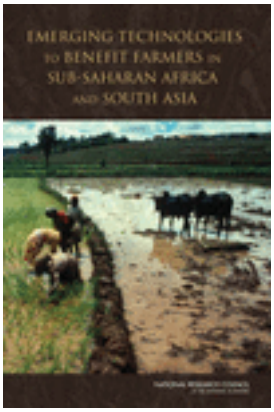
Free Executive Summary



Emerging Technologies to Benefit Farmers in Sub-Saharan Africa and South Asia

Committee on a Study of Technologies to Benefit Farmers in Africa and South Asia, National Research Council

ISBN: 978-0-309-12494-2, 292 pages, 6 x 9, paperback (2008)

Increased agricultural productivity is a major stepping stone on the path out of poverty in sub-Saharan Africa and South Asia, but farmers there face tremendous challenges improving production. Poor soil, inefficient water use, and a lack of access to plant breeding resources, nutritious animal feed, high quality seed, and fuel and electricity-combined with some of the most extreme environmental conditions on Earth-have made yields in crop and animal production far lower in these regions than world averages. Emerging Technologies to Benefit Farmers in Sub-Saharan Africa and South Asia identifies sixty emerging technologies with the potential to significantly improve agricultural productivity in sub-Saharan Africa and South Asia. Eighteen technologies are recommended for immediate development or further exploration. Scientists from all backgrounds have an opportunity to become involved in bringing these and other technologies to fruition. The opportunities suggested in this book offer new approaches that can synergize with each other and with many other activities to transform agriculture in sub-Saharan Africa and South Asia.

Executive Summary

Increased agricultural productivity is a major stepping stone on the path out of poverty, but farmers in sub-Saharan Africa and South Asia face tremendous challenges improving production. Poor soil, inefficient water use, and a lack of access to plant breeding resources, high-quality seed, and fuel and electricity—combined with some of the most extreme environmental conditions on Earth—have made yields in crop and animal production far lower in these regions than world averages. This report identifies 60 emerging technologies with the potential to significantly improve agricultural productivity in sub-Saharan Africa and South Asia. Of these, 18 technologies are selected as priorities for immediate development and deep exploration (Table ES-1).

"Tier I" tools and technologies are those that should be given the highest priority for development into specific applications. Although these technologies largely already exist, they are new from the perspective of farmers in sub-Saharan Africa and South Asia because applications specific to the needs of farmers in these regions have not been developed or widely used. "Tier II" technologies include ideas that are emerging from advances in different scientific fields. In concept, applications based on these technologies would have a great deal to offer farmers in the two regions.

In general, technologies with the greatest potential impact on agricultural production in sub-Saharan Africa and South Asia are those that help to (1) manage the natural resource base supporting agriculture; (2) improve the genetic characteristics of crops and animals; (3) reduce biotic constraints (such as disease, pests, weeds) that decrease yields; and (4) provide affordable, renewable energy for farmers.

TABLE ES-1 Priority Technologies and Applications for Improving Agriculture

Focus of Technology	Tier I High Priority for Development	Tier II High Priority for Additional Exploration
Natural Resources Management	• Soil management techniques • Integrated water management • Climate and weather prediction	• Soil-related nanomaterials • Manipulation of the rhizosphere • Remote sensing of plant physiology
Improving Genetics of Crops and Animals	• Annotated crop genomes • Genome-based animal breeding	• Site-specific gene integration • Spermatogonial stem cell transplantation • Microbial genomics of the rumen
Overcoming Biotic Constraints	• Plant-mediated gene silencing • Biocontrol and biopesticides • Disease-suppressive soils • Animal vaccines	
Energy Production		• Solar energy technologies • Photosynthetic microbe-based biofuels • Energy storage technology

Although these technologies offer many opportunities to address the challenges to agricultural production in sub-Saharan Africa and South Asia, a broader set of factors will influence the ability of a technology to have a positive impact on productivity:

- *A system-wide approach:* Agricultural production is a complex system; consequently, agricultural technologies are interdependent. For example, it is difficult to improve livestock or increase meat or milk production if the animals are chronically infected with pathogens and are fed low-quality, poorly digestible forages. Solving the problem of poor agricultural productivity requires a multifaceted approach.
- *Local expertise and participation:* Agricultural technologies developed in industrialized countries may not always work in sub-Saharan Africa and South Asia. Crop breeding requires the evaluation of traits under local environmental conditions; weather prediction algorithms need data collected at the ground level; farmers need an opportunity to provide input and acquire information. These tasks require a committed, trained, local workforce—a

workforce of extension agents, scientists, veterinarians, and engineers that must be built with national efforts and international help.

- *Agricultural innovations for the developing world do not need to be "low" technology:* Technologies addressing specific needs in sub-Saharan Africa and South Asia might never materialize if they do not fill a niche in the industrialized world. As a result, important opportunities, such as the development of advanced off-the-grid electrical power, might be missed. Farmers need more than "old" or "low" technology. Incentives and support for the development of specific applications could deliver benefits faster than waiting for market forces to propel technological development.
- *Attention to the implications of climate change:* Farmers in sub-Saharan Africa and South Asia already face severe environmental constraints. By all predictions, their livelihoods will be imperiled by the future consequences of global climate change, especially water scarcity. Comprehensive planning to alleviate the economic and ecological impacts of drought will be needed, as well as technologies that increase the availability of water and efficiency of water use.

A whole suite of approaches—some technological and some not—must come together for farmers to realize the benefit of any innovation. Scientists from all backgrounds have an opportunity to become involved in bringing these and other technologies to fruition. The opportunities identified in this report offer new approaches that can be used by the Bill & Melinda Gates Foundation and other actors to help transform agriculture in sub-Saharan Africa and South Asia.

EMERGING TECHNOLOGIES TO BENEFIT FARMERS IN SUB-SAHARAN AFRICA AND SOUTH ASIA

Committee on a Study of Technologies to Benefit Farmers in Africa and South Asia

Board on Agriculture and Natural Resources

Division on Earth and Life Studies

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

THE NATIONAL ACADEMIES PRESS 500 Fifth Street, N.W. Washington, DC 20001

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This study was supported by a grant from the Bill & Melinda Gates Foundation under Contract 223-01-2460/0031. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

International Standard Book Number-13: 978-0-309-12494-2
International Standard Book Number-10: 0-309-12494-8

Additional copies of this report are available from the National Academies Press, 500 Fifth Street, N.W., Lockbox 285, Washington, DC 20055; (800) 624-6242 or (202) 334-3313 (in the Washington metropolitan area); Internet, *http://www.nap.edu*

Cover: African women farmers transplanting rice. Courtesy, International Rice Research Institute.

Printed in the United States of America

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

www.national-academies.org

COMMITTEE ON A STUDY OF TECHNOLOGIES TO BENEFIT FARMERS IN AFRICA AND SOUTH ASIA

BRIAN A. LARKINS *(Chair)*, University of Arizona, Tucson
STEVEN P. BRIGGS, University of California, San Diego
DEBORAH P. DELMER, Rockefeller Foundation (retired), New York
RICHARD P. DICK, Ohio State University, Columbus
RICHARD B. FLAVELL, Ceres, Inc., Thousand Oaks, California
JONATHAN GRESSEL, Weizmann Institute of Science, Israel
TSEGAYE HABTEMARIAM, Tuskegee University, Alabama
RATTAN LAL, Ohio State University, Columbus
ALICE N. PELL, Cornell University, Ithaca, New York
RAYMOND J. ST. LEGER, University of Maryland, College Park
ROBERT J. WALL, United States Department of Agriculture, Agricultural Research Service, Beltsville, Maryland

Liaison from the Board on Agriculture and Natural Resources

TILAHUN D. YILMA, University of California, Davis (through December 2007)

Project Staff

ROBIN A. SCHOEN, Director, Board on Agriculture and Natural Resources
MICHAEL MA, Visiting Program Officer (through April 2008)
PEGGY TSAI, Program Officer
RUTHIE S. ARIETI, Research Associate
NORMAN GROSSBLATT, Senior Editor

Preface

In 2006, the Bill & Melinda Gates Foundation approached the National Research Council's Board on Agriculture and Natural Resources (BANR) about organizing a study to identify recent scientific knowledge and promising technologies that could transform the production capabilities of small-holder farmers in sub-Saharan Africa (SSA) and South Asia (SA). The premise underlying the proposed study was that the historical increase in agricultural productivity in the United States occurred largely through scientific and technological innovations. Crop productivity in SSA and SA lags far behind that in most agricultural areas of the world, but there also has not been a systematic application of science and technology that could improve the situation. The subsistence farming practiced in these regions results in yields and incomes that are unpredictable, leads to environmental degradation, and ultimately leads to a lack of food security. Many of the farmers produce barely enough food to survive, let alone provide a "cash crop."

Identifying ways to improve agricultural productivity in SSA and SA has been the focus of many private, national, and international organizations in recent years, and many publications describe the challenges and opportunities in addressing the factors that constrain agriculture in these regions. Among them is the 2004 publication by the InterAcademy Council, *Realizing the Promise and Potential of African Agriculture*. That report describes the unique features of African agriculture and the array of farming systems distributed across its agroecological zones and identifies broad science and technology strategies for increasing crop yields. With those reports in mind, the study committee assembled by the National Research Council

began its work by querying scientists and agriculturalists at research institutions in Africa and South Asia to learn what they thought were the most serious constraints affecting farmers (see Appendix C). But although the committee believed it important to ground its study in reality, the vision and expectation of the assignment were to take a longer view of the agricultural situation in SSA and SA and to consider science and technology that would bring about dramatic improvements, even if the technology required 10 to 20 years to implement. Indeed, the committee was asked to focus on nascent innovations, including those that posed high risks, but could also be novel and powerful. In light of that scope, the committee considered basic research projects that could be performed at any location, providing there were an application and a reasonable cost:benefit ratio.

The diverse study committee included people with appropriate knowledge of science and technology in plant and animal agriculture, many of whom had knowledge of and work experience in SSA and SA. It was important to find the right combination of committee members who knew the agricultural constraints of the regions and the status of cutting-edge agricultural science and technology, but it was not possible to include experts in all the relevant subjects. That was true not only for some aspects of plant and animal agriculture but for a number of topics in nanotechnology, chemistry, physics, and engineering. To try to address that limitation, experts representing diverse fields (economics, global and rural development, metagenomics, cyberinfrastructure, soil science, weed science, livestock reproductive physiology, environmental engineering, agricultural engineering, space-systems technology, nanotechnology systems for monitoring environmental quality, and molecular genetics and genomics) were invited to the first workshop to complement the knowledge and experience of the committee. The interdisciplinary approach proved to be valuable in shaping the scope of additional workshops, and the committee is grateful to all those experts (see Appendix D). The workshops covered a wide variety of topics that are described in the report.

The severity of the current agricultural situation in SSA and SA and the accompanying social, political, and health consequences made it difficult not to consider the potential benefits of currently available technologies and approaches that could be adapted to help farmers in these regions. Consequently, as we formulated our report, we felt it important to define "emerging" technologies as both existing technologies that might not yet have been effectively applied to problems in SSA and SA and approaches that will require additional research and technological development before they can be applied. The task required the committee to take on a mindset to be realistic and visionary at the same time. As the committee developed a framework for developing priorities among different research approaches and technological directions, it was struck with the difficulty of establish-

ing priorities among them, because improving agricultural productivity requires a systems approach. The committee's recommendations ultimately reflect that reality, and include priorities for improving all elements of the production system.

The committee believes that its report provides a compressive overview of many current and some future problems that will affect agricultural productivity in SSA and SA. It was prepared as an independent study funded by the Bill & Melinda Gates Foundation to identify emerging technologies in agriculture that have the potential to improve the quality of life of smallholder farmers in the regions. We hope that a broad range of stakeholders will find the report's conclusions and recommendations to be of value in their efforts to improve agriculture and enhance the lives of people living in those regions.

On behalf of the committee, I want to express our thanks and appreciation to Robin Schoen, director of BANR, for the time and effort she put into assembling the committee, planning the meetings and workshops, and organizing the written report. Those tasks would have been impossible without her enduring patience and hard work. We also thank all the BANR study staff for their support and assistance with our meetings and in preparing the final report.

Brian A. Larkins, *Chair*
Committee on a Study of
Technologies to Benefit Farmers in
Africa and South Asia

Acknowledgments

This report has been reviewed in draft form by persons chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards of objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Gary Anderson, University of California, Davis (*Emeritus*)
Edward Buckler, Cornell University, Ithaca, New York
Maarten Chrispeels, University of California, San Diego
Edward David, Jr., EED, Inc., Bedminster, New Jersey
Ken Giller, University of Wageningen, The Netherlands
Bruce Hammock, University of California, Davis
Jack Keller, Keller-Bliesner Engineering LLC, Logan, Utah
Fina Opio, Association for Strengthening Agricultural Research in Eastern and Central Africa, Uganda
M.V. Subba Rao, Agricultural University in Rajendranagar, Hyderabad, India
Robert Serafin, National Center for Atmospheric Research, Boulder, Colorado
Alfonso Torres, Cornell University, Ithaca, New York

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Enriqueta C. Bond, Burroughs Wellcome Fund, and R. James Cook, Washington State University (*Emeritus*). Appointed by the National Research Council, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Contents

EXECUTIVE SUMMARY 1

SUMMARY 5

1 INTRODUCTION 23
Agriculture and Poverty, 23
The Science and Technology of Tomorrow, 25
A Study of Emerging Technologies, 26
Study Approach, 27
Organization of the Report, 28
References, 28

2 CONSTRAINTS ON CROP AND ANIMAL PRODUCTIVITY IN SUB-SAHARAN AFRICA AND SOUTH ASIA 31
Overview of Crop Production in Sub-Saharan Africa and South Asia, 31
General Constraints on Crop Production, 35
Biotic Constraints on Crop Productivity, 44
Overview of Animal Production in Sub-Saharan Africa and South Asia, 51
General Constraints on Animal Production, 55
Constraints That Cannot be Solved by Science and Technology Alone, 57
A Future Uncertainty: Climate Change, 61

Lack of Quick Fixes, 63
References, 63

3 PLANT IMPROVEMENT AND PROTECTION 71
Enhancing Crop Performance, 71
Existing Tools for Conventional Plant Improvement, 74
Existing and Evolving Tools for Conventional and Transgenic Approaches to Plant Improvement, 78
Existing and Evolving Tools for Transgenic Crop Improvement, 88
Current Bottlenecks in Crop Improvement, 102
Plant Protection with Classical and Genetically Engineered Biocontrol Agents, 106
References, 111

4 WATER RESOURCE AVAILABILITY 123
Water Resources in Sub-Saharan Africa, 123
Water Resources in South Asia, 125
Demand on Water Resources in Sub-Saharan Africa and South Asia, 126
Water Resources and Climate Change, 128
Technologies for Water Management, 129
Weather and Climate Forecasting, 137
Model Development for Climate and Weather Prediction, 140
References, 141

5 TECHNOLOGIES FOR SOIL IMPROVEMENT 145
Soil Degradation in Sub-Saharan Africa and South Asia, 145
Restoring Soil Quality with Established Management Practices, 146
Novel Technologies to Improve Soil Productivity, 152
Manipulating Microorganisms in the Rhizosphere, 157
References, 167

6 TECHNOLOGIES TO IMPROVE ANIMAL HEALTH AND PRODUCTION 177
Roles of Animals in Society, 177
Animal Production Systems, 178
Improving Animal Nutrition, 179
Existing and Evolving Technologies for Improving Animal Germplasm, 185
Leapfrogging Selective Breeding with Molecular Sampling: DNA-Derived Pedigrees, 186
Genetic Engineering, 188
Germ Cell Distribution, 192

Spermatogonial Stem Cell Transplantation, 193
Improving Animal Health, 195
Needs for Drug and Vaccine Development for Sub-Saharan Africa and South Asia, 202
References, 204

7 EMERGING TECHNOLOGIES TO MEET LOCAL ENERGY NEEDS 211
The Role of Energy in Catalyzing Growth and Poverty Reduction, 211
Insufficiency of Electric-Power Grids, 212
Status of Large-Scale Renewable Energy Projects, 213
Local Electricity Generation, 215
References, 229

8 PRIORITIES FOR EMERGING TECHNOLOGIES 233
Evaluating Technologies in a Broad Context, 233
Criteria for Technology Evaluation, 236
Conclusions and Recommendations, 237
Discussion of Tier I and Tier II Techniques, 239
Final Thoughts: Building Local Capacity, 244
Conclusion, 245
References, 247

APPENDIXES

A Committee Statement of Task 251
B Biographic Sketches of Committee Members 253
C Responses from Sub-Saharan African and South Asian Scientists 259
D Contributors 263
E Recent Publications of the Board on Agriculture and Natural Resources 267

TABLES

ES-1 Priority Technologies and Applications for Improving Agriculture, 2

S-1 Priority Technologies and Applications for Improving Agriculture, 11

2-1 Cereal and Legume Yields in 2005, 35
2-2 Irrigated Areas in South Asia, 39
2-3 Regional Potential for Increasing Crop Water Productivity, 40

3-1 Economic Impact Analysis of Current Biocontrol Projects in Africa, 107

4-1 Total Water Withdrawal by Volume and as Percentage of Renewable Water, 127

7-1 Comparison of Lipid Production by Oil Crops and Microbes, 227

8-1 Priority Tools and Technologies to Improve Agriculture in Sub-Saharan Africa and South Asia, 238

FIGURES

1-1 Distribution of undernourished people, 24

2-1 Major food crops of Asia and sub-Saharan Africa, 32
2-2 Changes in cereal production, 1961-2001, in sub-Saharan Africa and Asia, 36
2-3 Areas in red are where current population exceeds agricultural capacity because of severe soil degradation and nutrient mining, 38
2-4 Tropical livestock unit density in sub-Saharan Africa and South Asia, 53

4-1 Major rivers of Africa, 124
4-2 The South Asia region showing the approximate boundary line at which rainfall or soil moisture is adequate to support a 90-day-long growing period for crops, 125
4-3 Rainfall and growth in gross domestic product in Ethiopia, 1982-2000, 127
4-4 Schematic of NOAH land surface model, 140

5-1 Soil-degradation-induced poverty, starvation, and political, ethnic, and social unrest are linked, 147

6-1 Digestibility and crude protein content of tropical grasses (fertilized and unfertilized) and legumes and their adequacy in meeting maintenance requirements of ruminants, 183

7-1 Schematic of a Stirling engine, 218

BOXES

S-1 Criteria for Evaluating Technologies, 10
S-2 Technologies Examined in the Study, 20

1-1 The Most Serious Agricultural Constraints in Sub-Saharan Africa and South Asia: Perspectives from Scientists in Those Regions, 27

2-1 Agriculture and Malnutrition, 34
2-2 Overcoming Barriers to the Use of Genetically Engineered Crops, 46
2-3 Meeting International Food Safety Standards, 52
2-4 Zoonotic Diseases, 58

3-1 Examples of Traits Targeted for Improvement, 72
3-2 Molecular Breeding and Transgenic Approaches Can Be Combined to Offer New Approaches to Crop Improvement, 77
3-3 Nontransgenic Herbicide Resistance in Maize for *Striga* Control, 78
3-4 Understanding Lignin Synthesis for Improving Tropical Forage, 86
3-5 Directed Evolution of Genes, 89
3-6 Opportunities to Control Weeds in SSA and SA Through Engineered Herbicide Resistance, 90
3-7 Engineering Plant Pathways to Decrease Postharvest Losses and Degrade Mycotoxins, 91
3-8 Opportunities to Apply RNAi to Agricultural Constraints in SSA and SA, 94
3-9 Disrupting Plant-Virus Replication, 96
3-10 Potential Transgenic Approaches to Protect Sorghum Against Birds, 97
3-11 An Inducible Suicide Gene for Weed Control?, 103

4-1 Nanomaterials for Water Purification, 133
4-2 Cloud Seeding Experiments, 136

5-1 Established Management Practices to Maintain Soil Productivity, 148
5-2 Carbon Sequestration: A Possible Opportunity for Resource-Limited Farmers, 150
5-3 Examples of Organisms Inoculated onto Crop Roots That Increased Yield or Growth, 159
5-4 Genera of Root Endophytic Bacteria That Can Fix Nitrogen, 162
5-5 Major Research and Technology Needs for Manipulating Microbes in the Rhizosphere, 166

6-1 Environmental Effects of Livestock Production, 179
6-2 Animal Production in Extensive Rangeland Systems, 180
6-3 Food Processing and Production, 182
6-4 Rumen Function, Fiber Digestion, and Metagenomics, 184
6-5 Genetic Improvement of Fish for Aquaculture, 186
6-6 Engineering Chitinase as an Insecticide, 190
6-7 RNAi Technology to Resist Bluetongue Virus, 191
6-8 Biosensors for Rapid Diagnosis, 201

7-1 Stirling Engine, 217
7-2 Breeding for Biofuels and Forage, 224

8-1 Criteria for Evaluating Technologies, 237
8-2 Bringing Talent to the Challenges of Agriculture, 246

C-1 Letter Inviting Comment About the Most Serious Constraints on Agriculture in Sub-Saharan Africa and South Asia, 260

Abbreviations and Acronyms

ACC	1-aminocyclopropane-1-carboxylate
ACMD	African cassava mosaic disease
AGRA	Alliance for a Green Revolution in Africa
AI	artificial insemination
AMSR-E	Advanced Microwave Scanning Radiometer for the Earth Observing System
BSE	bovine spongiform encephalopathy
Bt	*Bacillus thuringiensis*
CCDs	charge-coupled devices
cDNA	complementary DNA
CGIAR	Consultative Group on International Agricultural Research
CMV	cucumber mosaic disease
CS	circumsporozoite protein
DOE	U.S. Department of Energy
ELISA	enzyme-linked immunosorbent assay
ET	embryo transfer
FAO	Food and Agriculture Organization of the United Nations
GDP	gross domestic product
GRACE	Gravity Recovery and Climate Experiment

GW	gigawatt
HHMI	Howard Hughes Medical Institute
IAC	InterAcademy Council
IARCs	International Agricultural Research Centres
ICSI	intracytoplasmic sperm injection
IG	Indo-Gangetic
IT	information technology
IWMI	International Water Management Institute
LSM	NOAH Land Surface Model
MODIS	moderate-resolution imaging spectrometer
MSV	maize streak virus
MudPIT	multidimensional protein identification technology
MUS	managed underground storage
MW	megawatt
MWCNs	multiwall carbon nanotubes
NDVI	Normalized Difference Vegetation Index
NPK	nitrogen-phosphorus-potassium
NRC	National Research Council
PASS	Program for Africa's Seed System
PCD	programmed cell death
PCR	polymerase chain reaction
PIPRA	Public Intellectual Property Resource for Agriculture
PV	photovoltaic
QTL	quantitative trait loci
RNAi	RNA interference
RVF	Rift Valley fever
RYMV	rice yellow mottle virus
SA	South Asia
SDI	subsurface drip irrigation
shRNA	short double-stranded RNA
SNPs	single nucleotide polymorphisms
SOC	soil organic carbon
SSA	sub-Saharan Africa

SSC	spermatogonial stem cell
ssDNA	single-stranded DNA
TILLING	targeting induced local lesions in genomes
TLU	tropical livestock unit
TRMM	Tropical Rainfall Measuring Mission
TW	terawatt
vCJD	variant Creutzfeldt-Jakob disease
ZFNs	zinc finger nucleases