

FOOD SECURITY AND CLIMATE CHANGE

Edited by

SHYAM S. YADAV | ROBERT J. REDDEN | JERRY L. HATFIELD
ANDREAS W. EBERT | DANNY HUNTER



WILEY

Food Security and Climate Change

Food Security and Climate Change

Edited by

Shyam S. Yadav

Freelance International Consultant in Agriculture, Manav Memorial Trust/Manav Foundation,
Vikaspuri, New Delhi, India
and
Manav Mahal International School, Baghpat, Uttar Pradesh, India

Robert J. Redden

RJR Agricultural Consultants, Horsham, Victoria, Australia

Jerry L. Hatfield

USDA-ARS National Laboratory for Agriculture and the Environment, Ames, Iowa, USA

Andreas W. Ebert

Freelance International Consultant in Agriculture and Agrobiodiversity,
Schwaebisch Gmuend, Germany

Danny Hunter

Healthy Diets from Sustainable Food Systems Initiative, Bioversity International,
Rome, Italy
and
Plant and Agricultural Biosciences Centre (PABC), National University of Ireland, Galway (NUIG)

WILEY Blackwell

This edition first published 2019
© 2019 John Wiley & Sons Ltd

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, except as permitted by law. Advice on how to obtain permission to reuse material from this title is available at <http://www.wiley.com/go/permissions>.

The right of Shyam S. Yadav, Robert J. Redden, Jerry L. Hatfield, Andreas W. Ebert and Danny Hunter to be identified as the authors of the editorial material in this work has been asserted in accordance with law.

Registered Offices

John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA
John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial Office

The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

For details of our global editorial offices, customer services, and more information about Wiley products visit us at www.wiley.com.

Wiley also publishes its books in a variety of electronic formats and by print-on-demand. Some content that appears in standard print versions of this book may not be available in other formats.

Limit of Liability/Disclaimer of Warranty

While the publisher and authors have used their best efforts in preparing this work, they make no representations or warranties with respect to the accuracy or completeness of the contents of this work and specifically disclaim all warranties, including without limitation any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives, written sales materials or promotional statements for this work. The fact that an organization, website, or product is referred to in this work as a citation and/or potential source of further information does not mean that the publisher and authors endorse the information or services the organization, website, or product may provide or recommendations it may make. This work is sold with the understanding that the publisher is not engaged in rendering professional services. The advice and strategies contained herein may not be suitable for your situation. You should consult with a specialist where appropriate. Further, readers should be aware that websites listed in this work may have changed or disappeared between when this work was written and when it is read. Neither the publisher nor authors shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages.

Library of Congress Cataloging-in-Publication Data

Names: Yadav, S. S. (Shyam S.), editor.

Title: Food security and climate change / edited by Shyam S. Yadav, Robert J. Redden, Jerry L. Hatfield, Andreas W. Ebert, Danny Hunter.

Description: First edition. | Hoboken, NJ : John Wiley & Sons, Ltd, 2018. | Includes bibliographical references and index. |

Identifiers: LCCN 2018014807 (print) | LCCN 2018027212 (ebook) | ISBN 9781119180630 (pdf) | ISBN 9781119180654 (epub) | ISBN 9781119180647 (cloth)

Subjects: LCSH: Crops and climate. | Food security—Climatic factors.

Classification: LCC S600.5 (ebook) | LCC S600.5 .F68 2018 (print) | DDC 630.2/515—dc23

LC record available at <https://lcn.loc.gov/2018014807>

Cover Design: Wiley

Cover Images: ©ansonmiao/E+/Getty Images; ©danishkhan/iStock/Getty Images; ©no_limit_pictures/iStock/Getty Images; ©Juanillo1970/Shutterstock

Set in 10/12pt WarnockPro by SPi Global, Chennai, India

Contents

List of Contributors xvii

1	Climate Change, Agriculture and Food Security	1
	<i>Shyam S. Yadav, V. S. Hegde, Abdul Basir Habibi, Mahendra Dia, and Suman Verma</i>	
1.1	Introduction	1
1.1.1	Climate Change and Agriculture	3
1.1.2	Impact of Dioxide on Crop Productivity	4
1.1.3	Impact of Ozone on Crop Productivity	5
1.1.4	Impact of Temperature and a Changed Climate on Crop Productivity	6
1.2	Climate Change and Food Security	6
1.2.1	Climate Change and Food Availability	7
1.2.2	Climate Change and Stability of Food Production	8
1.2.3	Climate Change and Access to Food	8
1.2.4	Climate Change and Food Utilization	9
1.3	Predicted Impacts of Climate Change on Global Agriculture, Crop Production, and Livestock	10
1.3.1	Climate Change Mitigation, Adaptation, and Resilience	11
1.3.2	Mitigation	12
1.3.3	Adaptation and Resilience	12
1.3.4	Policies, Incentives, Measures, and Mechanisms for Mitigation and Adaptation	13
1.4	Impact of Divergent & Associated Technologies on Food Security under Climate Change	14
1.4.1	Integrated Pest Management (IPM)	15
1.4.2	Technological Options for Boosting Sustainable Agriculture Production	15
1.4.3	Mechanization in Agriculture Sector	16
1.4.4	Food Processing and Quality Agro-Products Processing	16
1.4.5	Planning, Implementing and Evaluating Climate-Smart Agriculture in Smallholder Farming Systems	17
1.5	The Government of India Policies and Programs for Food Security	17
1.6	Conclusions	18
	References	19
	In Riculture Seri	21

2	Changes in Food Supply and Demand by 2050	25
	<i>Timothy S. Thomas</i>	
2.1	Introduction	25
2.2	Model Description	26
2.3	Model Assumptions	26
2.3.1	Economic and Demographic Assumptions	26
2.4	Climate Assumptions	28
2.5	Results	30
2.5.1	Production	30
2.6	Underutilized Crops	38
2.7	Consumption	38
2.8	Trade and Prices	42
2.9	Food Security	46
2.10	Conclusion	48
	References	50
3	Crop Responses to Rising Atmospheric [CO₂] and Global Climate Change	51
	<i>Pauline Lemonnier and Elizabeth A. Ainsworth</i>	
3.1	Introduction	51
3.1.1	Rising Atmospheric [CO ₂] and Global Climate Change	51
3.1.2	Measuring Crop Responses to Rising [CO ₂]	53
3.1.3	Physiological Responses to Rising [CO ₂]	54
3.2	Crop Production Responses to Rising [CO ₂]	58
3.2.1	Effects of Rising [CO ₂] on Food Quality	59
3.2.2	Strategies to Improve Crop Production in a High CO ₂ World	61
3.2.2.1	Genetic Variability in Elevated [CO ₂] Responsiveness: The Potential and Challenges for Breeding	62
3.2.2.2	Strategies for Genetic Engineering	63
	Acknowledgements	64
	References	64
4	Adaptation of Cropping Systems to Drought under Climate Change (Examples from Australia and Spain)	71
	<i>Garry J. O'Leary, James G. Nuttall, Robert J. Redden, Carlos Cantero-Martinez, and M. Inés Minguez</i>	
4.1	Introduction	71
4.2	Water Supply	72
4.2.1	Changing Patterns of Rainfall	72
4.2.2	Rotations, Fallow, and Soil Management	74
4.3	Interactions of Water with Temperature, CO ₂ and Nutrients	77
4.3.1	High Temperature Response of Wheat	77
4.3.2	High Temperature and Grain Quality of Wheat	79
4.3.3	Atmospheric CO ₂ Concentration and Crop Growth	79
4.3.4	Elevated Atmospheric CO ₂ and Grain Quality	80

4.4	Matching Genetic Resources to The Environment and the Challenge to Identify the Ideal Phenotype	80
4.5	Changing Climate and Strategies to Increase Crop Water Supply and Use	82
4.6	Beyond Australia and Spain	84
4.7	Conclusions	85
	Acknowledgments	85
	References	86
5	Combined Impacts of Carbon, Temperature, and Drought to Sustain Food Production	95
	<i>Jerry L. Hatfield</i>	
5.1	Introduction	95
5.1.1	Need for Food to Feed the Nine Billion by 2050	95
5.2	Changing Climate	96
5.3	Carbon Dioxide And Plant Growth	97
5.3.1	Responses of Plants to Increased CO ₂	97
5.3.2	Effect of Increased CO ₂ on Roots	100
5.3.3	Effect of Increased CO ₂ on Quality	100
5.4	Temperature Effects on Plant Growth	102
5.4.1	Responses of Plants to High Temperatures	102
5.4.2	Mechanisms of Temperature Effect on Plants	104
5.5	Water Effects on Plant Growth	106
5.5.1	Mechanisms of Water Stress	107
5.6	Interactions of Carbon Dioxide, Temperature, And Water in a Changing Climate	108
	References	110
6	Scope, Options and Approaches to Climate Change	119
	<i>S. Seneweera, Kiruba Shankari Arun-Chinnappa, and Naoki Hirotsu</i>	
6.1	Introduction	119
6.2	Impact of CO ₂ and climate stress on growth and yield of agricultural crop	120
6.3	The Primary Mechanisms of Plants Respond to Elevated CO ₂	121
6.4	Interaction of Rising CO ₂ With Other Environmental Factors – Temperature and Water	121
6.5	Impact of Climate Change on Crop Quality	122
6.6	Climate Change, Crop Improvement, and Future Food Security	123
6.7	Intra-specific Variation in Crop Response to Elevated [CO ₂] - Current Germplasm Versus Wild Relatives	124
6.8	Identification of New QTLs for Plant Breeding	124
6.9	Association Mapping for Large Germplasm Screening	125
6.10	Genetic Engineering of CO ₂ Responsive Traits	125
6.11	Conclusions	126
	References	127

- 7 Mitigation and Adaptation Approaches to Sustain Food Security under Climate Change 131**
Li Ling and Xuxiao Zong
- 7.1 Technology and its Approaches Options to Climate Change in Agriculture System 132
- 7.1.1 Adjusting Agricultural Farming Systems and Organization, with Changes in Cropping Systems 133
- 7.1.2 Changing Farm Production Activities 135
- 7.1.3 Developing Biotechnology, Breeding New Varieties to Adapt to Climate Change 135
- 7.1.4 Developing Information Systems, and Establishing a Disaster Prevention System 136
- 7.1.5 Strengthening the Agricultural Infrastructure, Adjusting Management Measures 137
- 7.2 Development and Implementation of Techniques to Combat Climatic Changes 137
- 7.2.1 Improving Awareness of Potential Implications of Climate Change Among All Parties Involved (from grassroots level to decision makers) 138
- 7.2.2 Enhancing Research on Typical Technology 138
- 7.2.2.1 Enhancing Research on Typical Technology for Different Areas 138
- 7.2.2.2 Enhancing Research on Food Quality Under Climate Change 138
- 7.2.2.3 Enhancing Research on Legumes and Its Biological Nitrogen Fixation 139
- 7.2.3 Developing Climate-Crop Modelling as an Aid to Constructing Scenarios 140
- 7.2.4 Development and Assessment Efforts of Adaptation Technology 140
- References 141
- 8 Role of Plant Breeding to Sustain Food Security under Climate Change 145**
Rodomiro Ortiz
- 8.1 Introduction 145
- 8.2 Sources of Genetic Diversity and their Screening for Stress Adaptation 146
- 8.2.1 Crop-related Species 146
- 8.2.2 Domestic Genetic Diversity 146
- 8.2.3 Crossbreeding 147
- 8.2.4 Pre-breeding 148
- 8.2.5 Biotechnology and Modeling as Aids for Breeding Cultivars 148
- 8.3 Physiology-facilitated Breeding and Phenotyping 149
- 8.3.1 Abiotic Stress Adaptation and Resource-use Efficiency 150
- 8.3.2 Precise and High Throughput Phenotyping 150
- 8.4 DNA-markers for Trait Introgression and Omics-led Breeding 151
- 8.5 Transgenic Breeding 152
- References 153
- 9 Role of Plant Genetic Resources in Food Security 159**
Robert J. Redden, Hari Upadyaya, Sangam L. Dwivedi, Vincent Vadez, Michael Abberton, and Ahmed Amri
- 9.1 Introduction 159

9.2	Climate Change and Agriculture	160
9.3	Adjusting Crop Distribution	160
9.4	Within Crop Genetic Diversity for Abiotic Stress Tolerances	160
9.5	Broadening the Available Genetic Diversity Within Crops	161
9.6	Crop Wild Relatives as a Novel Source Of Genetic Diversity	161
9.7	Genomics, Genetic Variation and Breeding for Tolerance of Abiotic Stresses	162
9.8	Under-utilised Species	163
9.9	Genetic Resources in the Low Rainfall Temperate Crop Zone	164
9.10	Forage and Range Species	166
9.11	Genetic Resources in the Humid Tropics	166
9.12	Genetic Resources in the Semi-arid Tropics and Representative Subsets	168
9.13	Plant Phenomics	168
9.14	Discovering Climate Resilient Germplasm Using Representative Subsets	170
9.14.1	Multiple Stress Tolerances	170
9.14.2	Drought Tolerance	170
9.14.3	Heat Tolerance	173
9.14.4	Tolerance of Soil Nutrient Imbalance	174
9.15	Global Warming and Declining Nutritional Quality	174
9.16	Crop Wild Relatives (CWR) - The Source of Allelic Diversity	174
9.17	Introgression of Traits from CWR	175
9.18	Association Genetics to Abiotic Stress Adaptation	176
9.19	Strategic Overview	177
9.20	Perspectives	177
9.21	Summary	179
	References	179
10	Breeding New Generation Genotypes for Conservation Agriculture in Maize-Wheat Cropping Systems under Climate Change	189
	<i>Rajbir Yadav, Kiran Gaikwad, Ranjan Bhattacharyya, Naresh Kumar Bainsla, Manjeet Kumar, and Shyam S. Yadav</i>	
10.1	Introduction	189
10.2	Challenges Before Indian Agriculture	191
10.2.1	Declining Profit	191
10.2.2	Depleting Natural Resources:	193
10.2.2.1	Water:	193
10.2.2.2	Soil Health/ Soil Quality	193
10.2.3	Changing Climate	195
10.2.4	Climate Change Adaptation: Why it is Important in Wheat?	198
10.3	CA as a Concept to Address These Issues Simultaneously	199
10.4	Technological Gaps for CA in India	199
10.4.1	Machinery Issue	199
10.4.2	Non-availability of Adapted Genotypes for Conservation Agriculture	200
10.4.3	Designing the Breeding Strategies	201
10.5	Characteristics of Genotypes Adapted for CA	202
10.5.1	Role of Coleoptiles in Better Stand Establishment Under CA	202

- 10.5.2 Spreading Growth Habit During Initial Phase for Better Moisture Conservation and Smothering of Weeds 204
- 10.5.3 Exploitation of Vernalization Requirement for Intensification 205
- 10.5.4 Integrating Cropping System and Agronomy Perspective in Breeding for CA 209
- 10.6 Wheat Ideotype for Rice-Wheat Cropping Systems of Northern India 214
- 10.7 Breeding Methodology Adopted in IARI for CA Specific Breeding 215
- 10.8 Countering the Tradeoff Between Stress Adaptation and Yield Enhancement Through CA Directed Breeding 216
- 10.8.1 Yield Enhancement by Increasing Water Use Efficiency Through CA 218
- 10.9 Conclusions 220
- References 221

11 Pests and Diseases under Climate Change; Its Threat to Food Security 229

Piotr Trebicki and Kyla Finlay

- 11.1 Introduction 229
- 11.2 Climate Change and Insect Pests 231
- 11.3 Climate Change and Plant Viruses 235
- 11.4 Climate Change and Fungal Pathogens 238
- 11.5 Climate Change and Effects on Host Plant Distribution and Availability 240
- Acknowledgments 241
- References 241

12 Crop Production Management to Climate Change 251

Sain Dass, S. L. Jat, Gangadhar Karjagi Chikkappa, and C.M. Parihar

- 12.1 Introduction 251
- 12.2 Maize Scenario in World and India 251
- 12.3 The Growth Rate of Maize 254
- 12.4 Maize Improvement 256
- 12.5 Single Cross Hybrids 256
- 12.6 Pedigree Breeding for Inbred Lines Development 257
- 12.6.1 Seed multiplication 258
- 12.6.2 Single Cross Development 258
- 12.7 Preferred Characteristics for Good Parent 259
- 12.7.1 Female or Seed Parent 259
- 12.7.2 Development of Specialty Corn Schs 259
- 12.7.3 Baby Corn and Sweet Corn 259
- 12.7.4 Quality Protein Maize (QPM) 260
- 12.7.4.1 Improvement of Inbred Lines 260
- 12.7.4.2 Improvement of Inbred Lines through MAS 260
- 12.7.4.3 Foreground selection 260
- 12.7.4.4 Background selection 261
- 12.7.4.5 Marker Assisted Backcross Breeding strategies (MABB) 262
- 12.7.4.6 MABB at What Cost? 262
- 12.7.5 Doubled Haploid (DH) Technique 263
- 12.7.5.1 Steps Involved *In Vivo* DH Inbred Lines Development 263

12.7.5.2	Advantages of DH Lines over Conventional Inbred Lines	265
12.7.6	Transgenic Maize and its Potential	265
12.7.6.1	Abiotic Stresses	266
12.7.6.2	Drought Tolerance	267
12.7.6.3	Screening Techniques	267
12.7.7	Hybrid Seed Production	268
12.7.7.1	Pre-requisites of Single Cross Hybrid Seed Production	268
12.7.8	Important Considerations for Hybrid Seed Production	268
12.7.8.1	Isolation Distance	268
12.7.8.2	Male:female Ratio	269
12.7.8.3	How to Bring Male: female Synchrony?	269
12.7.8.4	Hybrid Seed Production Technology	269
12.7.8.5	Hybrid Seed Production Sites	272
12.7.9	Crop Production	272
12.7.9.1	Cropping System Optimization	272
12.7.9.2	Crop Sequence	273
12.7.9.3	Best Management Practices (BMP) for Crop Establishment	274
12.7.9.4	Crop Establishment	274
12.7.9.5	Raised Bed / ridge and Furrow Planting	276
12.7.9.6	Zero-till Planting	278
12.7.9.7	Conventional Till Flat Planting	278
12.7.9.8	Furrow Planting	278
12.7.9.9	Transplanting	279
12.7.9.10	BMP for Water Management	279
12.7.9.11	BMP for nutrient management	281
12.8	Nutrient Management Practices for Higher Productivity and Profitability in Maize Systems	283
12.8.1	Timing and method of fertilizer application	284
12.8.2	Integrated Nutrient Management (INM)	284
12.8.3	Biofertilizers	285
12.8.4	Micronutrient Application	285
12.8.5	Slow Release Fertilizers	285
12.8.6	Precision Nutrient Management	285
12.8.7	Conservation Agriculture and Smart Mechanization	286
	References	287
13	Vegetable Genetic Resources for Food and Nutrition Security under Climate Change	289
	<i>Andreas W. Ebert</i>	
13.1	Introduction	289
13.2	Global vegetable production	290
13.3	The Role of Genetic Diversity to Maintain Sustainable Production Systems Under Climate Change	290
13.4	Ex Situ Conservation of Vegetable Germplasm at The Global Level	296
13.5	Access to Information on Ex Situ Germplasm Held Globally	302
13.5.1	SINGER: Online Catalog of International Collections Managed by the GCIAR and WorldVeg	303

13.5.2	EURISCO: the European Genetic Resources Search Catalog	303
13.5.3	GRIN of USDA-ARS	304
13.5.4	GENESYS: the global gateway to plant genetic resources	304
13.5.5	The Crop Wild Relatives Portal	305
13.5.6	Crop Trait Mining Platforms	305
13.5.6.1	Crop Trait Mining Informatics Platform	305
13.5.6.2	The Diversity Seek Initiative	306
13.5.7	Trait information portal for CWR and landraces and crop-trait ontologies	307
13.5.8	Summary and Outlook	308
13.6	In Situ and On-farm Conservation of Vegetable Resources	310
13.7	Summary and Outlook	311
	Acknowledgment	312
	References	312
	Annex 1	315
14	Sustainable Vegetable Production to Sustain Food Security under Climate Change at Global Level	319
	<i>Andreas W. Ebert, Thomas Dubois, Abdou Tenkouano, Ravza Mavlyanova, Jaw-Fen Wang, Bindumadhava Hanumantha Rao, Srinivasan Ramasamy, Sanjeet Kumar, Fenton D. Beed, Marti Pottorff, Wu-Yang Chen, Ramakrishnan M. Nair, Harsh Nayyar, and James J. Riley</i>	
14.1	Introduction	319
14.2	Regional Perspective: Sub-Saharan Africa	320
14.2.1	The Effects of Climate Change in Sub-Saharan Africa	320
14.2.2	Interactions Between Climate Change and Other Factors Driving Vegetable Production and Consumption in Sub-Saharan Africa	321
14.2.3	Implications of Climate Change and Other Factors on Vegetable Production and Consumption in Sub-Saharan Africa	321
14.3	Regional Perspective: South and Central Asia	325
14.3.1	The Effects of Climate Change in South Asia	325
14.3.2	The Effects of Climate Change in Central Asia	326
14.3.3	Climate Change Adaptation Options in South and Central Asia	326
14.4	The Role of Plant Genetic Resources for Sustainable Vegetable Production	328
14.5	Microbial Genetic Resources to Boost Agricultural Performance of Robust Production Systems and to Buffer Impacts of Climate Change	329
14.6	Physiological Responses to a Changing Climate: Elevated CO ₂ Concentrations and Temperature in The Environment	330
14.6.1	CO ₂ and Photosynthesis	330
14.6.2	CO ₂ and Stomatal Transpiration	331
14.6.3	Dual Effect of Increased CO ₂ and Temperature	331
14.6.3.1	High Temperature (HT) Effect on Mungbean	332
14.6.3.2	Current and Proposed Mungbean Physiology Studies at Worldveg South Asia	332
14.6.4	Conclusion	334
14.7	Plant Breeding for Sustainable Vegetable Production	335

14.7.1	Formal Vegetable Seed System –Lessons Learned	335
14.7.2	Role of WorldVeg’s International Breeding Programs	336
14.7.3	Impact of WorldVeg’s Breeding Programs	337
14.7.4	Future Outlook	337
14.8	Management of Bacterial and Fungal Diseases for Sustainable Vegetable Production	338
14.9	Management of Insect and Mite Pests	342
14.10	Grafting to Overcome Soil-borne Diseases and Abiotic Stresses	344
14.11	Summary and Outlook	347
	Acknowledgment	347
	References	348
15	Sustainable Production of Roots and Tuber Crops for Food Security under Climate Change	359
	<i>Mary Taylor, Vincent Lebot, Andrew McGregor, and Robert J. Redden</i>	
15.1	Introduction	359
15.2	Optimum Growing Conditions for Root and Tuber Crops	361
15.2.1	Sweet Potato	361
15.2.2	Cassava	361
15.2.3	Edible Aroids	362
15.2.3.1	Taro	362
15.2.3.2	Cocoyam	362
15.2.3.3	Giant Taro	363
15.2.3.4	Swamp Taro	363
15.2.4	Yams	363
15.3	Projected Response of Root and Tuber Crops to Climate Change	364
15.3.1	Sweet Potato	364
15.3.2	Cassava	364
15.3.2.1	Edible Aroids	365
15.3.2.2	Yam	365
15.4	Climate Change and Potato Production	366
15.5	Sustainable Production Approaches	367
15.5.1	Agroforestry Systems	367
15.5.1.1	Combining Tree Crops and Roots and Tubers	367
15.5.2	Soil Health Management	368
15.5.3	Utilizing Diversity	368
15.6	Optimization of Root and Tuber Crops Resilience to Climate Change	369
15.7	Conclusion	371
	References	371
16	The Roles of Biotechnology in Agriculture to Sustain Food Security under Climate Change	377
	<i>Rebecca Ford, Yasir Mehmood, Usana Nantawan, and Chutchamas Kanchana-Udomkan</i>	
16.1	Introduction	377
16.2	Reduced Water Availability and Drought	378
16.3	Drought-proofing Wheat and Other Cereals	378

- 16.4 Drought Tolerance in Temperate Legumes 380
- 16.5 Drought Tolerance in Tropical Crops 381
- 16.6 Rainfall Intensity, Flooding and Water-logging Tolerance 383
- 16.7 Heat Stress And Thermo-tolerance 385
- 16.8 Thermo-tolerance and Heat Shock Proteins in Food Crops 385
- 16.9 Heat Stress Tolerance in Temperate Legumes 388
- 16.10 Salinity Stress, Ionic and Osmotic Tolerances 388
- 16.11 Salinity Tolerance in Rice 389
- 16.12 Salinity Tolerance in Legumes 390
- 16.13 Transgenics to Overcome Climate Change Imposed Abiotic Stresses 390
- 16.14 Conclusion 392
- References 393

- 17 Application of Biotechnologies in the Conservation and Utilization of Plant Genetic Resources for Food Security 413**
Toshiro Shigaki
- 17.1 Introduction 413
- 17.2 Climate change 413
 - 17.2.1 Population Explosion 414
 - 17.2.2 Vandalism 414
- 17.3 Collecting Germplasm 415
- 17.4 Conservation 415
 - 17.4.1 *In situ* Collection 415
 - 17.4.2 *Ex situ* Collection 416
 - 17.4.3 Slow Growth in Tissue Culture 416
 - 17.4.4 Cryopreservation 417
 - 17.4.5 Herbarium 419
 - 17.4.6 Svalbard Global Seed Vault 419
- 17.5 Characterization of Germplasm 420
 - 17.5.1 Early Developments 420
 - 17.5.1.1 RFLP 420
 - 17.5.1.2 RAPD 421
 - 17.5.2 New Developments 421
 - 17.5.2.1 Genotyping by Simple Sequence Repeats (SSR) 421
 - 17.5.2.2 Amplified Fragment Length Polymorphism (AFLP) 421
 - 17.5.3 Recent Developments 422
 - 17.5.3.1 Genotyping by Sequencing (GBS) 422
- 17.5.4 Future Prospects 422
- 17.6 Germplasm Exchange 422
 - 17.6.1 Bioassay 423
 - 17.6.2 Enzyme-Linked Immunosorbent Assay (ELISA) 423
 - 17.6.3 PCR 423
 - 17.6.4 Loop-mediated Isothermal Amplification (LAMP) 423
- 17.7 Germplasm Utilization 425
 - 17.7.1 Embryo Rescue 425
 - 17.7.2 Somatic Hybridization 426
 - 17.7.3 Molecular Breeding 426

17.7.4	Genetic Engineering	426
17.7.5	Biosafety	428
17.8	Future Strategies and Guidelines for the Preservation of Plant Genetic Resources	428
	References	430
18	Climate Change Influence on Herbicide Efficacy and Weed Management	433
	<i>Mithila Jugulam, Aruna K. Varanasi, Vijaya K. Varanasi, and P.V.V. Prasad</i>	
18.1	Introduction	433
18.2	Herbicides in Weed Management	434
18.3	Climate Factors and Crop-Weed Competition	434
18.4	Climate Change Factors, Herbicide Efficacy and Weed Control	438
18.4.1	Effects of Elevated CO ₂ and High Temperatures	438
18.4.2	Effects of Precipitation and Relative Humidity	440
18.4.3	Effects of Solar Radiation	441
18.5	Concluding Remarks and Future Direction	442
	Acknowledgments	442
	References	442
19	Farmers' Knowledge and Adaptation to Climate Change to Ensure Food Security	449
	<i>Lois Wright Morton</i>	
19.1	Farmers and Climate Change	449
19.2	Knowledge About Climate	451
19.3	Weather and Climate	452
19.4	Values and Beliefs About Climate Change	453
19.5	Farmer Climate Beliefs	454
19.6	Vulnerability, Experiences of Risk, Concern About Hazards and confidence	456
19.7	Climate Related Hazards	458
19.8	Adaptation Factors	460
19.9	Water is the Visible Face of Climate	462
19.10	Making Sense of Climate: Local, Indigenous and Scientific knowledge	463
19.11	System Adaptation or Transformation	465
	References	467
20	Farmer and Community-led Approaches to Climate Change Adaptation of Agriculture Using Agricultural Biodiversity and Genetic Resources	471
	<i>Tony McDonald, Jessica Sokolow, and Danny Hunter</i>	
20.1	Introduction	471
20.2	Impact of Climate Change on Farming Communities	472
20.3	Inequity of Climate Change across Farming Communities	474
20.4	Impact of Climate Change on the Many Elements of Genetic Resources and Agricultural Biodiversity	475
20.5	Monocultures	475

20.6	Wild Species	476
20.7	Role of Genetic Resources and Agricultural Biodiversity in Coping with Climate Change	477
20.8	Brief Overview of Approaches Using Genetic Resources and Agricultural Biodiversity to Cope with Climate Change	478
20.9	Identification of a Spectrum of Examples of Farmer-led Approaches	482
20.10	Examination of Barriers to Implementation of Farmer-led Approaches	483
20.10.1	Farmers & their Communities	490
20.10.2	Institutional & Collaborative mechanisms	491
20.10.3	Contextual & Background	492
20.11	Systems that are working	493
20.12	Conclusion	494
	References	494

**21 Accessing Genetic Diversity for Food Security and Climate Change
Adaptation in Select Communities in Africa 499**

Otieno Gloria

21.1	Introduction	499
21.2	Methodology	501
21.2.1	Reference Sites and Crops	501
21.2.2	Data and Methods	502
21.3	Results and Discussion	504
21.3.1	Summary of Climate Change in Selected Sites	504
21.3.2	Finding Potentially Adaptable Accessions from a Pool of National and International Plant Genetic Resources	504
21.3.2.1	Zambia	505
21.3.2.2	Zimbabwe	508
21.3.2.3	Benin	508
21.4	Conclusions and Policy Implications	520
	References	521

Index 523

List of Contributors

Michael Abberton

IITA Genetic Resources Centre
International Institute of Tropical
Agriculture
Ibadan
Nigeria

Elizabeth A. Ainsworth

USDA ARS Global Change and
Photosynthesis Research Unit
Urbana
USA

Ahmed Amri

International Center for Agricultural
Research in Dry Areas (ICARDA)
Rabat
Morocco

Kiruba Shankari Arun-Chinnappa

Centre for Crop Health
University of Southern Queensland
Toowoomba
Australia

Naresh Kumar Bainsla

Indian Agricultural Research Institute
ICAR
New Delhi
India

Fenton D. Beed

Food and Agriculture Organization of the
United Nations (FAO)
Rome
Italy

Ranjan Bhattacharyya

Indian Agricultural Research Institute
ICAR
New Delhi
India

Carlos Cantero-Martinez

Department of Crop and Forestry
Science, Agrotecnio
Universitat de Lleida
Lleida
Spain

Wuu-Yang Chen

World Vegetable Center
Shanhua
Tainan
Taiwan

Gangadhar Karjagi Chikkappa

ICAR-Indian Institute of Maize Research
New Delhi
India

Sain Dass

Ex Director Maize
Indian Council of Agricultural Research
New Delhi
India

Mahendra Dia

Department of Horticultural Sciences
North Carolina State University
Raleigh
North Carolina
USA

Thomas Dubois

World Vegetable Center, Eastern and
Southern Africa
Duluti
Arusha
Tanzania

Sangam L. Dwivedi

International Crops Research Institute for
the Semi-Arid Tropics (ICRISAT)
Patancheru
Telangana
India

Andreas W. Ebert

Freelance International Consultant in
Agriculture and Agrobiodiversity
Schwaebisch Gmuend
Germany

Kyla Finlay

Agriculture Victoria Research
Horsham
Victoria
Australia

Rebecca Ford

Environmental Futures Research Centre
Griffith University
Nathan
Queensland
Australia

Kiran Gaikwad

Indian Agricultural Research Institute
ICAR
New Delhi
India

Otieno Gloria

Bioversity International Regional Office
of Uganda
Kampala
Uganda

Abdul Basir Habibi

Afghanistan Agriculture Input Project
Ministry of Agriculture, Irrigation &
Livestock, Kabul
Afghanistan

Bindumadhava Hanumantha Rao

World Vegetable Center South Asia
Greater Hyderabad
Telangana
India

Jerry L. Hatfield

National Laboratory for Agriculture and
the Environment, USDA-ARS
Ames
Iowa
USA

V. S. Hegde

Division of Genetics
Indian Agricultural Research Institute
Indian Council of Agricultural Research
New Delhi
India

Naoki Hirotsu

Tokyo University
Japan

Danny Hunter

Healthy Diets from Sustainable Food
Systems Initiative Bioversity International
Rome
Italy

and

Plant and Agricultural Biosciences Centre
(PABC)
National University of Ireland
Galway (NUIG)

S. L. Jat

ICAR-Indian Institute of Maize Research
New Delhi
India

Mithila Jugulam

Department of Agronomy
Kansas State University
Manhattan
USA

Chutchamas Kanchana-Udomkan

Environmental Futures Research Centre
Griffith University
Nathan
Queensland
Australia

Manjeet Kumar

Indian Agricultural Research Institute
ICAR
New Delhi
India

Sanjeet Kumar

World Vegetable Center
Shanhua
Tainan
Taiwan

Vincent Lebot

CIRAD-AGAP
Vanuatu

Pauline Lemonnier

USDA ARS Global Change and
Photosynthesis Research Unit
Urbana
USA

Li Ling

Legume breeder
Liaoning Institute of Cash Crops
Liaoyang
Liaoning Province
China

Ravza Mavlyanova

World Vegetable Center, Central Asia and
the Caucasus
Tashkent
Uzbekistan

Andrew McGregor

Koko Siga Pacific
Fiji

Yasir Mehmood

Environmental Futures Research Centre
Griffith University
Nathan
Queensland
Australia

M. Inés Mínguez

Centre for The Management of
Agricultural and Environmental Risk
(CEIGRAM-ETSIAAB-UPM)
Technical University of Madrid
Madrid
Spain

Lois Wright Morton

Department of Sociology
Iowa State University
Ames
Iowa

Ramakrishnan M. Nair

World Vegetable Center South Asia
Greater Hyderabad
Telangana
India

Usana Nantawan

Environmental Futures Research Centre
Griffith University
Nathan
Queensland
Australia

Harsh Nayyar

Department of Botany
Panjab University
Chandigarh
India

James G. Nuttall

Agriculture Victoria Research
Department of Economic Development
Jobs, Transport and Resources
Horsham
Victoria
Australia

Garry J. O'Leary

Agriculture Victoria Research,
Department of Economic Development
Jobs, Transport and Resources
Horsham
Victoria
Australia

Rodomiro Ortiz

Department of Plant Breeding
Swedish University of Agricultural
Sciences (SLU)
Sundsvagen
Alnarp
Sweden

C.M. Parihar

ICAR-Indian Agricultural Research
Institute
New Delhi
India

Marti Pottorff

Department of Botany and Plant Sciences
University of California
Riverside
USA

P.V.V. Prasad

Department of Agronomy
Kansas State University
Manhattan
USA

Srinivasan Ramasamy

World Vegetable Center
Shanhua
Tainan
Taiwan

Robert J. Redden (Retired)

RJR Agricultural Consultants
Horsham
Victoria
Australia

James J. Riley

College of Agriculture and Life Sciences
University of Arizona
Tucson
USA

S. Seneweera

Centre for Crop Health
University of Southern Queensland
Toowoomba
Australia

and

National Institute of Fundamental Studies
(NIFS)
Kandy
Sri Lanka

Toshiro Shigaki

Laboratory of Plant Pathology
University of Tokyo
Tokyo
Japan

Jessica Sokolow

Research Associate
The Cabrera Research Lab
Ithaca
New York

and

The College of Human Ecology
Cornell Institute of Public Affairs
Cornell University
Ithaca
New York

Mary Taylor

University of the Sunshine Coast
Queensland
Australia

Abdou Tenkouano

CORAF/WECARD
Dakar-RP
Senegal

Timothy S. Thomas

International Food Policy Research
Institute (IFPRI)
Washington, DC
USA

Tony McDonald

Institute of Land Water and Society
Charles Sturt University
Australia

Piotr Trębicki

Agriculture Victoria Research
Horsham
Victoria
Australia

Hari Upadaya

International Crops Research Institute for
the Semi-Arid Tropics (ICRISAT)
Patancheru
Telangana
India

Vincent Vadez

International Crops Research Institute for
the Semi-Arid Tropics (ICRISAT)
Patancheru
Telangana
India

Aruna K. Varanasi

Department of Agronomy
Kansas State University
Manhattan
USA

Vijaya K. Varanasi

Department of Agronomy
Kansas State University
Manhattan
USA

Suman Verma

Government Holkar Science College
Devi Ahilya Vishwavidyalaya
Indor
India

Jaw-Fen Wang

Department of Agronomy
National Taiwan University
Taipei
Taiwan

Rajbir Yadav

Indian Agricultural Research Institute
ICAR
New Delhi
India

Shyam S. Yadav

Manav Foundation
Vikaspuri
New Delhi
India

and

Manav Mahal International School
Lohara
Ami Nagar Sarai
Baghpat
Uttar Pradesh
India

Xuxiao Zong

CAAS
China

1

Climate Change, Agriculture and Food Security

Shyam S. Yadav^{1,6}, V. S. Hegde², Abdul Basir Habibi³, Mahendra Dia⁴, and Suman Verma⁵

¹Manav Foundation, Vikaspuri, New Delhi, India

²Division of Genetics, Indian Agricultural Research Institute, Indian Council of Agricultural Research, New Delhi, India

³Afghanistan Agriculture Input Project, Ministry of Agriculture, Irrigation & Livestock, Kabul, Afghanistan

⁴Department of Horticultural Sciences, North Carolina State University, Raleigh, North Carolina, USA

⁵Government Holkar Science College, Devi Ahilya Vishwavidyalaya, Indore, India

⁶Manav Mahal International School, Lohara, Ami Nagar Sarai, Baghpat, Uttar Pradesh, India

1.1 Introduction

During recent years, worldwide heavy rainfalls and floods, forest fires, occurrences, and the spread of new diseases, as found in the new strains of different pathogens and viruses, abnormal bacterial growth, and higher incidences of insect pests are direct indications of drastic environmental changes globally. It is now well established and documented that anthropogenic greenhouse gas (GHG) emissions are the main reason for the climate change at global level. It is also well recognized that agriculture sectors are directly affected by changes in temperature, precipitation, and carbon dioxide (CO₂) concentration in the atmosphere. Thus, early and bold measures are needed to minimize the potentially drastic climate impacts on the production and productivity of various field crops. In most of the developing countries in Africa, Asia, and Asia Pacific regions, about 70% of the population depend directly or indirectly for its livelihood on the agriculture sector and most of this population lives in arid or semiarid regions, which are already characterized by highly volatile climate conditions (Yadav et al., 2015).

Food, from staple cereal grains to high protein legumes and oilseed crops, is central to human development and well-being (Misselhorn et al., 2012); however, the complexity of global food security is challenging and will be made more so under climate change. The world continues to face huge difficulties in securing adequate food that is healthy, safe, and of high nutritional quality for all (Redden et al., 2014a). Considering the complexity of climatic change, the crop, plants, and livestock are inherently affected by too much or too little water, too high or too low temperatures, the length of the growing season, seasonal variation, other climatic extremes, etc.

If we consider weather extremes during 2010 – 11, in Russia there were severe heat waves and approximately 30% of grain crops were lost due to burning, which resulted in huge losses to the Russian economy. Likewise, in Pakistan, the worst floods in 80 years of history occurred, and it was suggested in different media reports that one-fifth of the country area and more than 14% of cultivated land were submerged. Considering

the Indian weather scenarios during recent years some parts are having good rains and some parts are under drought and cultivation of many field crops is difficult in those areas and crop productivity is adversely affected.

The Intergovernmental Panel on Climate Change (IPCC) defined “climate change as any change in climate over a time period that alters the composition of the global atmosphere and this change might be due to natural climate variability or a result of human activity”. According to the United Nations Framework Convention on Climate Change (UNFCCC) climate change refers to “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and is in addition to natural climate variability observed over comparable time periods”. Human activities, most importantly the burning of fossil fuels, natural causes, industrialization, and changes in land use are modifying the concentrations of atmospheric constituents or properties of the surface that absorb or scatter radiant energy. The majority of the warming observed over the last 50 years was likely due to the increase in greenhouse gas concentrations (IPCC, 2001) and future changes in climate are expected to include additional warming, changes in the amount of rainfall and its distribution pattern, rise in sea-level, and increased frequency and intensity of some climate extreme events such as flood, drought, and temperature severity.

According to the Special Report on Emissions Scenarios (Nakic’enovic’ and Swart, 2000), the carbon dioxide concentration (CO_2) in the atmosphere which was 284 ppm in 1832 will increase to approximately 550 ppm by 2050. This, in combination with other changes in the atmosphere, is likely to change the Earth’s climate, making it warmer by an average of 1.8°C to 4.0°C by the end of this century (IPCC, 2007). The temperature increase is widespread over the globe, and is greater at higher northern latitudes, while land regions have warmed faster than the oceans. This warming will increase the evapotranspiration of water from wet surfaces and plants, leading to increased but more variable distribution of precipitation. The concentration of ozone (O_3) will also increase as a result of industrialization and this will have a negative impact on crop growth and productivity. The global average sea level has risen since 1961 at an average rate of 1.8 mm/year and since 1993 at 3.1 mm/year with contributions from thermal expansion, melting glaciers and ice caps, and the polar ice sheets (IPCC, 2007). The annual average Arctic sea ice extent has shrunken by 2.7% per decade, with larger decreases in summer of 7.4% per decade. Mountain glaciers and snow cover on an average have declined in both hemispheres (IPCC, 2007). These general features of climate change act on natural and biological systems. The changes in climate, particularly increases in temperature have already affected a wide range of physical and biological systems in many aquatic, terrestrial and marine environments in various parts of the world. The climate change will increase the risks of extinction of more vulnerable species and loss of biodiversity. The extent of damage or loss and the number of systems affected would increase with the magnitude and rate of climate change. The human systems that are sensitive to climate change mainly include water resources, agriculture and forestry, coastal zones and marine systems, human settlements, and human health. The extent of the vulnerability of these systems depends on the geographical location and environmental conditions. The projected adverse impacts of climate change on human systems (IPCC, 2001) include: i) a general reduction in potential yields of crops in most of the tropical and sub-tropical regions for increases in atmospheric temperature; ii) a general reduction in potential crop yields in most of the regions in Mid-latitudes due to increases in

annual average temperature of more than a few $^{\circ}\text{C}$; iii) decreased availability of potable water for populations in many water-scarce regions, particularly in the Sub-tropics; iv) increased incidences of vector-borne and water-borne diseases and an increase in heat-stress mortality; v) increased risk of flooding for many human settlements because of increased occurrences of heavy precipitation and also a rise in the sea-level; and vi) a general increase in the demand for energy due to higher summer temperatures in different parts of the world. Climate change is also known to have some beneficial effects on the human system (IPCC, 2001). The positive impacts of climate change include: i) an increase in the potential yields of some crops in some of the regions in Mid-altitudes for increases in temperatures of less than a few $^{\circ}\text{C}$; ii) a potential increase in global supply of timber from well managed forests; iii) an increase in the availability of water in some water-scarce regions in some parts of Southeast Asia; iv) A decrease in the winter-mortality in mid- and high altitudes; and v) reduced demand for energy due to higher winter temperatures.

1.1.1 Climate Change and Agriculture

The world population will continue to grow and is expected to reach 9.1 billion by 2050 (Charles et al. 2010). The total food production will have to be increased by 70–100%, if all these people are to be fed sufficiently (Smil, 2005; World Development Report, 2008). Increasing food production to feed this ever-increasing world population in a sustainable way is a great challenge, moreso at a time of rapid environmental change with rising temperatures and extreme climate events threatening food production globally. Agriculture is inherently sensitive to climate variability and change, as a result of either natural causes or human activities (Wheeler and Braun, 2013). Climate change caused by emissions of greenhouse gases is expected to directly influence crop production systems for food, feed, or fodder; to affect livestock health; and to alter the pattern and balance of trade of food and food products. Climate change has already started affecting agricultural growth and these impacts will vary with the degree of warming and associated changes in rainfall patterns, as well as from one location to another. According to the Intergovernmental Panel on Climate Change (IPCC, 2014), climate variations affect crop production in several regions of the world, with negative effects more common than positive, and developing countries highly vulnerable to further negative impacts. Climate change is estimated to have already reduced global yields of maize and wheat by 3.8% and 5.5% respectively (Lobell et al., 2011), and several researchers predicted steep decreases in crop productivity when atmospheric temperatures exceed critical physiological thresholds of agricultural crops (Battisti and Naylor, 2009; Wheeler et al., 2000).

Climate change is already happening and represents one of the greatest environmental and societal threats facing the planet and our own existence. With the Paris Agreement on Climate Change in force this month and the skeptics who threaten its implementation, the time for bold and unprecedented action has never been more critical. For the livelihoods of the so-called “forgotten billion,” who live in dryland, on the margins of environmental sustainability, and where the harshest climate change scenarios are the fact of life, such action is vital! It is expected that drylands will expand by 11% by 2100 due to climate change. Fifteen out of 24 ecosystem services are already in decline, making drylands increasingly unproductive. About 10% of drylands are already degraded, and more land will continue to degrade in the upcoming years. Yet, drylands and agricultural research in drylands do not receive much attention or investment from the wider

community of scientific research, development agencies, policy makers, or the private sector. This is in part due to huge misconceptions or oversimplifications socioeconomic factors, and the valuable things we can learn about climate change mitigation and adaptation from examining the complex interactions of these factors in drylands.

1.1.2 Impact of Dioxide on Crop Productivity

An important change for agriculture system is increased concentrations of carbon dioxide (CO_2) in the atmosphere. As per the IPCC Special Report on Emission Scenarios (SRES), the atmospheric CO_2 concentration is projected to increase to >550 ppm by 2050 and 800 ppm by 2100. Higher concentrations of CO_2 will have a positive effect on many crops resulting in enhanced accumulation of biomass and the overall yield. However, the magnitude of this effect varies depending on type of management of crop (e.g. irrigation and fertilization regimes) and also crop type. Experimental yield response to elevated CO_2 show that under optimal growth conditions, crop yields increase at 550 ppm CO_2 in the range of 10% to 20% for C_3 crops (such as wheat, rice, and soybean), and only 0–10% for C_4 crops such as maize and sorghum (IPCC, 2007). It has been projected that in the next few decades, CO_2 trends will be likely to increase global crop yields approximately by 1.8% per decade. The impact of climate change on nutritional quality of agricultural produce is not properly understood. However, some cereal and forage crops, for example, show lower protein concentrations under elevated CO_2 conditions (IPCC, 2001).

Some aspects of global climate change are expected to benefit agriculture. It has been projected that in the next few decades CO_2 trends will likely increase global crop yields by roughly 1.8% per decade (IPCC, 2001). The increasing concentrations of CO_2 in the atmosphere can have a positive impact on the rate of photosynthesis, particularly in C_3 plants. Rising CO_2 is estimated to account for approximately 0.3% of the observed 1% increase in global wheat production (Fischer and Edmeades, 2010). The free air carbon dioxide enrichment (FACE) experiments have shown that the average yield increase of C_3 species was 11%, but no significant responses in case of C_4 species such as maize and sorghum (Long et al., 2005). The CO_2 affects the water use by crop plants because higher concentrations cause partial closure of stomata, and the decrease in the aperture of stomata reduces the rate of water consumption. The FACE experiments in potatoes have shown that CO_2 enrichment increased tuber yield by 43%, decreased water consumption by 11%, and as a result increased the water use efficiency (WUE) by about 70% (Magliulo et al., 2003). In a similar experiment on sugar beet, it was found that the amount of water consumed during the growing season reduced by 20% while yield increased by 8% (Manderscheid et al., 2010). The magnitude of increased CO_2 effects on dry matter production depends upon the illumination conditions, water availability, N supply, and the transport and storage of the photosynthates (Jaggard, et al., 2010). In all cases of FACE experiments, the relative response to enriched CO_2 was generally positive when the Nitrogen amount applied was inadequate, as in the case of wheat (Kimball, et al., 1999), rice (Kim et al., 2003). Thus, the enriched CO_2 atmosphere should help to sustain the crop yield even when the use of nitrogenous fertilizer is restricted to protect the environment.

1.1.3 Impact of Ozone on Crop Productivity

Ozone (O_3) in the atmosphere is concentrated mostly in the upper layers of the atmosphere (Stratosphere) where it absorbs UV radiation. It is also present in the lowest layer of the atmosphere, called the troposphere or the Earth's surface. Tropospheric O_3 is a spatially and temporally dynamic air pollutant as well as a powerful greenhouse gas (Ainsworth, 2017). As a result of increased industrialization and human activities Tropospheric O_3 has risen from approximately 100 ppb in the late 1800s to monthly average daytime concentrations exceeding 40–50 ppb at present (Monks et al., 2015). This increased concentration of O_3 in the atmosphere has made it the third most potent anthropogenic greenhouse gas after CO_2 and methane (IPCC, 2013).

The distribution of O_3 over the land surface is not uniform globally. It varies from region to region and also from season to season within the region. Ozone concentrations vary from about 20 ppb in parts of Asia, the Middle East, Europe and North America (Gillespie et al., 2012). According to Ramankutty et al. (2008), croplands in parts of China, India, and the USA are exposed to higher concentrations of O_3 than croplands in Australia or Brazil. In India, O_3 concentrations are the highest during the spring (Rabi) crop growing season (October – April) with 8 h daily concentrations reaching 100 ppb (Roy et al., 2009). Unlike India, O_3 concentrations in the Corn Belt of the Mid-west USA are at the maximum during the summer growing season (Huang, et al., 2007). In India, O_3 concentrations increased 20% from 1990 to 2013 and in the case of China its concentrations increased 13% over the same period (Brauer et al., 2016). Thus, many of the world's most productive crop growing regions are exposed to continuously increasing concentrations of O_3 resulting in an adverse impact on agricultural productivity and hence food security.

Yield reductions owing to ozone pollution can start at concentrations as low as 20 ppb (Ashmore, 2002). The higher concentrations of O_3 during crop growing seasons found to have significant negative impact on crop yields (Burney and Ramanathan, 2014). Feng and Kobayashi (2009) found that by 2050 probable yield reductions will be 8.9%, 9% and 17.5% for barley, wheat and rice, whereas 19.0 and 7.7% for bean and soybean, respectively. Globally, it is estimated that 4–15% of wheat yields, 3–4% of rice yields, 2–5% of maize yields and 5–15% of soybean yields are lost to O_3 pollution (van Dingenen et al., 2009; Avnery et al., 2011). In the absence of stricter air pollution control, it is projected that increased O_3 will further reduce wheat yields by 8.1–9.4% in China and 5.4–7.7% in India by 2020 (Tang et al., 2013). Tai et al. (2014) found that increased O_3 pollution in South Asia could reduce wheat production as high as 40% in 2050. Such a trend would lead to increased demand for land area devoted to crops by as much as 8.9% in Asia in order to meet the increasing demand for food (Chuwah et al., 2015). The magnitude of negative impact of O_3 on crop yield depends on the growing season temperature and water availability, and during dry years yield reductions in soybean and maize ranged from 10–20%, depending on growing season temperature (McGrath et al., 2015). Crops can experience both high background O_3 concentrations throughout the growing season (termed chronic exposure) as well as acute O_3 stress when concentrations exceed approximately 100 ppb that can lead to hypersensitive response and induction of cell death. By 2050 the impact of rising O_3 is likely to eliminate most of the beneficial effects

of yield increase due to increasing CO₂ in C3 crops and cause a yield decrease of at least 5% in C4 species (Nelson, et al., 2009). As a result of the dynamic nature of O₃, there may be little potential for adaptation of crops to rising O₃ concentrations in the atmosphere through altered crop management practices (Teixeira et al., 2011). However, the studies with rice indicate that there is scope to select for reduced O₃ sensitivity. Therefore, recent efforts are focused on breeding and biotechnological approaches for genetically improving crops that can tolerate and respond to higher concentrations of Tropospheric O₃ (Ainsworth, 2008; Frei, 2015).

1.1.4 Impact of Temperature and a Changed Climate on Crop Productivity

The temperature variations and changes in the amount and distribution of rainfall associated with increased CO₂ concentration and continued emissions of greenhouse gases will bring about changes in land suitability for crop cultivation and crop yields. According to the Intergovernmental Panel on Climate Change (IPCC, 2007), global mean surface temperature is projected to rise in a range from 1.8°C to 4.0°C by 2100. In temperate latitudes, higher temperatures are expected to be beneficial to agriculture and as a result the area under agricultural cropping is likely to increase. The length of the growing period will also increase at higher latitudes and because of which there may be increased accumulation of biomass resulting in higher crop yields (Parry et al., 2004. Fisher et al. (2005) predicted that world cereal production will increase from 1.8 Gt to between 3.7 and 4.8 Gt by 2080 and much of this increase will be the result of cropping on an additional 320 million ha in the Northern Hemisphere. However, in low latitudes crop yields are likely to decrease, mainly because of increased temperature which shortens the period for grain filling and sometimes stresses the plants at the time of flowering and seed-set. A moderate incremental warming in some humid and temperate grassland may increase pasture productivity and reduce the need for housing and for compound feed (Rosenzweig et al., 2002). There may also be reduced livestock productivity and increased livestock mortality in semi-arid and arid pastures. In drier areas, there may be increased evapotranspiration and lower soil moisture levels (IPCC, 2001) and because of which some existing cultivated areas may become unsuitable for cropping and some tropical grassland may become increasingly arid. Temperature rise will also expand the range of many agricultural pests and diseases and increase the ability of pest populations to survive the winter and attack spring crops. In general, warming trends are likely to reduce global yields by about 1.5% per decade in the absence of effective adaptation. Thus, the increases in the atmospheric temperature are likely to impact adversely against the advantages of increasing concentrations of CO₂ in the atmosphere. Extreme weather events are more likely to happen in the changed climate of the future (Gornall et al., 2010).

1.2 Climate Change and Food Security

The Food and Agriculture Organization (FAO) defines food security as a “situation which exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life”. This definition of the FAO involves four important