell, 2000).

Source: Kaosa-ard and Rerkasem (2000), *Growth and Sustainability of Agriculture in Asia,* Oxford University Press, New York, with permission

the east coast. These soils, comprising Inceptisols and Entisols, cover 76.5 Mha. They have been the basis for the Green Revolution. Vertisols in central India are also inherently fertile soils that cover 60.4 Mha. These are clay soils, have low infiltration rate, and develop large deep cracks on drying. Mollisols are highly fertile soils that cover only a small area of 1.8 Mha. Ultisols and Alfisols are highly weathered soils in the tropics and subtropics. Together they represent 117.7 Mha. Arid-

TABLE 2.8
Principal Soils of India (Personal Communication with H. Eswaran, NRCS)

Soil type	Area (Mha)
I. Non-soil	
Water bodies	4.6
Shifting sand	14.3
Rock	7.8
Others	2.1
Subtotal	28.8
II. Soil	
Gelisols	0.8
Vertisols	60.4
Aridisols	18.3
Ultisols	36.6
Mollisols	1.8
Alfisols	81.1
Inceptisols	51.7
Entisols	24.8
Subtotal	275.5
Total	304.3

isols, found in dry regions, can be cropped only with supplemental irrigation. Land areas under different land quality classes are found in Table 2.9. Good quality soils in classes I through III cover a land area of 110 Mha or 37% of the total land area and have few constraints related to crop production.

5. Water resources: India is also endowed with vast water resources. Annual internal renewable water resources are estimated to be 1850 Km^3. In addition, annual river flow from external resources is 235 Km^3 (Table 2.10). Because of the large population base, however, per capita water supply in India is low and declining. In fact, water scarcity will be a greater problem than land scarcity during the 21st century.
   The per capita availability of renewable fresh water in India was 6008 m^3 in 1947, 5277 m^3 in 1955, 4237 m^3 in 1967, 3395 m^3 in 1977, 2737 m^3 in 1987, and 2263 m^3 in 1997 (Engelman and LeRoy, 1993; Pachauri and Sridharan, 1999). Data in Table 2.10 indicate temporal changes in per capita fresh water availability in India. Per capita water availability was 5,227 m^3 in 1955, 2451 m^3 in 1995 and 2085 m^3 in 2000. The projected population growth rate represents the medium projected U.N. population increase rate, and per capita available water resources will continue to decline to 1498 m^3 in 2025 and 1270 m^3 in 2050 (Table 2.11).

TABLE 2.9
Area in Different Land Quality Classes In India and its Population-Carrying Capacity at Low Input Lands

Land quality class	Land area (Mha)	Population carrying capacity (10^6)	Land characteristics
I	15.0	42	Few constraints to crop production
II	90.3	190	High temperature, low organic matter content, high shrink/swell potential
III	4.5	7	Seasonal wetness, short growing season due to low temperatures, minor root restriction
IV	8.5	8	Impeded drainage, crusting, compaction, high anion exchange capacity
V	103.7	62	Excessive leaching, calcareous/gypsiferous soils, aluminum toxicity, seasonal moisture stress
VI	6.0	2	Saline/alkaline soils, low moisture and nutrient status, acid sulphate soils, high nutrient fixation
VII	25.8	—	Shallow soils
VIII	4.7	—	Extended periods of low temperature, steeplands
IX	38.9	—	Extended periods of moisture stress
Total	297.3	310	

Source: From Beinroth et al. (2001), *Response to Land Degradation*, Science Publishers, Enfield, NH, with permission

TABLE 2.10
Water Resources of India.

Particulars	Value	Units
Annual interval renewable water resources	1,850	km^3
1998 per capita internal water resources	1,896	m^3
Annual river flow from external sources	235	km^3
Annual withdrawal of water volume	380	km^3
per capita withdrawal	612	m^3
proportion of internal resources	20.54	%
proportion of total resources	18.23	%

Source: From Kaosa-ard and Rerkasem (2000), *Growth and Sustainability of Agriculture in Asia,* Oxford University Press, New York, with permission

Despite abundant water resources, most of India's population experiences water scarcity due to the unequal distribution of rainfall in the region. Most rainfall is concentrated in three months between June and September. Consequently, both drought and floods are common throughout the country. Droughts are exacerbated by landscapes

TABLE 2.11
Annual Renewable Freshwater Availability in India

Year	Population (millions)				Per capita water availability (m³)			
	Actual	Low projec-ion	Med. projec-tion	High projec-tion	Actual	Low projec-tion	Med. projec-tion	High projec-tion
1955	395	—	—	—	5277	—	—	—
1995	850	—	—	—	2451	—	—	—
2000	1000	—	—	—	2085	—	—	—
2025	—	1286	1392	1501	—	1621	1498	1389
2050	—	1345	1639	1980	—	1549	1271	1053

Based on total annual renewable freshwater resources of 2085 km^3

Source: Adapted from Engelman and LeRoy (1993), Sustaining water: Population and the future of renewable water supplies, population Action International, Washington, D.C.

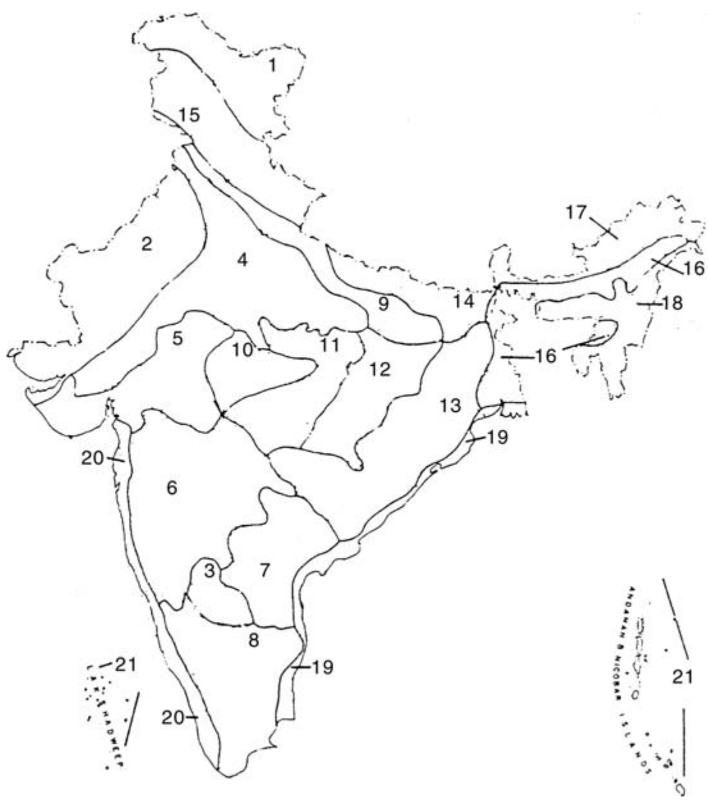

FIGURE 2.1. Agroecological regions of India (Adapted from Sehgal et al., 1990, ICAR, NBSS Publ. 24, Nagpur, India, with permission).

stripped of protective vegetal cover and by soils that are crusted and compacted and have low water-infiltration capacity. Most rainfall, therefore, is lost as runoff. Consequently, even high rainfall areas are often prone to drought stress.
The quality of surface and groundwater is poor. Most water resources are polluted, contaminated and unsuitable for consumption by people and domestic animals.

6. Agroecoregions of India: India can be divided into 21 ecoregions on the basis of rainfall and physiographic characteristics (Figure 2.1). Agriculturally important ecoregions in Figure 2.1 are 3, 4, 6, 7, 9, 14, 19, and 20. A brief description of these regions is given opposite, after Sehgal et al. (1990).

AGRICULTURAL PRODUCTION IN INDIA

Crop yields in India have increased considerably from the 1970s through the 1990s. Data in Table 2.12 indicate increased crop yields of 2.41 to 2.44%/yr for rice; of 3.10 to 4.26%/yr for wheat; and of 2.09 to 2.76%/yr for maize. Despite impressive gains, however, crop yields in India are below the world average (Table 2.13). The area under cereal production represents 14.3% of the world area, but total cereal production in India represents only 10.7% of the world production. Similarly, the area under rice cultivation in India is 28.1% of the total world area, but represents merely 21.7% of the world's total rice production. The area under sorghum cultivation in India is 25.2% of the total world area while the production is only 14.1% of the world's total sorghum production. The yield of soybeans in India is considerably lower. Area under soybean production in India represents 9% of the world's area, but produces only 3.9% of the world's total soybean production. Data in Tables 2.12 and 2.13 indicate a large potential for improving yields of grain and other crops in India through developing site-specific systems of soil, water, fertilizer and crop management. The demand for food grain production in India is likely to increase, not only because of the increase in population, but also because of increased demands for livestock products (See Table 2.14). Improvements in the livestock industry will also result in additional demand for food grains.

SOIL DEGRADATION

Soil degradation is a major cause of declining crop yields and low fertilizer- and water-use efficiencies in India (see Chapters 5 and 6 in this volume). Soil degradation results from water erosion, wind erosion, soil fertility decline, waterlogging, salinization and declining water table. The total land area affected by different processes of soil degradation is estimated to be about 59 Mha compared with 205 Mha in South Asia and 1965 Mha in the world (Table 2.15). Principal causes of soil degradation in India and elsewhere in South Asia include the non-adoption of soil conservation and management practices, extension of cultivation onto marginal lands

Eco-region #	Name	Description	Growing period (days)
1	Western Himalayas	Cold, arid, shallow skeletal soils	< 90
2	Western Plains & Kutch Peninsula	Hot, arid, saline soils	< 90
3	Deccan Plateau	Hot, arid, mixed red and black soils	< 90
4	Northern Plains & Central Highlands	Hot, semi-arid, alluvium-derived soils	90-150
5	Central Highlands & Kathiawar Peninsula	Hot, semi-arid, medium & deep black soils	90-150
6	Deccan Plateau	Hot, semi-arid, shallow & medium black soils	90-150
7	Decan Plateau & Eastern Ghats	Hot, semi-arid, red & black soils	90-150
8	Eastern Ghats & Deccan Plateau	Hot, semi-arid, red loamy soils	90-150
9	Northern Plains	Hot, subhumid, alluvium-derived soils	50-180
10	Central Highlands	Hot, subhumid, medium & deep black soils	90-150
11	Deccan Plateau & Central Highlands	Hot, subhumid, mixed red & black soils	150-180
12	Eastern Plateau	Hot, subhumid, red & yellow soils	150-180
13	Eastern Plateau & Eastern Ghats	Hot, subhumid, red loamy soils	150-180
14	Eastern Plains	Hot, subhumid, alluvium-derived soils	180-210
15	Western Himalayas	Warm, subhumid, brown forest & podzolic soils	180-210(+)
16	Assam & Bengal Plains	Hot, humid, alluvium-derived soils	> 210
17	Eastern Himalayas	Warm, perhumid, brown & red hill soils	> 210
18	Northeastern Hills	Warm, perhumid, red & lateritic soils	> 210
19	Eastern Coastal Plains	Hot, sub-humid, alluvium-derived soils	150-210
20	Western Coastal Plains	Hot, humid-perhumid; red, lateritic & alluvium-derived soils	> 210
21	Islands of Andaman-Nicobar & Lakshadweep	Hot, perhumid, red loamy and sandy soils	> 210

FIGURE 2.1 (CONTINUED) Eco-Regions of India.

TABLE 2.12
Yield of Different Crops in India

Crop	Yield (Mg/ha)		Growth (%/yr)	
	1977	1997	1977-89	1987-97
Rice	1.86	2.87	2.41	2.44
Wheat	1.43	2.53	4.26	3.10
Maize	1.06	1.59	2.09	2.76
Coconuts	3.81	5.41	0.53	2.99
Rubber	0.80	1.45	1.41	4.48
Tea	1.51	1.84	0.01	2.00
Coffee	0.64	0.85	2.11	0.71
Sugercane	53.4	66.5	1.24	0.95

Source: From Kaosa-ard and Rerkasem (2000), *Growth and Sustainability of Agriculture in Asia,* Oxford University Press, New York, with permission

TABLE 2.13
Food Grain Production in the World and India in 1998

Particular	World	India	% of the world
Population (billions)	6.0	1.0	16.7
Total area (Mha)	13387.0	382.7	2.9
Arable land (Mha)	1379.1	162.0	11.7
Irrigated land (Mha)	267.7	57.0	21.3
Total cereal area (Mha)	691.6	99.5	14.3
Total cereal production (m tons)	2054.4	219.4	10.7
Wheat area (Mha)	224.4	25.6	11.4
Wheat production (m tons)	588.8	66.0	11.2
Rice area (Mha)	150.3	42.3	28.1
Rice production (m tons)	563.25	122.2	21.7
Millet area (Mha)	37.6	13.3	35.3
Millet production (m tons)	29.2	10.5	35.9
Sorghum area (Mha)	44.4	11.2	25.2
Sorghum production (m tons)	63.5	9.0	14.1
Soybeans area (Mha)	70.7	6.4	9.0
Soybeans production (m tons)	158.3	6.1	3.9

Source: Recalculated from FAO (1998), Production Yearbook, Rome.

(e.g., steeply sloping, shallow soils), improper crop rotations, unbalanced fertilizer use, poor planning and improper management of canal irrigation and overpumping of groundwater (FAO, 1994).

Soil degradation is a biophysical process driven by socioeconomic and political forces. Among them are land shortage and declining per capita land area, land tenure

TABLE 2.14
Demand for Livestock Products in India

Particular	1993	2010
Per capita (kg)	4.3	5.8
Total demand (10^6 Mg)	3.8	6.8

Source: From Rosegrant and Hazell (2000), *Transforming the Rural Asian Economy: The Unfinished Revolution*, Oxford University Press, New York, with permission.

TABLE 2.15
Estimate of Land Area Affected by Soil Degradation

Process	India	South Asia Mha	World
Water erosion	32.8	81.8	1094
Wind erosion	10.8	59.0	549
Soil fertility decline	3.2	11.0	135
Water logging	3.1	4.6	?
Salinization	7.0	28.5	76
Lowering of the water table	2.0	19.6	?
Total	58.9	204.5	1965

Source: From FAO (1994), World Soil Resources Report 78, Rome; Oldeman (1994), *Soil Resilience and Sustainable Land Use*, CABI International, Wallingfor, U.K., with permission.

and tenancy, economic pressure and poverty. Depletion of the soil organic matter content of agricultural soils is also a widespread problem. The organic matter content of some soils is as low as 0.2%, because crop residues are either removed for use as fodder and fuel, heavily grazed or burnt. Animal waste, rather than being used as manure, is also used for household fuel.

WATER POLLUTION

A widespread problem of water pollution also exists. Principal sources of pollution are city sewage and industrial water discharges into rivers. Nonpoint-source pollution related to agricultural land uses also exists. Excessive and inappropriate application of fertilizers has led to increases in the nitrate content of well water, especially in Punjab, Haryana and Uttar Pradesh states. The nitrate contents in well water have ranged from 240 to 694 mg/l in Uttar Pradesh, from 419 to 1310 mg/l in Haryana, and from 265 to 567 mg/l in Punjab (Pachauri and Sridharan, 1 999). In addition to mineral fertilizers, manure and other organic residues are also important sources of nitrates in surface and groundwater. High contents of mercury, lead, manganese,

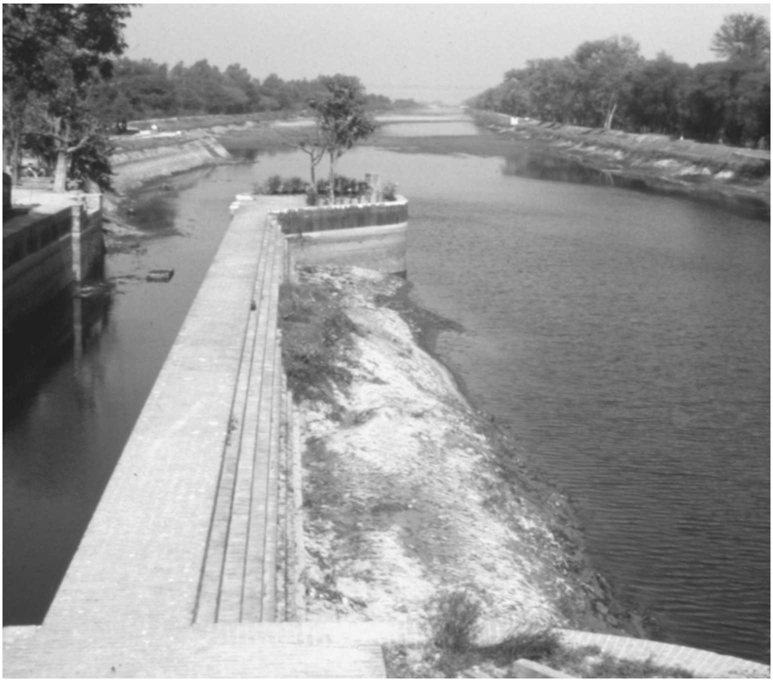

FIGURE 2.2 Seepage from an unlined canal is raising the water table.

DDT, phenolics and other compounds have also been observed in groundwater, and the concentration of these and other pollutants is increasing over time.

A problem of water imbalance also exists due to mismanagement of irrigation water. Waterlogging and salinity are severe problems in canal-irrigated areas with poor surface and subsurface drainage (Table 2.15). Excessive irrigation and seepage from canals (Figure 2.2)is causing groundwater levels to rise. In Bathinda, Punjab, the water table has been rising at the rate of 0.6 m/yr (FAO, 1990). Once waterlogging has occurred, soil salinity becomes a problem (Figure 2.3).Waterlogging can be addressed by judicious irrigation, by providing drainage or by reducing seepage losses. For flat topographies such as the Indo-Gangetic plains, disposal of drainage effluents is a major problem. In contrast to areas with canal irrigation, the water table is receding in areas irrigated by tube wells. For example, in the central region of Punjab, the water table is falling at the rate of 30 cm/yr. Once again, excessive irrigation, caused by subsidized water and electricity, has led to overexploitation of the groundwater resources.

AIR POLLUTION

Air is also a common resource that is prone to severe pollution. Air pollution in rural areas is caused by biomass burning (e.g., crop residue of rice and wheat) and the use of wood and dung or crop residue as a cooking fuel. Biomass fuels accounted

FIGURE 2.3 Waterlogging is followed by salinization.

for 74% of the household energy consumption in 1972, 66% in 1982 and 50% in 1989 (TERI, 1989). In 1978–79, 85 million households in rural areas and 19 million in urban areas used biomass fuels to meet their energy needs, especially to cook. At that time, the total annual consumption was 76 million Mg (Tera gram = 10^{12} g = 1 Tg) of wood, 16 Tg of crop residue, 22 Tg of dung cakes (NCER, 1985). Biofuel use in 2004–05 is estimated to be 300 to 330 Tg of wood, 192–221 Tg of crop residues and 90–104 Tg of dung cakes (Pachauri and Sridharan, 1999).

By contrast, air pollution in urban centers is primarily caused by automobiles, industry and thermal plants. Delhi is considered to be the fourth most polluted city in the world (Pachauri and Sridharan, 1999). Principal pollutants are particulate matter, sulfur dioxide, nitrogen oxides (NO_x), carbon monoxide, hydrocarbons, ozone and heavy metals such as lead and mercury. Pollutant emissions are estimated to be 1046 Mg/day in Delhi, 660 Mg/day in Mumbai, 305 Mg/day in Bangalore, 294 Mg/day in Calcutta and 226 Mg/day in Chenai (Pachauri and Sridharan, 1999). The Indian Ocean Experiment (INDOEX) reported high pollution levels over all of the northern Indian Ocean toward the Intertropical Convergence Zone at about 6° S (Leliveld et al., 2001). It was observed that agricultural burning, and especially biofuel use, enhanced carbon monoxide concentration, and that fossil fuel combustion and biomass burning caused a high aerosol loading. This extensive air quality degradation has global implications.

CONCLUSIONS

India is endowed with an abundance of natural resources. It has a wide range of climates and agroecoregions, soil types, rainfall regimes, and water resources. However, resource scarcities have resulted from rapid population increases during the 20th century. Population growth is expected to continue until the middle of the 21st century. Consequently, per capita arable land area and per capita renewable fresh water supply are progressively decreasing. Crop yields have increased substantially since the 1960s, but national average yields are still lower than their ecological potential. In some cases, crop yields are declining and incremental increases in yields per unit of fertilizer and other input are lower than they have been in the past. Inappropriate and indiscriminate use of chemical and organic fertilizers, pesticides and irrigation water have caused soil and environmental degradation, and water and air pollution. Accelerated soil erosion caused by water and wind results from India's lack of adoption of conservation-effective measures and the extension of agriculture onto marginal soils. Inappropriate use of irrigation is responsible for waterlogging and salinization in areas irrigated by canals, and excessive exploitation of groundwater in those irrigated by tubewells. Yet, India has a potential to enhance production and meet the demands of population increases. This will require restoration of degraded soils and ecosystems; improvement of irrigation water delivery systems; the return of crop residue and biosolids to the soil and adoption of sustainable systems of soil and water management.

REFERENCES

Beinroth, F.H., H. Eswaran and P.F. Reich. 2001. Land quality and food security in Asia. In: E.M. Bridges, I.D. Hannam, L.R. Oldeman, F.W.T. Penning de Vries, S.J. Scherr and S. Sombatpanit (Eds.) *Response to Land Degradation*, IBSRAM/ISRIC, Science Publishers, Enfield, NH, pp 83–97.

Bread for the World Institute. *Hunger 2000: A Program to End Hunger.* Silver Spring, MD, 161pp.

Economist. A survey of India's economy. *The Economist*, June 2001: 3-22.

Engelman, R. and P. LeRoy. 1993. Sustaining water: Population and the future of renewable water supplies. Population Action International, Washington, D.C.

Engelman, R. and P. LeRoy. 1995. Conserving land: population and sustainable food production. Population Action International, Washington, D.C.

FAO. 1990. Water and Sustainable Agricultural Development. A strategy for the implementation of the Mar del Plata Action Plan for the 1990s. FAO, Rome, Italy, 42 pp.

FAO. 1994. Land degradation in South Asia: Its severity, causes and effects on people. World Soil Resources Report 78, FAO, Rome, Italy, 100 pp.

FAO. 1998. Production yearbook. Rome, Italy.

Forest Survey of India. The State of Forest Report, Dehradun, India. 1988, 1990, 1991, 1994, 1995, 1996, 2000.

Kaosa-ard, M.S. and B. Rerkasem. 2000. Status of the natural resource base. In: *Growth and Sustainability of Agriculture in Asia*, Asian Development Bank, Oxford University Press, New York, Ch. 2, 303 pp.

Lal, R. 2000. Soil management in the developing countries. *Soil Sci.* 165:57-72.

Lelieveld, J., P.J. Crutzen, V. Ramanathan et al. 2000. The Indian Ocean Experiment. widespread air pollution from South and Southeast Asia. *Science* 291, 2000. pp 1031-1036.

Ministry of Agriculture. 1994. Annual Report, New Delhi, India.

Oldeman, L.R. 1994. The global extent of soil degradation. In: D.J. Greenland and I. Szabolcs (Eds.) *Soil Resilience and Sustainable Land Use*, CAB International, Wallingford, U.K., pp 99–118.

Pachauri, R.K. and P.V. Sridharan (Eds.). 1999. *Looking Back to Think Ahead: Green India* 2047, TERI, New Delhi, India, 346 pp.

Rosegrant, M.W. and P.B.R. Hazell. 2000. *Transforming the Rural Asian Economy: The Unfinished Revolution*, Asian Development Bank, Oxford Univ. Press, New York, 512 pp.

Sehgal, J.L., D.K. Mandal, C. Mandal and S. Vadiveul. 1990. Agroecological Regions of India. National Bureau of Soil Survey & Land Use Planning. ICAR, NBSS Publ. 24, Nagpur, India, 76 pp.

Siamwalla, A. 2000. *The Revolving Roles of State, Private and Local Actors in Rural Asia.* Asian Development Bank, Oxford Univ. Press, New York, 413 pp.

TERI. *TERI Energy Data, Directory and Yearbook 1989.* Tata Energy Research Institute, New Delhi, India, 281 pp.

3 Food Security: Is India at Risk?

*Dina Umali-Deininger and Shahla Shapouri**

CONTENTS

Introduction....................31
Assessing India's Food Security Performance: Current and Future Prospects......33
Major Factors Influencing Projections....................36
Agricultural Land is a Limiting Factor....................36
Importance of Agricultural Productivity Growth....................37
Increasingly Scarce Water Resources....................39
Adoption of Productivity Enhancing Technologies....................42
Changes in Demand Can Influence Production Patterns....................42
Government Food Distribution Program....................43
Summary and Conclusion....................44
References....................45
Appendix 3A: Food Security Model....................47

INTRODUCTION

Recent developments indicate that India has made progress in terms of some key food security indicators. Food grain production grew by 2.7% per year over the last two decades, so that India at the national level achieved food grain self-sufficiency by the late 1990s. Indeed, the government held almost 60 million metric tons (mt) of food-grain (rice and wheat) stocks in 2001. The Food and Agriculture Organization (FAO) data (2001) indicate that the average per capita calorie available for consumption during 1996–98 had reached about 2,500 calories per day, an increase of 27% relative to 1980. Per capita incomes (GDP) grew at an even more extraordinary rate of about 5.5% per year during 1980–98 (constant 1995 price) leading to the expectation of significant improvements in food purchasing power and food security. These achievements, however, should not divert attention from the considerable remaining challenges, both current and future.

* Dina Umali-Deininger is lead agricultural economist at the World Bank and Shahla Shapouri is senior economist at the USDA-ERS. The findings, interpretations and conclusions expressed in this paper are those of the authors; they do not necessarily reflect the views of United States Department of Agriculture Economic Research Service and the World Bank and its executive directors or the countries they represent.

1-5667-0594-0/02/$0.00+$1.50

With its population of 1 billion people, India's food security is of significance to global food security in many important respects. Ensuring adequate access to and utilization of food by about 17% of the world's population is a the tremendous challenge. Due to its size, the numbers of people who are potentially at risk also unavoidably become of global significance. Indeed, income poverty in India, a major factor contributing to food insecurity, is widespread and extremely high in absolute numbers by global standards. Although the figures are still subject to some debate, the government of India in 2000 declared that more than a quarter of the population (260 million people) is still living below the poverty line (Planning Commission, 2001). Per capita incomes are not only low (gross national income per capita in 2000 was $460) but income distribution is also highly skewed. The poorest 20% of the population receive about 9% of total income compared with the 39% received by the richest 20% of population (World Bank, 2000a). While India accounts for 20% of the world's children under age 5, it also accounts for about 62 million or 40% of the children who are malnourished (World Bank, 1998). Moreover, experience in the mid-1990s further illustrates how meeting unexpected local wheat production shortfalls and subsequent imports by India can push world wheat prices upward, affecting all other food import-dependent countries.

At the World Food Summit in November 1996, 186 countries committed themselves to reducing the number of undernourished people by half by 2015. The estimate of the number of hungry people* in 67 lower-income countries (excluding China) was 839 million out of a total population of 2.4 billion in 1995 and was expected to decline to about 774 million people by 2000 (Food Security Assessment, USDA-ERS, 2000). During the next decade, even though the number of people affected is expected to decline, the projected rate is slower than the years before. An important reason is the uncertainty about food availability in Africa, because of concerns for slowing agricultural output growth rate due to the spread of AIDS. Another reason is that in Asia, in particular India, the slow pace of poverty reduction depresses purchasing power and influences food access. Progress in improving food security in India has important ramifications at the global level because of the size of its population. In fact, eliminating hunger in India alone would cut the number of hungry people globally by half, thus achieving the goal of the World Food Summit.

The objectives of this chapter are to review the food security situation and prospects for 2010 in India, evaluate factors that contribute to food insecurity, examine India's food policies, and finally discuss policy options that can help improve the situation. In the next section, we assess India's current performance in ensuring household food security based on three indicators — status quo gap, nutrition gap and distribution gap, using the Economic Research Service (ERS) Food Security Assessment Model. Using the same model, we project India's prospects for achieving food security by 2010. In the subsequent sections, we examine how different factors, such as land quality, technology, water availability, and changing demand patterns, would influence the pace of progress in meeting the government's food security goals and then go on to describe the nature and scope of the government's food distribution policies. Finally, the last section outlines some key reform measures to ensure achievement of the government's longer-term food security goals.

---

* Defined as people consuming less than 2,100 calories per day.