

Mannava V. K. Sivakumar · Raymond P. Motha (Eds.)

Managing Weather and Climate Risks in Agriculture



World Meteorological Organization



India Meteorological Department



सत्यमेव जयते

Government of India,
Ministries of Science and Technology
and Earth Sciences

Mannava V. K. Sivakumar
Raymond P. Motha
Editors

Managing Weather and Climate Risks in Agriculture

With 134 Figures

 Springer

Dr. Mannava V.K. Sivakumar
Agricultural Meteorology Division
World Meteorological Organization
7bis, Avenue de la Paix
1211 Geneva 2
Switzerland

Dr. Raymond P. Motha
USDA/OCE/WAOB
1400 Independence Ave. SW
Room 5133
Washington D.C. 20250
USA

Library of Congress Control Number: 2007928832

ISBN 978-3-540-72744-6 Springer Berlin Heidelberg New York

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilm or in any other way, and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German Copyright Law of September 9, 1965, in its current version, and permission for use must always be obtained from Springer-Verlag. Violations are liable to prosecution under the German Copyright Law.

Springer is a part of Springer Science+Business Media
springeronline.com
© Springer-Verlag Berlin Heidelberg 2007

The use of general descriptive names, registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

Cover design: deblik, Berlin
Production: Almas Schimmel
Typesetting: Satz-Druck-Service (SDS), Leimen
Printed on acid-free paper 30/3180/as 5 4 3 2 1 0

Foreword

Decision making in agricultural production is a complex process in which many risks need to be considered for an informed decision to be made. Farmers face many types of risks related to production, marketing, legal, social and human aspects. In many parts of the world, weather and climate are one of the biggest production risk and uncertainty factors impacting on agricultural systems performance and management. Extreme climatic events such as severe droughts, floods, cyclonic systems or temperature and wind disturbances strongly impede sustainable agricultural development. Hence weather and climate variability is considered in evaluating all environmental risk factors and coping decisions.

Coping with agrometeorological risk and uncertainties is the process of measuring or otherwise assessing agrometeorological risks and uncertainties and then developing strategies to cope with these risks. There are many challenges. In many developing countries technology generation, innovation and adoption are too slow to sufficiently counteract the increasingly negative effects of degrading environmental conditions. Even in the high rainfall areas, increased probability of extreme events can for example cause increased nutrient losses due to excessive leaching, runoff and water logging. Lack of attention to preparedness and response strategies is a major challenge.

Currently there are many opportunities that can assist in coping effectively with agrometeorological risks and uncertainties. One of the most important strategies is improved use of climate knowledge and technology, which includes the development of monitoring and response mechanisms to current weather. By providing new, quantitative information about the environment within which the farmers operate or about the likely outcome of alternative or relief management options, uncertainties in crop productivity can be reduced. Quantification is essential and computer simulations can assist such information and may be particularly useful to quantitatively compare alternative management and relief options in areas where seasonal climatic variability is high and/or that are prone to extremes. Given the current recognition of the importance of preparedness to cope with risks and uncertainties as compared to the practice of reactive responses, it is necessary to take stock of the opportunities that exist in coping with agrometeorological risks, to develop suitable practices/strategies and to disseminate them widely.

It is with this background that WMO had organized the International Workshop on Agrometeorological Risk Management: Challenges and Opportunities in conjunction with the 14th Session of the Commission for Agricultural Meteorology of WMO held in New Delhi, India. The workshop was co-sponsored by the Asia-Pacific Network for Global Change Research (APN), the Bureau of Meteorology,

Australia; the Centre Technique de Coopération Agricole et Rurale – Technical Centre for Agricultural and Rural Co-operation (CTA); the Food and Agriculture Organization of the United Nations (FAO); the India Meteorological Department, Météo-France; the Ministries of Science and Technology and Earth Sciences, Government of India; the UK Met Office; and the United States Department of Agriculture (USDA).

The workshop reviewed the components of farmers' agrometeorological coping strategies with risks and uncertainties in different regions of the world and discussed the major challenges to these coping strategies, such as reducing the vulnerability of different agro-ecosystems to weather and climate related risks and uncertainties, access to technological advances, particularly in developing countries, and attention to preparedness and response strategies. Structural measures such as irrigation, water harvesting etc., and non-structural measures such as use of seasonal to inter-annual climate forecasts and improved application of medium-range weather forecasts for strategic and tactical management of agriculture were addressed. A special evening symposium on weather risk insurance for agriculture reviewed the use of crop insurance strategies and schemes to reduce the vulnerability of the farming communities to agrometeorological risks.

I hope that the papers presented in this book will serve as a significant source of information to all agencies and organizations involved with designing and implementing appropriate strategies and related services to farmers in their efforts cope with weather and climate risks.

A handwritten signature in black ink, appearing to read 'M. Jarraud', is written over a large, stylized, abstract graphic element consisting of several overlapping, sweeping lines.

M. Jarraud
Secretay-General
World Meteorological Organization

Preface

In many parts of the world climate change and extreme climatic events such as severe droughts, floods, storms, tropical cyclones, heat-waves, freezes and extreme winds are one of the biggest production risk and uncertainty factors impacting agricultural systems performance and management. These events direct influence on the quantity and quality of agricultural production, and in many cases adversely affect it. Although agrometeorology particularly deals with production risks and evaluation of possible production decisions, to solve local problems of farming systems the other risk factors have to be taken into account. Inappropriate management of agroecosystems, compounded by severe climatic events such as recurrent droughts, from West Africa to northern Sudan, have tended to make the drylands increasingly vulnerable and prone to rapid degradation and hence desertification.

In the context of the need for increased agricultural productivity to meet the food and nutritional needs of the growing populations in the world, coping with agrometeorological risk and uncertainties is a very important issue and there are many challenges as well as opportunities as explained in the foreword by Mr M. Jarraud, the Secretary-General of WMO. Accordingly, the Management Group of the Commission for Agricultural Meteorology (CAgM) of WMO recommended the organization of the International Workshop on Agrometeorological Risk Management: Challenges and Opportunities from 25 to 27 October 2006 in New Delhi, India in conjunction with the 14th Session of the Commission for Agricultural Meteorology of WMO. The workshop, hosted by the India Meteorological Department (IMD) and the Ministry of Science and Technology and Earth Sciences of the Government of India, was attended by 188 participants from 78 countries. The specific objectives of the workshop were:

- To identify and assess the components of farmers' agrometeorological coping strategies with risks and uncertainties in different regions of the world, e.g. extreme climatic events (droughts, floods, cyclonic systems, temperature and wind disturbances etc.), inadequate attention to agroclimatic characteristics of a location, lack of timely information on weather and climate risks and uncertainties, lack of crop diversification etc;
- To discuss the major challenges to these coping strategies with agrometeorological risks, such as reducing the vulnerability of different agro-ecosystems to weather and climate related risks and uncertainties, access to technological advances -- particularly in developing countries --, attention to preparedness and response strategies, to agrometeorological services, to training of intermediaries between NMHSs and farmers etc;

- To review the opportunities for farmers to cope with agrometeorological risks and uncertainties in different parts of the world, e.g. with structural measures (irrigation, water harvesting, microclimate management and manipulation and other preparedness strategies) and non-structural measures (use of seasonal to inter-annual climate forecasts, improved application of medium-range weather forecasts) for strategic and tactical management of agriculture;
- To provide on-farm examples of appropriate coping strategies for minimizing agrometeorological risks and uncertainties and of sustainable agriculture;
- To review, through appropriate case studies, the use of crop insurance strategies and schemes to reduce the vulnerability of the farming communities to agrometeorological risks;
- To discuss and recommend suitable policy options, such as agrometeorological services for coping with agrometeorological risks and uncertainties in different parts of the world.

Altogether there were 8 sessions (including opening and closing session) in the workshop during which 25 invited papers were presented. In the workshop sessions, firstly weather and climate events and risks to farming from droughts, floods, cyclones and high winds, and extreme temperatures were identified through risk and risk characterization. Papers on approaches to dealing with risks highlighted preparedness planning, risk assessments and improved early warning systems which can lessen the vulnerability of society to weather and climate risks. Enterprise diversification, contract hedging, crop insurance, weather derivatives and weather index insurance play a key role in developing agricultural risk management strategies. A special session examined the use of crop insurance strategies and schemes to reduce the vulnerability of the farming communities to risks posed by weather and climate extremes.

A number of strategies were identified to cope with risks. These include the use of seasonal forecasts in agriculture, forestry and land management to assist alleviation of food shortages, drought and desertification. The use of integrated agricultural management and crop simulation models with climate forecasting systems give the highest benefits. Strategies to improve water management and increase the efficient use of water included crop diversification and better irrigation. Especially important was the application of local indigenous knowledge. A combination of locally adapted traditional farming technologies, seasonal weather forecasts and warning methods were important for improving yields and incomes. Challenges to coping strategies were many and identified in several papers. Particularly important was the impact of different sources of climate variability and change on the frequency and magnitude of extreme events. Lack of systematic data collected from disasters impeded future preparedness, as did the need for effective communication services for the timely delivery of weather and climate information to enable effective decision making. Finally a range of policy options to cope with such risks were presented. These included contingency planning, use of crop simulation modelling, and use of agrometeorological services.

All the participants in the workshop were engaged in discussions on these papers and developed several useful recommendations for all organizations involved in agrometeorological risk management, particularly the National Meteorologi-

cal and Hydrological Services. These have been presented in the final paper in this book.

As Editors of this volume, we would like to thank all the authors for their efforts and for their cooperation in bringing out this volume in time. We are most grateful to the India Meteorological Department (IMD) and the Ministry of Science and Technology and Earth Sciences of the Government of India for hosting this meeting and to the Secretary-General of WMO for his continuous support and encouragement.

M.V.K. Sivakumar

R.P. Motha

Editors

Contents

1 Extreme Weather and Climate Events, and Farming Risks

John Hay

1.1	Introduction	1
1.2	Risk and Risk Management – Some Basic Concepts	3
1.2.1	Step A – Risk Scoping.	4
1.2.2	Step B – Risk Characterization and Evaluation	4
1.2.3	Step C – Risk Management.	4
1.2.4	Step D – Monitoring and Review	6
1.3	Farming Risks	6
1.4	Risk Characterization	7
1.4.1	Weather Extremes.	9
1.4.2	Climate Anomalies	11
1.5	Changing Risk	12
1.6	Risk Management	16
1.7	Conclusions	18
	Acknowledgements.	18
	References	19

2 Preparedness and Coping Strategies for Agricultural Drought Risk Management: Recent Progress and Trends

Donald A. Wilhite

2.1	Introduction	21
2.2	Agricultural Drought Risk Management: Understanding the Hazard and Societal Vulnerability.	22
2.3	Drought as Hazard.	22
2.4	Drought: Understanding Vulnerability	23
2.5	Drought Types and Vulnerability	24
2.6	Decision-Support Tools for Drought Risk Management.	26
2.6.1	U.S. Drought Monitor	26
2.6.2	Drought Monitor: Decision Support System.	29
2.6.3	The Drought Impact Reporter: A Web-based Impact Assessment Tool and Database	31
2.6.4	Drought Risk Atlas	35
2.6.5	Vegetation Drought Response Index (VegDRI)	35

2.6.6	Ranching Drought Plan: A Drought Planning Tool for Livestock and Forage Producers	36
2.7	Summary	37
	References	37
3	Challenges to Coping Strategies with Agrometeorological Risks and Uncertainties in Africa <i>Elijah Mukhala, Adams Chavula</i>	
3.1	Introduction	39
3.2	Farmers' coping strategies	41
3.3	Provision of climatic information	42
3.3.1	Intra-seasonal distribution	43
3.3.2	Language/terminology and communication	43
3.3.3	Capacity of key institutions	43
3.3.4	Stakeholder awareness/training	44
3.3.5	Tailored forecasts	44
3.3.6	Key relationships	44
3.3.7	Timely issuance	45
3.4	Key recommendations to address identified weaknesses	45
3.4.1	Forecast improvement	45
3.4.2	Access to technological advances	47
3.4.3	Structural and non-structural measures to mitigate risks and uncertainties	47
3.4.4	Crop insurance activities	48
3.5	Conclusions	49
	References	50
4	Challenges to Coping Strategies with Agrometeorological Risks and Uncertainties in Asian Regions <i>L.S. Rathore, C.J. Stigter</i>	
4.1	Introduction	53
4.2	Challenges to disaster risk mainstreaming	54
4.2.1	Adaptation strategies	54
4.2.2	High intensity rainfall and floods	55
4.2.3	Tropical storms, tornadoes and strong winds	55
4.2.4	Extreme temperatures including heat waves and cold waves	56
4.2.5	Droughts	56
4.2.6	Wildfires and bushfires	57
4.3	Challenges to contingency planning and responses	58
4.4	Challenges to mitigation practices as a coping strategy	58
4.4.1	Impact reductions	58
4.4.2	High intensity rainfall and floods	59
4.4.3	Tropical storms, tornadoes and strong winds	60
4.4.4	Extreme temperatures including heat waves and cold waves	60

4.4.5 Droughts 61

4.4.6 Wildfires and bushfires. 61

4.5 Challenges to preparedness as a coping strategy 62

4.6 Challenges to methodologies in disaster science
to support preparedness 63

4.6.1 Early warning systems for assessing agrometeorological risks . . 63

4.6.2 Remote sensing for spatial information 64

4.6.3 Data analysis in research 65

4.7 Agrometeorological Advisory Service (AAS). 65

4.8 Conclusion and recommendation 66

References 66

**5 Challenges and Strategies to face Agrometeorological Risks and Uncertainties –
Regional Perspective in South America**

Constantino Alarcón Velazco

5.1 Introduction 71

5.2 Climatology and Geography of South America. 72

5.3 Natural Phenomena that affect Agriculture in South America 73

5.3.1 Landslides 73

5.3.2 Volcanic Eruptions 73

5.3.3 Floods. 73

5.3.4 Droughts 74

5.3.5 Extreme temperatures including heat waves and cold waves . . . 74

5.3.6 The Climate Change 74

5.3.7 El Niño – La Niña Phenomenon. 75

5.3.8 Strong winds. 76

5.4 Vulnerability of the Region 76

5.5 Capacities and Resources in the region to face Agrometeorological
Risks and Uncertainties 77

5.5.1 Economic status of the countries 77

5.5.2 Government policies 77

5.5.3 Creation and strengthening of specialized institutions. 77

5.5.4 Risk identification and analysis 78

5.5.5 Monitoring networks and early warning. 78

5.5.6 Information on the risks for decision making. 79

5.6 Defining Policies and Tools to face Agrometeorological Risks
and Uncertainties 79

5.7 Strategies to cope with Agrometeorological Risks and Uncertainties . . . 80

5.8 Conclusions 81

References 82

6 Agrometeorological Risk and Coping Strategies – Perspective from Indian Subcontinent

N. Chattopadhyay, B. Lal

6.1	Introduction	83
6.2	Extreme weather events and its impacts on Indian agriculture.	84
6.2.1	Cold wave	84
6.2.2	Drought.	86
6.2.3	Fog	88
6.2.4	Thunderstorm, Hailstorm and Dust storm.	88
6.2.5	Heat waves	89
6.2.6	Tropical Cyclones	90
6.2.7	Floods.	93
6.3	Crop Insurance	94
6.4	Strategies adopted in areas with high weather risk.	95
6.5	Conclusions	97
	References	97

7 Challenges to coping strategies in Agrometeorology: The Southwest Pacific

James Salinger

7.1	Introduction	99
7.2	El Niño-Southern Oscillation (ENSO)	99
7.3	Decadal Variability.	103
7.4	Regional Warming	103
7.5	Challenges to Agriculture and Forestry	105
7.5.1	ENSO	105
7.5.2	Tropical Cyclones	107
7.5.3	Regional Warming	107
7.6	Discussion and Conclusions	108
	References	110

8 Challenges to agrometeorological risk management – regional perspectives: Europe

Lučka Kajfež Bogataj, Andreja Sušnik

8.1	Introduction	113
8.2	Seasonal weather forecasts for crop yield modeling in Europe	114
8.3	Climate change as a challenge to agrometeorological risk management in Europe	115
8.3.1	The use of different high resolution climate models in Europe	115
8.3.2	Expected impacts of climate change in Europe during this century	117
8.3.3	Increasing drought Risk with Global Warming in Europe.	119
8.3.4	Options for future adaptation strategies	120
8.3.5	European agrometeorological research needs	121

8.4.	Conclusions	122
	References	123
9	Methods of Evaluating Agrometeorological Risks and Uncertainties for Estimating Global Agricultural Supply and Demand <i>Keith Menzie</i>	
9.1	Introduction	125
9.2	Sources of Risk	125
9.3	Risk, Uncertainty, and the Agricultural Marketing System.	127
9.4	Information - the Key to Efficient Market Function	129
9.5	Global Crop Assessment Methods and Risk Reduction – Tools and Analysis	130
9.6	Global Crop Assessment Methods and Risk Reduction – the Case of Brazilian Soybeans	136
9.7	Conclusions	139
	References	140
10	Weather and climate and optimization of farm technologies at different input levels <i>Josef Eitzinger, Angel Utset, Miroslav Trnka, Zdenek Zalud, Mikhail Nikolaev, Igor Uskov</i>	
10.1	Introduction	141
10.2	Strategies for optimizing farm technologies in various agricultural systems	144
	10.2.1 Optimization of farm technologies and water resources	145
	10.2.2 Optimization of farm technologies and soil resources	149
	10.2.3 Optimization of farm technologies and crop resources	152
	10.2.4 Optimization of farm technologies and the microclimate of crop stands	162
10.3	Conclusions	164
	Acknowledgement	165
	References	165
11	Complying with farmers' conditions and needs using new weather and climate information approaches and technologies <i>C.J. Stigter, Tan Ying, H.P. Das, Zheng Dawei, R.E. Rivero Vega, Nguyen Van Viet, N.I. Bakheit, Y.M. Abdullahi</i>	
11.1	Introduction	171
11.2	Complying with conditions and needs	172
11.3	Differentiated information needs and channels for various farmers.	174
	11.3.1 Information demands of different income levels in poor areas of China	174
	11.3.2 Differentiation between income levels in poor areas of China.	176

11.3.3	Information channels for different income levels in poor areas of China	178
11.3.4	Demand and supply of information for different income levels in poor areas of China	179
11.3.5	General implications of the findings for different income levels in poor areas of China	179
11.4	Implications for information approaches and technologies	180
11.4.1	Poor farmers	180
11.4.2	Low-income farmers	181
11.4.3	Middle-income farmers	181
11.4.4	Richer farmers	182
11.4.5	Other developing countries	183
11.5	What WMO/CAGM should realize as implications of the above	186
	References	187

12 Information Technology and Decision Support System for On-Farm Applications to cope effectively with Agrometeorological Risks and Uncertainties

Byong-Lyol Lee

12.1	Introduction	191
12.1.1	On-Farm Applications Against Risks.	191
12.2	Risk & Uncertainty in Agriculture	193
12.2.1	Agrometeorological risks.	193
12.2.2	Risk Management in Agrometeorology	193
12.3	Decision-making Support Against Risks	194
12.3.1	Emergency Response System	194
12.4	Information Technology Required	199
12.4.1	Requirements for Agrometeorological Products	199
12.4.2	Requirements for DMSS Infrastructure	200
12.5	Resource Sharing System: Case of WAMIS	200
12.5.1	WAMIS as a Web Portal	201
12.6	Discussion & Conclusions.	206
	References	207

13 Coping Strategies with Agrometeorological Risks and Uncertainties for Crop Yield

Lourdes V. Tibig, Felino P. Lansigan

13.1	Challenges and opportunities.	209
13.2	Types of coping strategies with agrometeorological risks and uncertainties for crop yield	210
13.2.1	Optimal and sustainable utilization of resources	210
13.2.2	Change in cultural practices or improved farming practices	213
13.2.3	Modifications of resource potential including controlled micro-climates.	214
13.2.4	Local indigenous knowledge systems/networks.	214

13.2.5 Access to extension services 214

13.2.6 Technological innovations 215

13.2.7 Others, including resilience and divestment of natural capital . . 216

13.3 Some examples of coping strategies 216

13.3.1 Canada 216

13.3.2 The United States 218

13.3.3 Latin America 219

13.3.4 Africa 219

13.4 Case studies: Regional/national coping strategies 220

13.4.1 The Philippine experience: Empowering farmers
for rural development. 220

13.4.2 The West African semi-arid tropics (WASAT) 227

13.4.3 Improving rice-based cropping systems in the Indo-Gangetic
Plains and in north-west Bangladesh 229

13.4.4 Special Case: Small-holder rubber production
in South Sumatra, Indonesia 232

13.5 Conclusions 233

References 233

14 Water management in a semi-arid region: an analogue algorithm approach for rainfall seasonal forecasting

Giampiero Maracchi, Massimiliano Pasqui and Francesco Piani

14.1 Introduction 237

14.2 Methods and Dataset 238

14.3 Skill evaluation 241

14.4 Conclusions 242

References 243

15 Water Management – Water Use in Rainfed Regions of India

YS Ramakrishna, GGSN Rao, VUM Rao, AVMS Rao and KV Rao

Abstract 245

15.1 Introduction 245

15.2 Water Resources of the Country 247

15.3 Rainwater Management 248

15.4 Issues and Perspective in Water Management 248

15.5 Strategies for Improving the Water Management
and Water Use Efficiencies 249

15.6 Water Management through Watershed Program 251

Conclusions 262

References 262

16 Examples of coping strategies with agrometeorological risks and uncertainties for Integrated Pest Management*A.K.S. Huda, T. Hind-Lanoiselet, C. Derry, G. Murray and R.N. Spooner-Hart*

16.1	Introduction	265
16.1.1	Crop Diseases - Stripe rust in wheat and Sclerotinia rot in canola	267
16.1.2	Implications for technology transfer	269
16.1.3	Resource allocation for risks	270
16.1.4	Supportive Decision-Making Tools	271
16.1.5	Effectiveness of decision-making tools	271
16.1.6	Importance of Experimental Observation	272
16.1.7	Desirable level of complexity.	272
16.1.8	Economic balance in control.	273
16.1.9	Towards the Future	273
16.2	Conclusions	277
	Acknowledgements.	278
	References	278

17 Coping Strategies with Agrometeorological Risks and Uncertainties for Drought Examples in Brasil*O. Brunini, Y. M. T. da Anunciação, L. T.G. Fortes, P. L. Abramides, G. C. Blain, A. P. C. Brunini, J. P. de Carvalho*

17.1	Introduction	281
17.2	Methodologies to Assess Precipitation Anomaly and Drought.	286
17.2.1	Meteorological Indices	286
17.2.2	Agrometeorological Indices	290
17.3	Results and Analysis	296
17.3.1	Meteorological Aspects of Drought Monitoring and Prediction	296
17.3.2	Agrometeorological Aspects of Drought	304
17.3.3	Drought Monitoring and Mitigation Center.	306
17.3.4	Climatic Risk Zoning	309
17.4	Conclusions	313
	References	313

18 Coping Strategies with Desertification in China*Wang Shili, Ma Yuping, HouQiong, Wang Yinshun*

18.1	Introduction	317
18.2	Status of Desertification in China	318
18.2.1	Status of Desertified Land	318
18.2.2	Status of land most vulnerable to sand encroachment	319
18.2.3	Dynamic Changes of Desertification	319

18.3 Development and Causes of Desertification in North China 319
 18.3.1 Development and Cause Analysis 319
 18.3.2 Possible influence of climate change on desertification. 321
 18.4 Desertification Monitoring in China. 321
 18.4.1 Indicator system for desertification monitoring and evaluation . . 321
 18.4.2 Desertification monitoring in China 322
 18.5 China’s Key Forestry Programs on Combating Desertification. 324
 18.5.1 Program for converting cropland to forest/shrubbery 324
 18.5.2 Programme of Combating desertification in the wind
 sand sources areas affecting Beijing and Tianjin city 325
 18.5.3 Three-North Shelterbelt Programme and Shelterbelt Programme
 in upper and middle reaches of the Yangtze River 326
 18.6 Practical Strategies and Countermeasures to Combat Desertification. . . 326
 18.6.1 Stabilizing sands techniques system 327
 18.6.2 Shelterbelt techniques system 329
 18.6.3 Typical models in combating desertification in China 330
 18.7 Services for combating desertification in Chinese Meteorological Offices. . 334
 18.7.1 Research on desertification development and combating
 in terms of meteorological conditions 334
 18.7.2 Monitoring and assessing services to combating desertification
 of grassland 336
 18.7.3 Monitoring and predicting of dust storms in China 338
 18.8 Conclusions and Discussion 339
 Acknowledgements. 340
 References 340

**19 Coping strategies with agrometeorological risks and uncertainties
 for water erosion, runoff and soil loss**

P.C. Doraiswamy, E.R. Hunt, Jr., V.R.K. Murthy

19.1 Introduction 343
 19.2 Agrometeorological coping strategies 344
 19.3 Soil Management Strategies. 346
 19.3.1 Organic Matter 346
 19.3.2 Tillage Practices 346
 19.3.3 Crop Management Strategies 349
 19.3.4 Mechanical Control Strategies. 350
 19.4 Conclusions 351
 References 352

20 Developing a global early warning system for wildland fire

*Michael A. Brady, William J. de Groot, Johann G. Goldammer,
Tom Keenan, Tim J. Lynham, Christopher O. Justice, Ivan A. Csiszar,
Kevin O’Loughlin*

20.1 Introduction 355

 20.1.1 EWS-Fire Proposal 356

20.2 Objectives and Expected Impact of EWS-Fire 357

20.3 Planned System Development 358

 20.3.1 Warning System Design 358

 20.3.2 Operational Implementation. 359

 20.3.3 Technology Transfer 360

20.4 Implementing Organizations and Division of Tasks. 360

 20.4.1 Natural Resources Canada - Canadian Forest Service (CFS) . . . 361

 20.4.2 Bureau of Meteorology Research Centre (BMRC). 361

 20.4.3 Bushfire Cooperative Research Centre, Australia. 362

 20.4.4 University of Maryland (UMD), USA, acting on behalf
of GOFC-GOLD. 362

 20.4.5 Global Fire Monitoring Center (GFMC), Germany on behalf of
the UNISDR Wildland Fire Advisory Group / Global Wildland
Fire Network and the United Nations University (UNU) 362

 20.4.6 Global Observation of Forest and Land Cover Dynamics
(GOFC-GOLD) Secretariat, Edmonton, Canada 362

20.5 Sustainability 362

20.6 Case Study in EWS-Fire Development. 363

 20.6.1 System Development 363

 20.6.2 Operational FDRS. 364

 20.6.3 Lessons Learned. 364

References 366

21 Scientific and Economic Rationale for Weather Risk Insurance for Agriculture

Peter Höppe

21.1 Introduction 367

21.2 Natural Disasters and Losses 367

21.3 Climate Change and Natural Disasters 370

21.4 Agricultural Risk Insurance 371

 21.4.1 Crop Insurance Products. 373

 21.4.2 Crop Insurance in Developing Countries 373

21.5 Conclusions 374

References 375

22 Weather index insurance for coping with risks in agricultural production

Ulrich Hess

22.1 Introduction 377

22.1.1 Are there any effective precedents for agricultural insurance mechanisms in developing countries? 377

22.1.2 Is this kind of insurance only suitable for large-scale commercial farmers? 378

22.1.3 Is India’s insurance program sustainable? 378

22.2 Risk and Risk Management in Agriculture 379

22.2.1 Informal risk management mechanisms 380

22.3 Crop Insurance Programs in Developed Countries 383

22.3.1 The United States 384

22.3.2 Canada 385

22.3.3 Spain 386

22.3.4 Experiences of developed countries provide inadequate models for developing countries 387

22.4 Weather index insurance alternatives 388

22.4.1 Basic characteristics of an index. 388

22.4.2 Structure of index insurance contracts 389

22.4.3 Relative advantages and disadvantages of index insurance 391

22.4.4 The trade-off between basis risk and transaction costs 391

22.4.5 Where index insurance is inappropriate 392

22.5 Application of weather index insurance in developing countries: The role of government 393

22.5.1 Premise: The concept of risk layering. 393

22.5.2 Policy instruments 395

22.6 Overview of ongoing agricultural risk pilot programs. 400

22.6.1 India 400

22.6.2 Malawi 401

22.7 Conclusions 403

References 404

23 Weather Risk Insurance for Coping with Risks to Agricultural Production

Pranav Prashad

23.1 Weather and Indian Agriculture 407

23.2 Introduction to Weather Insurance 407

23.2.1 Process of making an index based product 407

23.3 Advantages of Index based Insurance products like Weather Insurance 409

23.4 Initiatives in Weather Insurance 409

23.5 Innovative ways to reach to the hinterland – reduction of basis risk. . . 410

23.6 Designing Crop and situation specific products 410

23.6.1 Wheat. 410

23.6.2 Apples. 411

23.6.3	Salt manufacturing	412
23.7	Snapshot of 2005-2006	412
23.8	Distribution: a key challenge	412
23.9	Conclusions	414
24	Contingency planning for drought – a case study in coping with agrometeorological risks and uncertainties <i>Roger C Stone, Holger Meinke</i>	
24.1	Introduction	415
24.2	The basis of drought contingency planning	416
24.3	Preparedness strategies	422
24.4	Risk management systems and tools	426
24.5	Issues associated with contingency planning for drought under climate change	428
24.6	Conclusions	430
	References	430
25	Agrometeorological services to cope with risks and uncertainties <i>Raymond P. Motha, V.R.K. Murthy</i>	
25.1.	Introduction	435
25.2	Weather, Natural Disasters, and Agriculture	435
25.2.1	Fundamental importance of weather in agriculture	436
25.2.2	Impact of natural disasters in agriculture, rangeland, forestry, and environment	436
25.2.3	The role of Indigenous Technical Knowledge (ITK) in agrometeorological services	439
25.2.4	The role of contemporary technological advances in agrometeorological services	441
25.3.	Operational Agrometeorological Services to Cope with Risks and Uncertainties of Natural Disasters	444
25.3.1	United States (U.S.A.).	444
25.3.2	India	447
25.4	Strategies to Improve the Agrometeorological Services to Cope with Risks and Uncertainties	449
25.4.1	Improving the agrometeorological services	450
25.4.2	Improving the support systems of agrometeorological services.	456
25.4.3	A comprehensive agrometeorological service strategy to cope with risks and uncertainties	458
25.5	Conclusions	459
	References	460

**26 Using Simulation Modelling as a Policy Option
in Coping with Agrometeorological Risks and Uncertainties**

Simone Orlandini, A. Dalla Marta, L. Martinelli

26.1 Introduction 463
 26.2 Conditions of model implementation and application. 464
 26.3 Examples of Using Agrometeorological Models 466
 26.3.1 Models for soil erosion 466
 26.4 Water balance and irrigation 468
 26.5 Crop protection. 471
 26.6 Early Warning Systems (EWS) 474
 26.7 Conclusions 475
 References 476

**27 Managing Weather and Climate Risks in Agriculture Summary
and Recommendations**

Mannava V.K. Sivakumar, Raymond P. Motha

27.1 Introduction 477
 27.2 Risk and Risk Management in Agriculture 477
 27.3 Addressing Agrometeorological Risk Management
 during the Workshop 478
 27.4 Workshop Summary. 479
 27.4.1 Risk in Agriculture 479
 27.4.2 Risk and Risk Characterization 480
 27.4.3 Approaches to Dealing with Risks 481
 27.4.4 Risk Coping Strategies 483
 27.4.5 Perspectives for Farm Applications 484
 27.4.6 Challenges to Coping Strategies 485
 27.5 Recommendations 486
 27.5.1 Risk Management 486
 27.5.2 Risk Management Tools 486
 27.5.3 Research Needs 487
 27.5.4 Emphasis on User Needs 488
 27.5.5 Communication 488
 27.5.6 Marketing 489
 References 489

Subject Index. 493

List of Contributors

Y.M. Abdullahi

Ahmadu Bello University
National Agricultural Extension
and Rural Living Services
Zaria, Nigeria
E-mail: ymabdullahi@yahoo.com

P.L. Abramides

Instituto Agronômico
Av- Barão de Itapura, 1481
13.020-902, Campinas
Sao Paulo, Brazil
E-mail: pedro@apta.sp.gov.br

N.I. Bakheit

Sinnar University
Faculty of Agriculture,
Abu Naama, Sinnar, Sudan
E-mail: Nagibrahim@hotmail.com

G.C. Blain

Instituto Agronômico -Ciiagro
Av- Barão de Itapura, 1481
13.020-902, Campinas
Sao Paulo, Brazil
E-mail: gabriel@iac.sp.gov.br

Lučka Kajfež Bogataj

University of Ljubljana
Agronomy Department
Jamnikarjeva 101, 000
Ljubljana, Slovenia
E-mail: lucka.kajfez.bogataj@bf.uni-lj.si

Michael A. Brady

Global Observation of Forest
and Land Cover Dynamics
(GOFC-GOLD) Project Office
c/o Canadian Forest Service
5320-122 St.,
Edmonton AB, Canada T6H 3S5
E-mail: mbrady@nrcan.gc.ca

A.P.C. Brunini

Instituto Agronômico –Ciiagro-Cepa
Av- Barão de Itapura, 1481
13.020-902, Campinas
Sao Paulo, Brazil
E-mail: andrew@cepaempresa.com.br

O. Brunini

Instituto Agronomico
R. Fernao de Magalhaes 1080
Sao Paulo, Brazil
E-mail: brunini@iac.sp.gov.br

J.P de Carvalho

Instituto Agronômico
Av- Barão de Itapura, 1481
13.020-902, Campinas
Sao Paulo, Brazil
E-mail: jotape@iac.sp.gov.br

N. Chattopadhyay

India Meteorological Department
Agrimet Division
Shivajinagar
Pune, India
E-mail: agrimet_pune@yahoo.com

Adams Chavula

Agricultural Meteorologist
Malawi Meteorological Services
Blantyre, Malawi
Email: adamschavula@metmalawi.com

Ivan A. Csiszar

University of Maryland
Department of Geography
2181 LeFrak Hall
College Park, MD 20742, U.S.A.
E-mail: icsiszar@hermes.geog.umd.edu

Y.M.T. Da Anunciação
Instituto Nacional de Meteorologia
Eixo Monumental Via S1
70680-900, Brasília
DF, Brazil
E-mail: marina.tanaka@inmet.gov.br

H.P. Das
India Meteorological Department
Agrimet Division
Shivajinagar
Pune 5, India
E-mail: hpd_ag@rediffmail.com

C. Derry
University of Western Sydney
Hawkesbury Campus
Locked Bag 1797
Penrith South D.C. NSW1797, Australia
E-mail: c.derry@uws.edu.au

P.C. Doraiswamy
United States Department
of Agriculture (USDA)
Agricultural Research Service
1400 Independence Avenue, S.W.
Room 114, Hydrology and Remote Sensing
Laboratory
Washington, D.C. 20705, U.S.A..
E-mail: pdoraiswamy@hydrolab.arsusda.gov

J. Eitzinger
Institute of Meteorology
Univ. of Natural Resources
and Applied Life Sciences (BOKU)
Peter Jordan Str. 82
A-1190 Wien, Austria
E-mail: josef.eitzinger@boku.ac.at

L.T.G. Fortes
Instituto Nacional de Meteorologia
Eixo Monumental Via S1
70680-900, Brasília
DF- Brasil
E-mail : lfortes@inmet.gov.br

William J. de Groot
Natural Resources Canada
Canadian Forest Service
5320-122 St., Edmonton, AB
Canada T6H 3S5
E-mail: bdegroot@nrcan.gc.ca

Johann G. Goldammer
The Global Fire Monitoring Center
Max Planck Institute for Chemistry
c/o Freiburg University
Georges-Koehler-Allee 75
D - 79110 Freiburg, Germany
E-mail: johann.goldammer@fire.uni-freiburg.de

John Hay
Institute for Global Change
Adaptation Science
Ibaraki University
Mito City, Japan
E-mail: johnhay@mx.ibaraki.ac.jp

Ulrich Hess
World Food Programme (WFP)
Via C.G.Viola 68
Parco dei Medici
Rome, Italy
E-mail: ulrich.hess@wfp.org

Peter Höppe
Department of Geo Risks Research
Munich Reinsurance Company AG
D-80791 Munich, Germany
E-mail: phoeppe@munichre.com

A.K.S. Huda
University Western Sydney
Hawkesbury Campus
Locked Bag 1797
Penrith South D.C. NSW1797, Australia
E-mail: s.huda@uws.edu.au

Christopher O. Justice
University of Maryland
Department of Geography
2181 LeFrak Hall
College Park, MD 20742, U.S.A.
E-mail: justice@hermes.geog.umd.edu

Tom Keenan
Weather Forecasting Group
Bureau of Meteorology Research Centre
GPO Box 1289K
Melbourne, VIC, Australia 3001
E-mail: T.Keenan@bom.gov.au

B. Lal
India Meteorological Department
New Delhi, India
E-mail: lalrp@yahoo.com

T. Hind-Lanoiselet
 New South Wales Department
 of Primary Industries
 Wagga Wagga Agricultural Institute
 PMB Wagga Wagga
 NSW 2650 Australia
 E-mail: tamrika.hind@dpi.nsw.gov.au

Felino P. Lansigan
 INSTAT and SESAM
 University of the Philippines Los Banos (UPLB)
 4031 Laguna, Philippines
 E-mail: fplansigan@yahoo.com/fpl@instat.
 uplb.edu.ph

Tim J. Lynham
 Natural Resources Canada
 Canadian Forest Service
 1219 Queen St. East,
 Sault Ste. Marie, ON, Canada P6A 2E5
 E-mail: tlynham@nrca.gc.ca

Byong Lyol Lee
 Korea Meteorological Administration
 208-16 Seodun-dong, Gwonson-gu
 Suwon 441-856, Republic of Korea
 E-mail: blee@kma.go.kr

G. Maracchi
 I.A.T.A. - C.N.R.
 National Research Council
 Institute of Agrometeorology & Environmental
 Analysis for Agriculture
 P.le delle Cascine, 18
 I-50144 Florence, Italy
 E-mail: g.maracchi@ibimet.cnr.it

A. Dalla Marta
 Department of Agronomy
 and Land Management
 University of Florence
 Piazzale delle Cascine, 18 50144
 Florence, Italy
 E-mail: anna.dallamarta@unifi.it

L. Martinelli
 Department of Agronomy
 and Land Management
 University of Florence
 Piazzale delle Cascine, 18 50144
 Florence, Italy
 E-mail: luca.martinelli@unifi.it

Holger Meinke
 Department of Plant Sciences
 Wageningen University
 P.O. Box 430
 NL 6700 AK Wageningen, The Netherlands
 E-mail: holger.meinke@wur.nl

Keith Menzie
 United States Department
 of Agriculture (USDA)
 World Agricultural Outlook Board
 Office of the Chief Economist
 1441 Independence Avenue, S.W.
 Room 4438 South Building
 Washington, D.C. 20250, U.S.A.
 E-mail: kmenzie@oce.usda.gov

Elijah Mukhala
 SADC Secretariat
 Food Agriculture and Natural
 Resources Directorate
 P/B 0095
 Gaborone, Botswana
 Email: emukhala@yahoo.com

Raymond P. Motha
 United States Department
 of Agriculture (USDA)
 Office of the Chief Economist
 World Agricultural Outlook Board
 1441 Independence Avenue, S.W.
 Room 4419 South Building
 Washington, D.C. 20250, U.S.A.
 E-mail: rmotha@oce.usda.gov

G. Murray
 New South Wales Department
 of Primary Industries
 Wagga Wagga Agricultural Institute
 PMB Wagga Wagga NSW 2650 Australia
 E-mail: gordon.murray@dpi.nsw.gov.au

V.R.K. Murthy
 Acharya N.G.Ranga Agricultural University
 College of Agriculture,
 Department of Agronomy
 Rajendranagar, Hyderabad-500 030
 Andhra Pradesh, India
 E-mail: vrkmurthy11@hotmail.com

M. Nikolaev

Agrophysical Research Institute (ARI)
Grazhdansky pr. 14
195220 St. Petersburg, Russia
E-mail: clenrusa@mail.ru

Kevin O'Loughlin

Bushfire Cooperative Research Centre
Level 5, 340 Albert St. East
Melbourne, VIC, Australia 3002
E-mail: kevin.oloughlin@bushfirecrc.com

S. Orlandini

Department of Agronomy
and Land Management
University of Florence
Piazzale delle Cascine, 18
I - 50144 Florence, Italy
E-mail address: simone.orlandini@unifi.it

M. Pasqui

Institute of Biometeorology –
National Research Council
Laboratory for Meteorology
and Environmental Modelling
Via Caproni, 8
I – 50145 Florence, Italy
E-mail: m.pasqui@ibimet.cnr.it

F. Piani

Institute of Biometeorology –
National Research Council
Laboratory for Meteorology
and Environmental Modelling
Via Madonna del Piano, 10
I – 50019 Sesto Fiorentino (FI), Italy
E-mail: f.piani@ibimet.cnr.it

P. Prashad

ICICI Lombard Bank
Zenith House, Keshavrao Khade Marg
Mahalaxmi
Mumbai 400 034, India
E-mail: pranav.prashad@icicilombard.com

Hou Qiong

Inner Mongolia Meteorological Institute
No.49 Hailar Street, Hohhot,
Inner Mongolia, China, 010051
E-mail: Qiong_hou@sina.com

Y. Ramakrishna

Central Research Institute
for Dryland Agriculture (CRIDA)
Santoshnagar
Hyderabad 500059, India
E-mail: ramakrishna.ys@crida.ernet.in

G.G.S.N. Rao

Central Research Institute
for Dryland Agriculture (CRIDA)
Santoshnagar
Hyderabad 500059, India
E-mail: ggsnrao@crida.ernet.in

V.U.M. Rao

Central Research Institute
for Dryland Agriculture (CRIDA)
Santoshnagar
Hyderabad 500059, India
E-mail: vumrao@crida.ernet.in

A.V.M.S. Rao

Central Research Institute
for Dryland Agriculture (CRIDA)
Santoshnagar
Hyderabad 500059, India
E-mail: vumrao@crida.ernet.in

K.V. Rao

Central Research Institute
for Dryland Agriculture (CRIDA)
Santoshnagar
Hyderabad 500059, India
E-mail: vumrao@crida.ernet.in

L.S. Rathore

National Centre for Medium Range
Weather Forecasting
A-50, Institutional Area, Phase II, Sector-62
NOIDA (UP), 201 307, India
E-mail: lsathore@ncmrwf.gov.in

James Salinger

National Institute of Water
and Atmospheric Research (NIWA)
P.O. Box 109-695, New Market
Auckland, New Zealand
E-mail: j.salinger@niwa.co.nz

Wang Shili

Institute of Eco-environment
and Agrometeorology
Chinese Academy of Meteorological Sciences
No. 46 Zhongguancun, Nandajie
Beijing, China, 100081
E-mail: wangsl@cams.cma.gov.cn

R.N. Spooner-Hart

University Western Sydney
Hawkesbury Campus
Locked Bag 1797
Penrith South D.C. NSW1797, Australia
E-mail: r.spooner-hart@uws.edu.au

C.J. Stigter

Agromet Vision and INSAM
Groenestraat 13, 5314 AJ, Bruchem,
The Netherlands & Jl. Diponegoro 166,
68214 Bondowoso, Indonesia
E-mail: cjstigter@usa.net

Roger C. Stone

Australian Centre for Sustainable Catchments
Faculty of Sciences, University
of Southern Queensland,
Darling Heights, Toowoomba, Australia, 4350
E-mail: stone@usq.edu.au

Andreja Sušnik

Environmental Agency
of the Republic of Slovenia
Agrometeorological Department
Vojkova 1b, 1000
Ljubljana, Slovenia
E-mail: andreja.susnik@rzs-hm.si

Lourdes V. Tibig

Philippine Atmospheric, Geophysical
and Astronomical Services Administration
(PAGASA)
PAGASA Science Garden Complex
Agham Road, Quezon City, Philippines
E-mail: lvtibig@yahoo.com

M. Trnka

Institute of Agriculture Systems
and Bioclimatology
Mendel University of Agriculture and Forestry
Zemedelska 1
61300 Brno, Czech Republic
E-mail: mirek_trnka@yahoo.com

I. Uskov

Agrophysical Research Institute (ARI)
Grazhdansky pr. 14
195220 St. Petersburg, Russia
E-mail: office@agrophys.ru

A. Utset

Instituto Tecnológico Agrario de Castilla y
Leon (ITACYL)
Ctra. Burgos km 119
47071 Valladolid, Spain
E-mail: utssuaan@jcyl.es

R.E. Rivero Vega

Meteorological Centre
of Camagüey Province,
Camagüey, Cuba
E-mail: roger@cmw.insmet.cu

Constantino Alarcón Velazco

Servicio Nacional de Meteorología
e Hidrología (SENAMHI)
Jr. Cahuide N° 785 Jesus María
Lima 11, Perú
E-mail: calarcon@senamhi.gob.pe

Nguyen van Viet

Agrometeorological Research Centre
Institute of Meteorology and Hydrology
Ministry of Natural Resources
and Environment
5/62 Nguyen Chi Thanh Street
Dong Da District
Hanoi, Viet Nam
E-mail: agromviet@hn.vnn.vn

Donald A. Wilhite

National Drought Mitigation Center
University of Nebraska-Lincoln
819 Hardin Hall
Lincoln, NE 68583-0988, U.S.A.
E-mail: dwilhite@unlnotes.unl.edu

Tan Ying

China Agricultural University
College of Humanity and Development,
Department of Media and Communication
Beijing, China
E-mail: tanying9966@sohu.com

Wang Yingshun

Xilinhot National Climate Observatory
of Inner Mongolia
No.10 of Group 11 in Eerdemuteng Street,
Xilinhot City
Inner Mongolia, China, 026000
E-mail:Wys5959@yahoo.com.cn

Zheng Dawei

China Agricultural University
Department of Agricultural Meteorology
College of Resources and Environment
Beijing, China
E-mail: zhengdawei44@263.net

Z. Zalud

Institute of Agriculture Systems
and Bioclimatology
Mendel University of Agriculture
and Forestry
Zemedelska 1
61300 Brno, Czech Republic
E-mail: zalud@mendelu.cz

Extreme Weather and Climate Events, and Farming Risks

John Hay

1.1 Introduction

Extreme weather events, and climatic anomalies, have major impacts on agriculture. Of the total annual crop losses in world agriculture, many are due to direct weather and climatic effects such as drought, flash floods, untimely rains, frost, hail, and storms. High preparedness, prior knowledge of the timing and magnitude of weather events and climatic anomalies and effective recovery plans will do much to reduce their impact on production levels, on land resources and on other assets such as structures and infrastructure and natural ecosystems that are integral to agricultural operations. Aspects of crop and livestock production, as well as agriculture's natural resource base, that are influenced by weather and climatic conditions include air and water pollution; soil erosion from wind or water; the incidence and effects of drought; crop growth; animal production; the incidence and extent of pests and diseases; the incidence, frequency, and extent of frost; the dangers of forest and bush fires; losses during storage and transport; and the safety and effectiveness of all on-farm operations (Mavi and Tupper 2004).

Figure 1.1 illustrates how the climate influences agricultural production – specific climatic conditions, including absence of extremes, are required for optimum production. There are major gaps between the actual and attainable yields of crops, largely attributable to the pests, diseases and weeds, as well as to losses in harvest and storage.

When user-focused weather and climate information are readily available, and used wisely by farmers and others in the agriculture sector, losses resulting from adverse weather and climatic conditions can be minimized, thereby improving the yield and quality of agricultural products. While most emphasis should be placed on preparedness and timely management interventions, there will always be a need for the capacity to recover quickly and minimize the residual damages of adverse events and conditions (Stigter et al. 2003).

This paper focuses on a risk-based approach to managing the detrimental consequences of extreme weather events and climatic anomalies such as those described above. Basic concepts related to risk and to risk management are explained, followed by a discussion of farming risks. Details of risk characterization procedures are provided, along with some practical examples. Given the important consequences of climate change for agriculture, attention is given to projection of risk levels into the future. Again some practical examples are provided. Finally, relevant aspects of risk management are discussed. Overall conclusions are also presented.

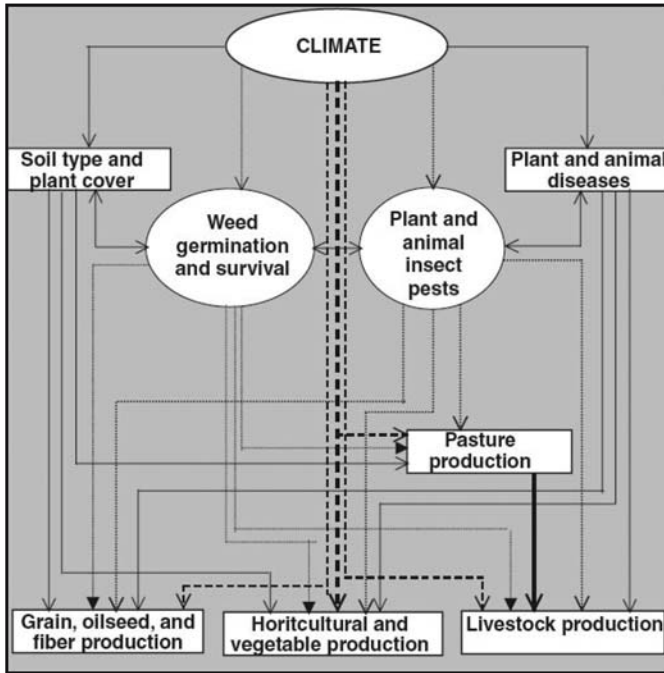


Fig. 1.1. The role of climate in agricultural production (from Mavi and Tupper 2004).

Why a risk-based approach? In recent decades there have been major advances in short-term and seasonal weather forecasting, as well as in long-term climate modelling. These have yielded major improvements in early warnings and advisories as well as in longer-term planning. This is resulting in increasing emphasis on proactive rather than reactive management of the adverse consequences of extreme weather events and anomalous climatic conditions on agriculture. It is also increasing the diversity of options available to farmers and others in the agriculture sector to manage those impacts. Increasingly, farm managers and other practitioners are seeking more rational and quantitative guidance for decision making, including cost benefit analyses. As will be demonstrated in the following sections, a risk-based approach to managing the adverse consequences of weather extremes and climate anomalies for agriculture goes a long way towards meeting these requirements. It also provides a direct functional link between, on the one hand, assessing exposure to the adverse consequences of extreme weather and anomalous climatic conditions and, on the other, the identification, prioritization and retrospective evaluation of management interventions designed to reduce anticipated consequences to tolerable levels.

Finally, risk assessment and management procedures have already been embraced by many sectors in addition to agriculture – e.g. health, financial, transport, energy, and water resources. As will be shown in the following section, a risk-based approach provides a common framework that facilitates coordination and cooper-