Mannava V.K. Sivakumar · Rattan Lal
Ramasamy Selvaraju · Ibrahim Hamdan
Editors

Climate Change and Food Security in West Asia and North Africa

Springer

Climate Change and Food Security in West Asia and North Africa

Mannava V.K. Sivakumar • Rattan Lal
Ramasamy Selvaraju • Ibrahim Hamdan
Editors

Climate Change and Food Security in West Asia and North Africa

Springer

Editors
Mannava V.K. Sivakumar
Climate Prediction and Adaptation Branch
World Meteorological Organization (WMO)
Geneva, Switzerland

Ramasamy Selvaraju
Climate, Energy and Tenure Division (NRC)
Food and Agriculture Organization
of the United Nations (FAO)
Rome, Italy

Rattan Lal
Carbon Management
and Sequestration Center
School of Environment
and Natural Resources
The Ohio State University
Columbus, OH, USA

Ibrahim Hamdan
Association of Agricultural Research
Institutions in the Near East
and North Africa (AARINENA),
c/o ICARDA
Amman, Jordan

ISBN 978-94-007-6750-8 ISBN 978-94-007-6751-5 (eBook)
DOI 10.1007/978-94-007-6751-5
Springer Dordrecht Heidelberg New York London

Library of Congress Control Number: 2013945430

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Foreword

The West Asia and North Africa (WANA) region has fragile ecosystems in semi-arid and arid areas facing challenging issues of absolute water scarcity, drought, land degradation and desertification. In addition to these, the region also has to deal with other issues including a significant increase in population, poverty, a geo-politically fragile environment, gender imbalance, weak investment in agricultural research for development and constraints in human resources and institutional capacities. As a result of all these factors, the WANA region is one of the largest food-deficit regions in the world.

Agriculture is the primary source of revenue and livelihood for a significant population in many countries in the region. The major climatic factors that affect crop yield stability in the WANA region are inter-annual and intra-seasonal rainfall variability and temperature extremes. The risks associated with extreme climate events are already posing a number of threats to agriculture and livestock enterprise in the region. Many negative impacts of climate variability on freshwater systems in the region have been observed in recent times. According to the Fourth Assessment Report released in 2007 by the Intergovernmental Panel on Climate Change (IPCC), which is sponsored by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), future projections of climate change indicate that the WANA region is expected to become warmer and drier with reduced crop productivity. The region is already a large net importer of grains and in the future it will become increasingly dependent on food imports, worsening the regional food security situation. Areas with high rates of population growth and natural resource degradation are likely to continue to have high rates of food insecurity.

To cope with climate variability and change more effectively in the WANA region, it is necessary to identify integrated adaptation and mitigation options for a range of agroecosystems so as to enable a favourable policy environment for the implementation of these options. There is an urgent need to integrate climate change concerns into the establishment of unified national frameworks and the enhancement of cross-sectoral coordination. In addition to strengthening enabling policies, the decision support systems need to be enhanced at the institutional level. Regional cooperation in data collection, exchange of information and monitoring and assessment of impacts of climate change are other key activities. These are also in agreement with the priorities identified under Agriculture and Food Security, which is one of the priority sectors of the Global Framework for Climate Services (GFCS), established in 2009 by the World Climate Conference-3.

It is against this background that the WMO, the Association of Agricultural Research Institutions in the Near East and North Africa (AARINENA) and the Food and Agriculture Organization (FAO) of the United Nations, organized the International Conference on Adaptation to Climate Change and Food Security in West Asia and North Africa in Kuwait City, Kuwait, from 13 to 16 November 2011. The Conference was co-sponsored by the International Center for Agricultural Research in the Dry Areas (ICARDA), the Ohio State University (OSU), the Kuwait Institute for Scientific Research (KISR), the Meteorological Department of the State of Kuwait, the Global Forum on Agricultural Research (GFAR) and the European Union (EU). The Conference in its final declaration identified several key recommendations, knowledge gaps and opportunities for policy makers, researchers and extension systems, international organizations and NGOs to implement programs designed to minimize short- and long-term vulnerability of the WANA region to climate change.

We wish to convey our sincere thanks to Dr. Naji Al Mutari, Director General, Kuwait Institute for Scientific Research (KISR), and all his colleagues for their excellent cooperation in providing conference facilities, making local arrangements and ensuring the full success of this Conference.

Several papers presented in the Conference are brought together in this book and we are sure that this volume will serve as a significant source of information to all agencies and organizations interested in the subject of climate change and food security and in promoting effective adaptation strategies to cope with climate change in the WANA region.

Secretary General, WMO — Michel Jarraud
Director General, FAO — José Graziano da Silva
President, AARINENA — Faisal Awawdeh

Preface

The countries of West Asia and North Africa (WANA) have long had the challenge of providing sustainable livelihoods for their populations in the fragile ecosystems of semi-arid and arid areas. The region is facing the challenging issues of absolute water scarcity, drought, land degradation, and desertification. In addition to these, the region also has to deal with other issues including a significant increase in population, poverty, a geo-politically fragile environment, gender imbalance, weak investment in agricultural research for development, and constraints in human resources and institutional capacities.

Climate change is already a reality in WANA and it places additional constraints on the already fragile ecosystems of dry areas and limited natural resources in WANA. A striking example of the potential impacts is the Nile delta with six million people, which will be directly affected by sea level rise. Hence there is an urgency to develop, and strengthen further, research and technology transfer on adaptation, mitigation, and production system resilience.

The Fourth Assessment Report of the WMO/UNEP Intergovernmental Panel on Climate Change (IPCC) released in 2007, suggested several adaptation strategies to deal with projected climatic changes which include changing crop varieties; enhancing more efficient water use; appropriate scheduling of cropping activities; adoption of more effective pest, disease, and weed management practices and insurance; and making better use of seasonal climate forecasts to reduce production risks.

A comprehensive and integrated approach to planning and implementing the climate change adaptation strategies across the wide range of agro-ecosystems in different countries in WANA could help both the planners and the local communities to deal effectively with the projected impacts and also contribute to overall sustainability of agricultural production systems.

Therefore, an international conference entitled "Adaptation to Climate Change and Food Security in West Asia and North Africa" was organized in Kuwait City, Kuwait, from 13 to 16 November 2011. The Conference was jointly sponsored by the World Meteorological Organization (WMO), the Association of Agricultural Research Institutions in the Near East and North Africa (AARINENA), the Food Agriculture Organization (FAO), the International Center for Agricultural Research in the Dry Areas (ICARDA), the Ohio State University (OSU), the Kuwait Institute for Scientific Research (KISR), the Meteorological Department of the State of Kuwait, the Global Forum on Agricultural Research (GFAR), and the European Union (EU).

The specific objectives of the Conference were:

- To provide a better understanding and assessment of the climate change impacts on agriculture and the associated vulnerability in the WANA region
- To discuss and make informed decisions on practical adaptation strategies for the agricultural sector in the WANA region
- To discuss and suggest the appropriate ways to promote adaptation planning and implementation and it's integration into the sustainable development planning in different countries in the WANA region
- To develop a Regional Adaptation Framework for continuous information exchange on climate change impacts and adaptation amongst the different countries in the WANA region

The Conference was attended by around 80 participants from 18 countries and nine international and regional organizations and institutions. The Conference was opened by Mr. Ahmad Al-Mulaifi, Minister of Education and Higher Education and Chairman, Kuwait Institute for Scientific Research (KISR) Board of Trustees and Representative of His Highness The Amir of the State of Kuwait, and closed by Dr. Naji Al Mutari, Director General, Kuwait Institute for Scientific Research (KISR).

All presentations were organized into seven technical sessions. Twenty-three papers submitted for the conference proceedings were reviewed and revised for publication in this volume.

The editors thank all of the authors for their outstanding contributions to this volume. We hope that the strategies presented by the authors for climate change adaptation and food security in the WANA region would lead to the development of new policies to help better adapt agriculture production systems and enhance food security in WANA.

We wish to convey our sincere thanks to the staff of Springer Verlag for their excellent cooperation in bringing out this volume.

Switzerland Mannava V.K. Sivakumar
USA Rattan Lal
Italy Ramasamy Selvaraju
Jordan Ibrahim Hamdan

Contents

Part I
Climate Change in West Asia and North Africa

Chapter 1
Climate Change in the West Asia and North Africa Region

Mannava V.K. Sivakumar, Alex C. Ruane, and Jose Camacho

Abstract The countries of West Asia and North Africa (WANA) have long had the challenge of providing sustainable livelihoods for their populations in the fragile ecosystems of semi-arid and arid areas, facing the challenging issues of water scarcity, drought, land degradation and desertification. Climate change is already a reality in WANA and it places additional constraints on its fragile ecosystems and limited natural resources. The most common and high-impact manifestations of local climate variability in the WANA region involve temperature and precipitation, which have marked effects on local and regional economies and livelihoods. 2010 was the warmest year on record in West Asia and North Africa. The Saharan/Arabian region was 2.22 °C above normal, 0.89 °C above the previous record and the largest annual anomaly ever recorded for any subregion outside the Arctic. Temperatures for the 2001–2010 decade in Africa averaged 0.85 °C above normal, 0.49 °C warmer than any previous decade, and the five hottest years on record for the continent have all occurred since 2003. These temperature effects were connected to alterations in the hydrological cycle, especially the amount, frequency, intensity, duration, and type of precipitation. Data on Palmer Drought Severity Index (PDSI) show a widespread drying trend over much of the WANA region since the mid-1950s. Global climate models (GCMs), which represent the interacting effects of greenhouse gases on the atmosphere, oceans, and land-surface, provide projections of future climate changes. All of the major GCMs agree that regional temperatures will warm between now and the 2050s, with temperature gains of

M.V.K. Sivakumar (✉)
Climate Prediction and Adaptation Branch, World Meteorological Organization (WMO), 7bis, Avenue de la Paix, 1211 Geneva 2, Switzerland
e-mail: msivakumar@wmo.int; mannavas@gmail.com

A.C. Ruane
NASA Goddard Institute for Space Studies, New York, NY, USA

J. Camacho
World Meteorological Organization (WMO), Geneva, Switzerland

M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_1,

2–3 °C ± 0.5 °C over much of the area. Changes in precipitation are less clear. The GCM ensemble shows a robust signal of increasingly dry conditions (10–20 % reduction in rain) surrounding the Mediterranean and extending east over the Mashreq, the northern Arabian Peninsula, and Western Asia. The GCMs agree in their projections of increased rainfall over the Indus valley (+10 % to 20 %), but are less confident in their projections of wetter conditions over the Nile Valley and Red Sea. Over the Horn of Africa and the southern Arabian Peninsula the GCMs project wetter conditions, but recent observations suggest that circulation changes have led to a regional drying demonstrated most visibly by the substantial drought in 2011. A warmer climate is also expected to impact the distribution of extreme events, with an increased frequency of heat waves and dry spells likely even in areas with slight rainfall increases.

Keywords Mean annual rainfall • Land surface temperature trends • Sea surface temperature trends • Palmer Drought Severity Index (PDSI) • Standardized Precipitation Index (SPI) • Coupled general circulation models

1.1 Introduction

The West Asia and North Africa (WANA) region is economically diverse, including both the oil-rich countries of the Gulf and countries that are resource scarce. According to the Association of Agricultural Research Institutions in the Near East and North Africa (AARINENA), the WANA countries fall in five sub-regions i.e., Maghreb, Nile Valley and Red Sea, Mashreq, Arabian Peninsula, and Western Asia which cover roughly 21.6 million km^2 with some 610 million people.

Differences in land area, total population and population density amongst the countries in the WANA region are very high. Figure 1.1 represents a scattergram of land area (km^2) against population (thousands of habitants) for selected countries in WANA, with the bubble size representing population density. Bahrain and Palestine have the highest population density, while Libya and Mauritania are examples of large countries with small population density. Syria, Tunisia, Iraq and Morocco are grouped in terms of surface area and population density. Egypt is by far the most populous country, with high density in the Nile River Valley and low density in its desert area.

The WANA region has the world's lowest rates of renewable water resources per capita (e.g., less than 150 m^3 year^{-1} capita^{-1} in Jordan) (World Water Council 2002) and suffers from associated environmental degradation and social problems.

1.2 Climate and Agriculture in the WANA Region

The WANA region covers the subtropical Atlantic across the southern shores of the Mediterranean Sea and the northern Sahara desert to the Sinai Peninsula in Western Asia reaching Arabian Peninsula and the Tigris-Euphrates basin. Temperatures are

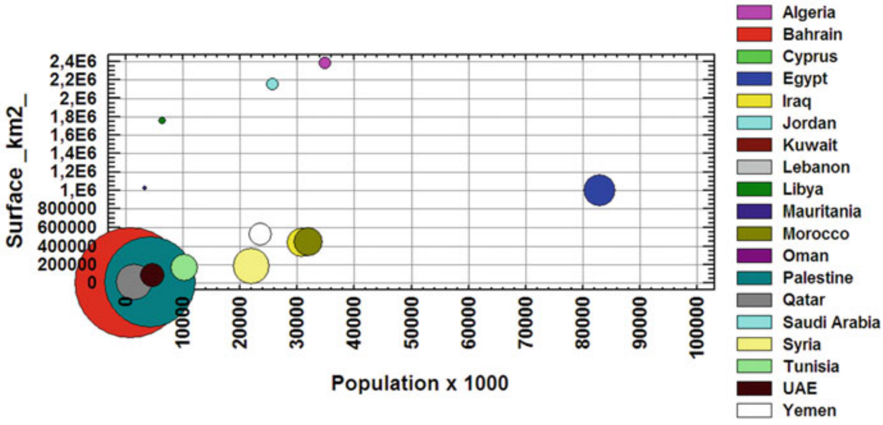


Fig. 1.1 Scattergram of country surface in km² vs population in thousands of habitants in selected countries in West Asia and North Africa. Bubble size is proportional to the density population (Source: UNSTATS)

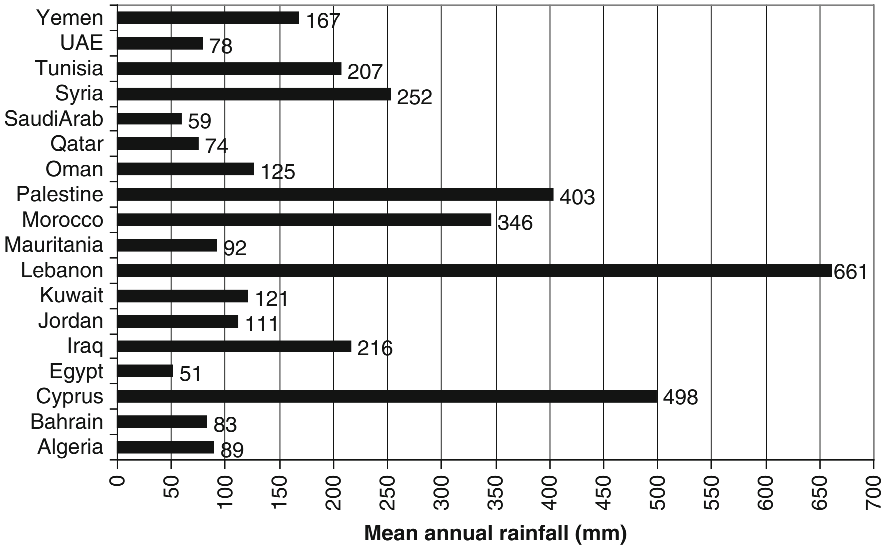


Fig. 1.2 Mean annual rainfall (mm) in selected countries in West Asia and North Africa (Source: AQUASTATS-FAO)

moderate or high, but the main characteristic of the climate is the low rainfall. Figure 1.2 shows the mean annual rainfall (mm) in selected countries in the WANA region. Lebanon and Cyprus are relative exceptions to the general aridity. Mean annual rainfall in Morocco is higher due to the effect of the Atlas Mountains, while in Tunisia, Syria, Yemen and Iraq, the mean annual rainfall is around 200 mm. In Egypt, the most populous country, mean annual rainfall is only 51 mm. Countries

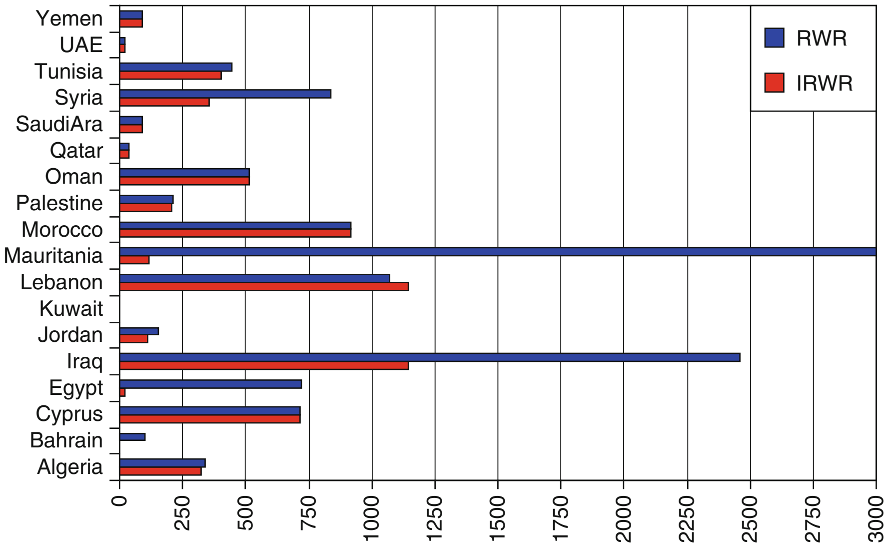


Fig. 1.3 Total renewable water per capita (*RWR*, m^3 $inhab^{-1}$ $year^{-1}$) and total internal renewable water per capita (*IRWR*, m^3 $inhab^{-1}$ $year^{-1}$) in selected countries in West Asia and North Africa

near the Arabian Gulf record less than 100 mm $year^{-1}$. Mean annual rainfall in Algeria, Libya, Egypt, and Saudi Arabia is low due to the vast arid territory where rainfall is far below the average precipitation in more densely settled areas.

In global-scale assessments, basins are defined as being water stressed if they have either water availability below 1,000 m^3 per capita per year (based on long-term average runoff) or a ratio of withdrawals to long-term average annual runoff above 0.4 (Bates et al. 2008). A water volume of 1,000 m^3 per capita per year is typically more than is required for domestic, industrial and agricultural water uses. There are important differences in the access to water resources in the WANA region. Figure 1.3 shows the total renewable water (m^3 per capita per year refreshed by annual rainfall) and total internal renewable water per capita for selected countries in WANA. Countries such as Yemen, Tunisia, Oman, Morocco, Saudi Arabia, Lebanon, Algeria or Cyprus mainly have internal water resources. In quantitative terms, countries that have large rivers tend to have more water per capita but this is largely modulated by population. Egypt has five times less water per capita than Italy and it is highly dependant on the Nile River. Arabian Peninsula countries have very low water availability per capita and rely on non-renewable ground water or sea water desalination to meet their water needs.

The contribution of agriculture to national GDP is very low in the Arabian Peninsula states with the exception of Yemen (Fig. 1.4). In Syria and Sudan (which includes the current Sudan and South Sudan), the contribution of agriculture to the GDP is higher. In many WANA countries communities rely on local agriculture and only rarely interact with international commodities markets.

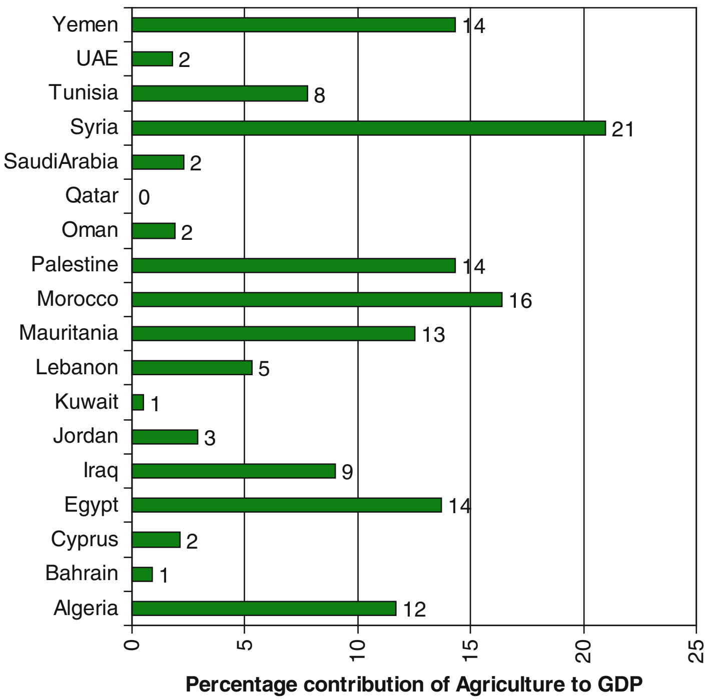


Fig. 1.4 Percentage contribution of agriculture to GDP in different countries in selected countries in West Asia and North Africa (Source: FAO-AQUASTATS)

1.3 Direct Observations of Recent Climate Change

The climate system is a complex, interactive system consisting of the atmosphere, land surface, snow and ice, oceans and other bodies of water, and living things. Assessment of scientific information on climate change, as well as its environmental and socioeconomic impacts, and formulation of response strategies is currently being carried out by the Intergovernmental Panel on Climate Change (IPCC), which was established in 1988, by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP). Information on the direct observations of climate change described below is based on the reports of the IPCC.

Evidence from observations of the climate system and global climate model experiments has led to the conclusion that human activities are contributing to a warming of the earth's atmosphere (IPCC 2007a). Human activities – primarily burning of fossil fuels and changes in land cover – are modifying the concentration of atmospheric constituents or properties of the Earth's surface that absorb or scatter radiant energy. In particular, increases in the concentrations of greenhouse gases (GHGs) and aerosols are strongly implicated as contributors to climatic changes observed during the twentieth century and are expected to contribute to further changes in climate in the twenty-first century and beyond.

The IPCC released its Fourth Assessment Report (AR4) in 2007 that focused on observed climate change and the potential impacts of future climate change. According to the IPCC Working Group I report (Solomon et al. 2007), warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level. Evidence from observations of the climate system show an increase of 0.74 °C ± 0.18 °C in global average surface temperature during the 100 year period from 1906 to 2005 and an even greater warming trend over the 50 year period from 1956 to 2005 (0.13 °C ± 0.03 °C/decade) than over the entire 100 year period (0.07 °C ± 0.02 °C/decade; IPCC 2007b). Eleven of the 12 years between 1995 and 2006 are among the warmest years since the instrumental record of global surface temperature was started in 1850 (Solomon et al. 2007). Warming has occurred in both land and ocean domains, and in both sea surface temperature (SST) and nighttime marine air temperature over the oceans. However, for the globe as a whole, surface air temperatures over land have risen at about double the ocean rate after 1979 (more than 0.27 °C per decade vs. 0.13 °C per decade). Hot days, hot nights and heat waves have become more frequent over the past 50 years. The AR4 concluded that the observed changes cannot be explained by natural phenomena and that there is now clear evidence of human influence.

In a further check on the observed warming signal, the Berkeley Earth Surface Temperature (BEST) group developed a new mathematical framework for producing maps and large-scale averages of temperature changes from weather station data for the purposes of climate analysis (Rohde et al. 2011). The study used over 39,000 unique stations, which is more than five times the 7,280 stations found in the Global Historical Climatology Network Monthly data set (GHCN-M). Their mathematical framework allows one to include short and discontinuous temperature records, so that nearly all temperature data can be used. The framework contains a weighting process that assesses the quality and consistency of a spatial network of temperature stations as an integral part of the averaging process. The BEST analysis found that the global land mean temperature has increased by 0.911 °C ± 0.042 °C since the 1950s (95 % confidence for statistical and spatial uncertainties). This change is consistent with global land-surface warming results previously reported by the IPCC, but with reduced uncertainty.

According to the WMO Statement on the Status of Global Climate in 2010 (WMO 2011), average global temperatures in 2010 were estimated to be 0.53 °C ± 0.09 °C above the 1961–1990 annual average of 14 °C. Temperatures for the 2001–2010 decade in Africa averaged 0.85 °C above normal, 0.49 °C warmer than any previous decade, and the five hottest years on record for the continent have all occurred since 2003 (WMO 2011). Anomalous years can have even larger deviations, exemplified by the year 2010, which was the warmest year on record in West Asia and North Africa. The Saharan/Arabian region was 2.22 °C above normal, 0.89 °C above the previous record and the largest annual anomaly ever recorded for any subregion outside the Arctic.

1.4 Land Surface Temperature Trends in WANA

The Global Historical Climatology Network-Monthly (GHCN-M) temperature dataset was first developed in the early 1990s (Vose et al. 1992). Effective May 2, 2011, the Global Historical Climatology Network-Monthly (GHCN-M) version 3 dataset of monthly mean temperature has replaced GHCN-M version 2 as the dataset for operational climate monitoring activities. The dataset is available at ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/v3/.

In order to assess the land surface temperature trends in WANA, the time series for GHCNM (v3) monthly mean temperature anomalies (for the annual time period) were computed over the following three specified rectangular-shaped spatial domains or regions:

Domain 1: −20° W to 60° E and 15° N to 40° N (North Africa)
Domain 2: 30° E to 50° E and 25° N to 40° N (Tigris-Euphrates Basins)
Domain 3: 20° E to 80° E and 20° N to 45° N (West Asia)

A schematic representation of the three domains is shown in Fig. 1.5. A 1×1 degree grid was placed over each of these regions and the station data were interpolated to this grid and anomalies were calculated from this grid domain. For these regions, the percentage of available data is often very low for most years (<10 %).

Time series of temperature anomalies in Domain 1 (North Africa) show a steady increase from 1901 to 2011 (Fig. 1.6), with a rapid increase in the period from 1991 to 2011. In Domain 2 (Tigris-Euphrates) the temperature anomalies show a greater degree of scatter (Fig. 1.7), while in Domain 3 (West Asia), the pattern is similar to the observed pattern in Domain 1 (Fig. 1.8).

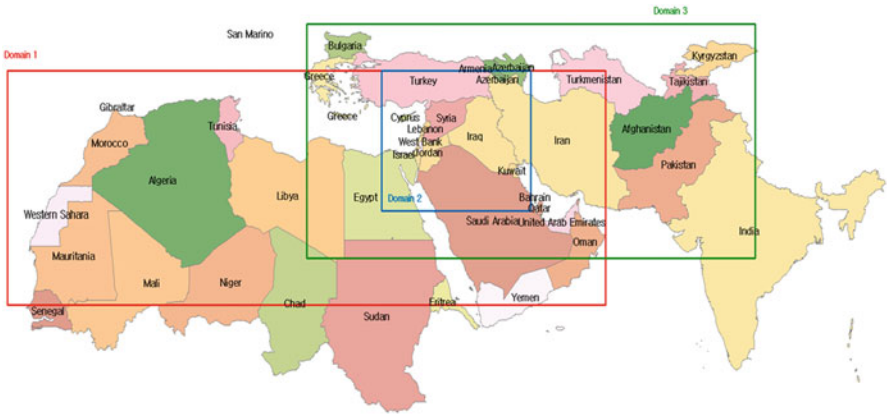


Fig. 1.5 Schematic representation of the three domains for which time series for GHCNM (v3) monthly mean temperature anomalies (for the annual time period) were computed (*Domain 1*: −20° W to 60° E and 15° N to 40° N; *Domain 2*: 30° E to 50° E and 25° N to 40° N; *Domain 3*: 20° E to 80° E and 20° N to 45° N)

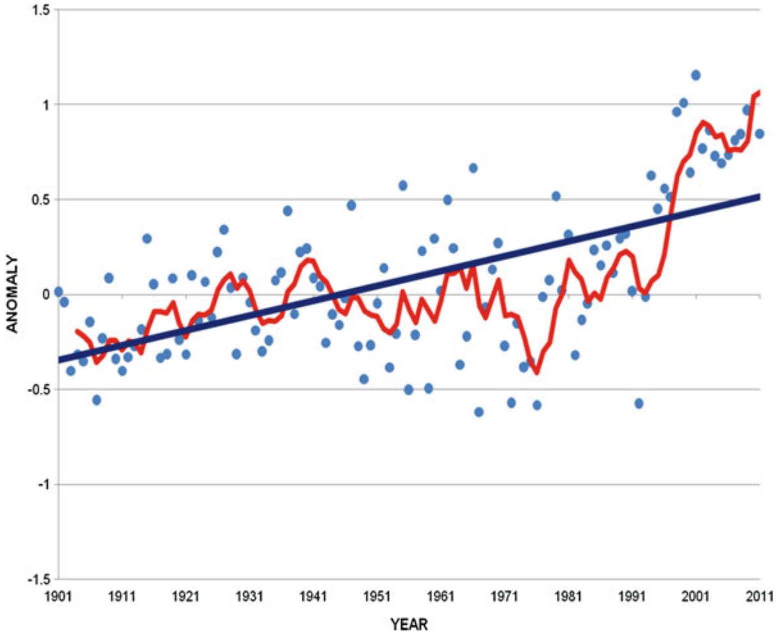


Fig. 1.6 Time series for GHCNM (v3) monthly mean temperature anomalies (for the annual time period) over domain 1 (−20° W to 60° E and 15° N to 40° N)

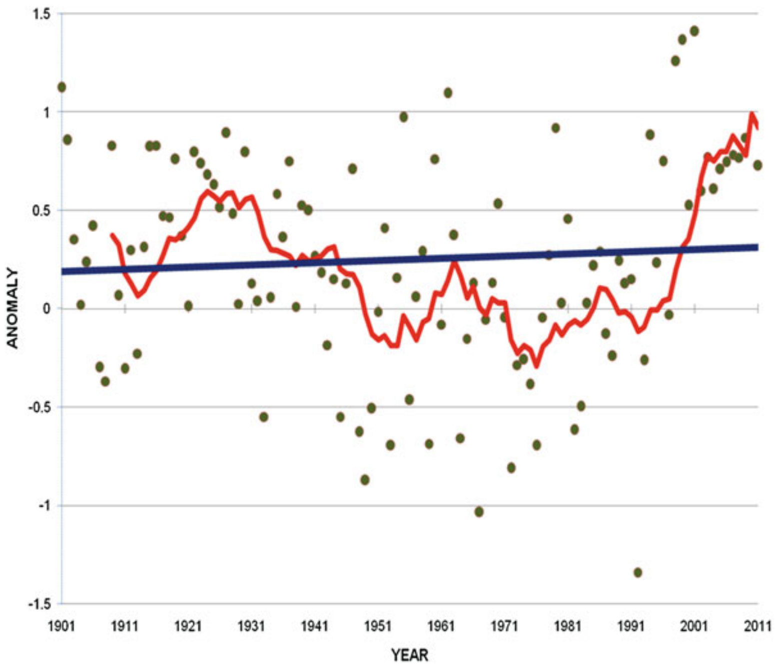


Fig. 1.7 Time series for GHCNM (v3) monthly mean temperature anomalies (for the annual time period) over domain 2 (30° E to 50° E and 25° N to 40° N)

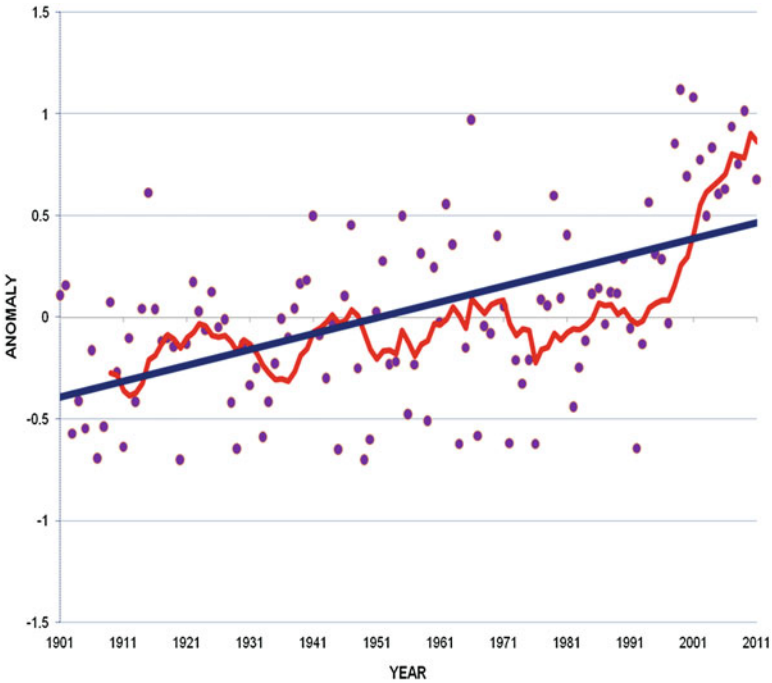


Fig. 1.8 Time series for GHCNM (v3) monthly mean temperature anomalies (for the annual time period) over domain 3 (20° E to 80° E and 20° N to 45° N)

1.5 Sea Surface Temperature Trends in WANA

Sea Surface Temperature (SST) analysis for climate monitoring utilized a new method based on in-situ observations conducted by the Japanese Meteorological Agency (Ishii et al. 2005). The SST analysis has a resolution of 1° latitude and 1° longitude with monthly-averaged Sea Surface Temperature (SST) data made available through Japanese Meteorological Agency's Tokyo Climate Center (TCC) Web site (http://ds.data.jma.go.jp/tcc/tcc/products/elnino/cobesst/cobe-sst.html). The characteristics of the data are described in JMA (2006), which are available on the TCC Web site at: (http://ds.data.jma.go.jp/tcc/tcc/library/MRCS_SV12/index_e.htm).

Annual mean SST data, averaged over the northwestern part of the Indian Ocean (Eq. to 30° N, 30° to 75° E; Fig. 1.9), show a steady increase over the observation period. SSTs over the Mediterranean Sea (30° to 40° N, 10° W to 40° E; Fig. 1.10) do not show a similar trend.

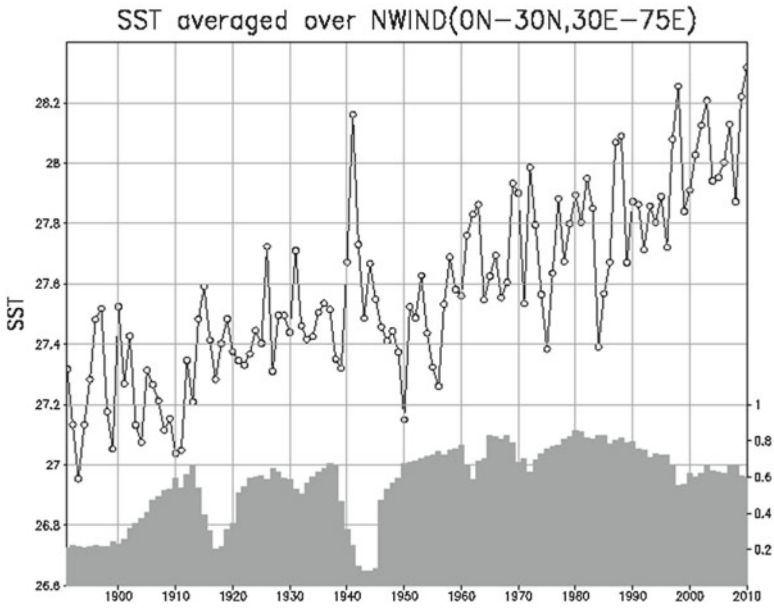


Fig. 1.9 Annual mean Sea Surface Temperature (*SST*) averaged over the north western part of the Indian Ocean (Eq. –30° N, 30° E –75° E). *Bars* show annual mean of monthly data coverage (ratio of number of grids where observations exist to total number of grids) (Source: Japanese Meteorological Agency)

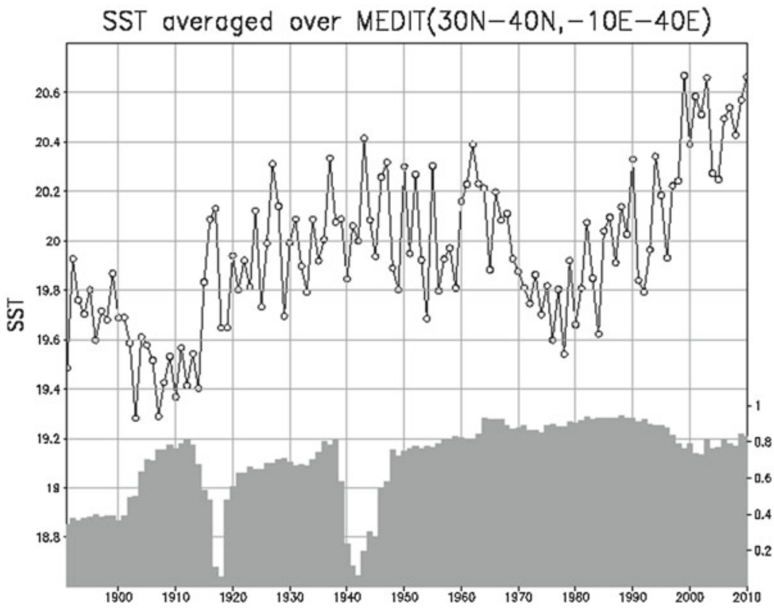


Fig. 1.10 Annual mean SST averaged over the Mediterranean Sea (30° N –40° N, 10° W –40° E). *Bars* show annual mean of monthly data coverage (ratio of number of grids where observations exist to total number of grids) (Source: Japanese Meteorological Agency)

1.6 Drought Trends in WANA

According to the IPCC, more intense and longer droughts have been observed since the 1970s, particularly in the tropics and subtropics. The fraction of land surface area experiencing drought conditions has risen from 10 % to 15 % in the early 1970s to more than 30 % by early 2000 (Dai et al. 2004). The IPCC AR4 concluded that it is *more likely than not* that there is a human contribution to this trend.

Decreased land precipitation and increased temperatures, which enhance evapotranspiration and reduce soil moisture, are important factors that have contributed to more regions experiencing droughts. For the drylands of West Asia and North Africa, it is not the effects of increased temperatures *per se* that are of major concern but rather the changes in precipitation, storm events, snowfall and snow melt, evapotranspiration, run off and soil moisture and the associated manifestations of drought (Thomas 2008). A global analysis has shown that abrupt changes in rainfall are more likely to occur in the arid and semi-arid regions, and that this susceptibility is possibly linked to strong positive feedbacks between vegetation and climate interactions (Narisma et al. 2007).

According to Hoerling et al. (2012), the land area surrounding the Mediterranean Sea has experienced 10 of the 12 driest winters since 1902 in just the last 20 years. Anthropogenic greenhouse gas and aerosol forcing were identified as the key attributable factors for this increased drying, though the external signal explains only half of the drying magnitude. Furthermore, sea surface temperature (SST) forcing during 1902–2010 likely played an important role in the observed Mediterranean drying. In the area from 10° N to 30° N, Bates et al. (2008) found that precipitation increased markedly from 1900 to the 1950s, but declined after about 1970.

One of the important ways to characterize drought trends is through the use of drought indices. Two indices that are commonly in use are the Palmer Drought Severity Index (PDSI; Palmer 1965), which is based on evapotranspiration anomalies, and the Standardized Precipitation Index (SPI; McKee et al. 1993, 1995), which is based on precipitation anomalies.

Using the PDSI, Dai et al. (2004) found a large drying trend over Northern Hemisphere land since the mid-1950s. Very dry areas (defined as land areas with a PDSI of less than −3.0) more than doubled (from ~12 % to 30 %) since the 1970s, with a large jump in the early 1980s due to an ENSO-related precipitation decrease over land, and subsequent increases primarily due to surface warming.

Using point data, PDSI estimates were made for Marrakech (Morocco), Kairouan (Tunisia), and Ankara (Turkey). Values of PDSI from −2 to −4 indicate moderate to severe drought and data in Fig. 1.11 show that the frequency of moderate to severe droughts has been increasing at all the three locations in the WANA region.

SPI characterizes droughts based on the cumulative probability of a given rainfall event occurring at a station. If rainfall over a particular period gives a low probability on the cumulative probability function, then this is indicative of a likely drought event. Plotting a time series of year against SPI gives a good indication of the drought history of a particular station. SPI values between −1 and −2 indicate moderate to severe dryness and values below −2 indicate severe dryness.

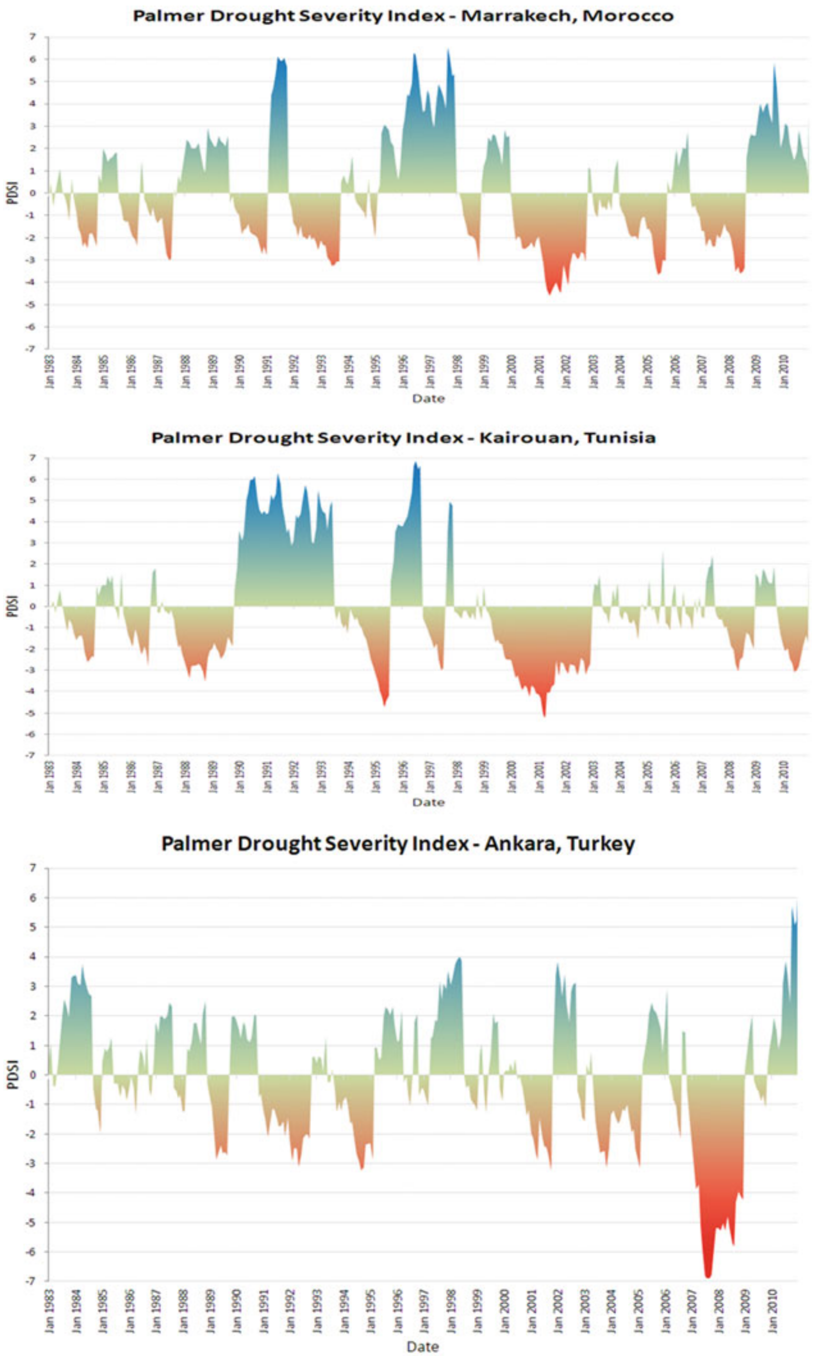


Fig. 1.11 Temporal trends in Palmer Drought Severity Index at Marrakech (Morocco), Kairouan (Tunisia), and Ankara (Turkey)

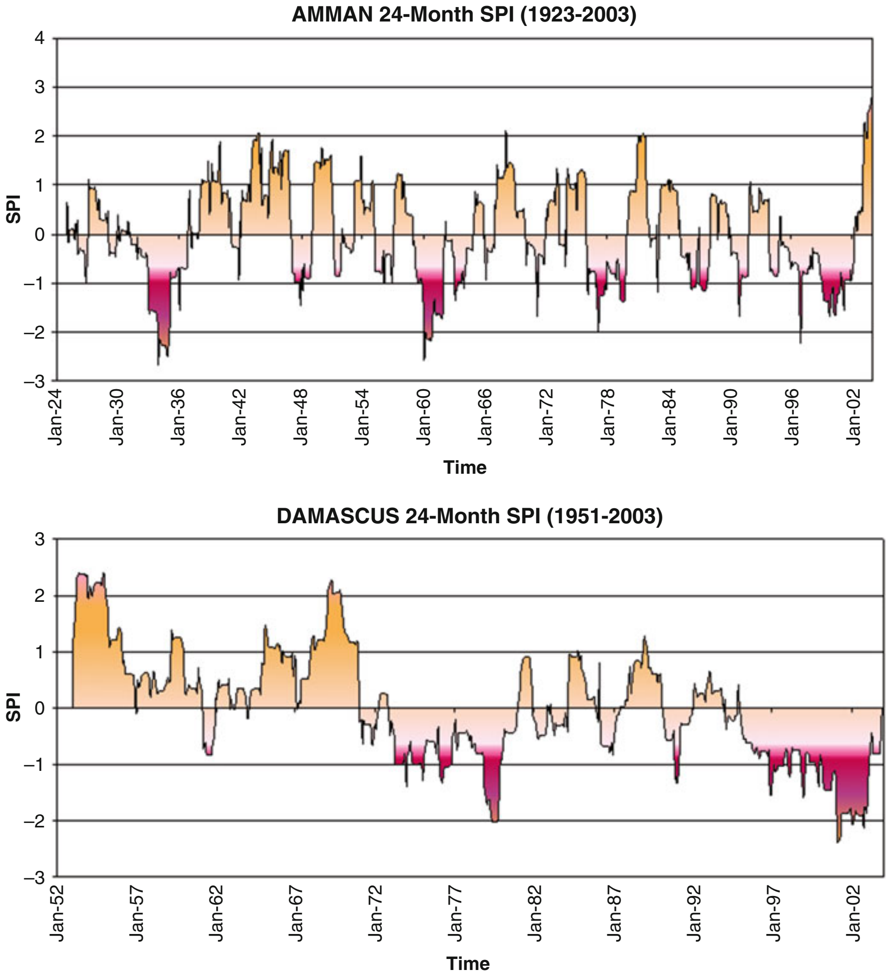


Fig. 1.12 Time series of Standardized Precipitation Index (*SPI*) for Amman, Jordan and Damascus, Syria

Figure 1.12 shows the time series of 24 month SPI values for Amman, Jordan (1923–2003) and Damascus, Syria (1953–2003). While there is considerable variability in the occurrence of droughts in Amman, data for Damascus show increased frequency of droughts from 1972 onwards.

1.7 Projections for Future Climate Change in WANA

According to the IPCC Fourth Assessment Report, A warming of about 0.2 °C per decade is projected for the next two decades for a range of GHG emission scenarios (IPCC 2007a). Even if the concentration of all greenhouse gases and aerosols are kept constant at year 2000 levels, a further warming of about 0.1 °C per decade would be expected. Previous IPCC projections of a temperature rise 0.15–0.3 °C/ per decade are now supported by an observed global value of 0.2 °C/decade.

This section examines climate change projections for five sub-regions in WANA, with a focus on uncertainty to inform risk management. Climate impacts on the WANA region are also discussed in the IPCC's Fourth Assessment Report (Solomon et al. 2007; Christensen et al. 2007; Cruz et al. 2007; Boko et al. 2007).

1.7.1 Methodology

1.7.1.1 Coupled General Circulation Models

The primary tools for understanding future climate changes are coupled general circulation models (CGCMs) that simulate the Earth's climate and its response to changing concentrations of greenhouse gases and aerosols (natural and man-made). CGCMs also simulate the ocean, land-surface, and the cryosphere as they interact with the atmosphere. CGCMs are built upon physical and chemical equations to capture dynamical and thermodynamic processes, and are evaluated against historical and present-day climates to capture natural variability and responses to shifts in atmospheric forcing from changes in the sun, volcanic emissions, sea-surface temperature anomalies, and greenhouse gas concentrations (Randall et al. 2007).

CGCMs require intense computational resources to capture the complex nature of the climate system at a scale sufficient for resolving important interactions and phenomena; thus climate change simulations are run on some of the most powerful computers in the world. Because these dynamical models are rooted in physical equations that are valid under a wide range of greenhouse gas concentrations, CGCMs allow experiments of future conditions that have not been previously observed. It is the response of the system to changing climatic forcings that is of primary interest, however, rather than the short-term forecasts that are the focus of numerical weather prediction models. In many cases, the ways in which climate changes is more consistent among CGCMs than is the climate of any particular experiment.

1.7.1.2 CGCM Uncertainties

Even employing the most powerful computational resources, climate model resolution is not optimal and important differences remain among projections from various modeling groups (Table 1.1). Each CGCM has known biases and errors due to computational and observational limitations, and therefore climate change projections are best examined through the use of ensemble analysis. The Third Coupled Model Intercomparison Project (CMIP3; Meehl et al. 2007) was organized to facilitate this type of ensemble analysis, resulting in a set of climate models run under identical

Table 1.1 CMIP3 General Circulation Models analyzed, along with their hosting center, approximate grid box resolution, and the equilibrium climate sensitivities of each model's atmospheric component to an instantaneous doubling of carbon dioxide relative to preindustrial levels (Based upon Randall et al. 2007)

GCM	Institution	Atmospheric resolution (lat × lon°)	Climate sensitivity (°C)
bccr_-bcm2.0	Bjerknes Centre for Climate Research, Norway	1.9 × 1.9	Not reported
cccma-cgcm3.1(T63)	Canadian Centre for Climate Modeling and Analysis, Canada	1.9 × 1.9	3.4
cnrm-cm3	CERFACS, Center National Weather Research, METEO-FRANCE, France	1.9 × 1.9	Not reported
csiro-mk3.0	CSIRO Atmospheric Research, Australia	1.9 × 1.9	3.1
gfdl-cm2.0	Geophysical Fluid Dynamics Laboratory, USA	2 × 2.5	2.9
gfdl-cm2.1	Geophysical Fluid Dynamics Laboratory, USA	2 × 2.5	3.4
giss-er	NASA Goddard Institute for Space Studies, USA	4 × 5	2.7
inm-cm3.0	Institute for Numerical Mathematics, Russia	4 × 5	2.1
ipsl_cm4	Insitut Pierre Simon Laplace, France	2.5 × 3.75	4.4
miroc3.2 (medium resolution)	Center for Climate System Research; National Institute for Environmental Studies; Frontier Research Center for Global Change, Japan	2.8 × 2.8	4.0
miub-echo-g	Meteorological Institute of the University of Bonn, Germany	3.9 × 3.9	3.2
mpi_echam5	Max Planck Institute for Meteorology, Germany	1.9 × 1.9	3.4
mri-cgcm2.3.2a	Meteorological Research Institute, Japan	2.8 × 2.8	3.2
ncar_ccsm3.0	National Center for Atmospheric Research, USA	1.4 × 1.4	2.7
ncar_pcm1	National Center for Atmospheric Research, USA	2.8 × 2.8	2.1
ukmo_hadcm3	Hadley Centre for Climate Prediction, Met Office, UK	2.5 × 3.75	3.3

forcing scenarios (Nakićenović and Swart 2000) and stored in a central archive at the Program for Climate Model Diagnosis and Intercomparison (PCMDI; http://www-pcmdi.llnl.gov). Sixteen CGCM groups archived global outputs for the years 2000–2100 from the SRES A2 (relatively high) and SRES B1 (relatively low) emissions scenarios. The higher emissions scenario is of primary focus in the analysis described here, as global emissions have tracked above the A2 scenario's rates since 2000 (Raupach et al. 2007).

Several techniques exist to analyze this 16 CGCM ensemble according to historical performance in a given region of interest (Giorgi and Mearns 2002; see Evans 2009, for analysis of CGCM performance in the Middle East). However this type of statistical basis for exclusion is necessarily dependent on the metrics used for evaluation, which vary according to application. Further, skill in the historical period does not necessarily correspond with accuracy in the evolution of the climate system. Only the full ensemble contains the full distribution of CGCM climate sensitivity (Table 1.1), which is the critical metric that determines the global climate system response to the greenhouse forcing driving anthropogenic climate change.

CGCMs tend to have much higher agreement on the sign and magnitude of temperature changes than on the sign and magnitude of precipitation changes (Solomon et al. 2007; Randall et al. 2007). This is due to the nature of precipitation's sensitivity to both thermodynamic and dynamic triggers and the fact that it is organized at a range of scales including those finer than CGCMs can directly resolve. The wider range on precipitation projections should not be taken as a sign that precipitation changes may not be projected with any certainty, however, as there is often strong agreement on the direction of precipitation change due to large-scale moisture convergence changes or shifts in the thermodynamic properties of broad regions. Likewise, it would be tempting to assume that the more extreme precipitation change projections are overestimated when, in fact, there is no reason to expect that the magnitude of change is negatively correlated to model skill. In managing risk it is therefore important to consider how the full range of ensemble projections would affect a particular system.

1.7.1.3 Downscaling

The resolution of climate model output is often too coarse for applications and impacts analysis (Table 1.1). This is particularly true in mountainous regions and along coastlines, where small distances can lead to substantially different climates. To interpret climate projections on a more useful scale, CGCM outputs were subjected to bias-correction and spatially-disaggregation (BCSD) to a ½-degree resolution according to historical observations and empirical relationships between elevation and slope with temperature and precipitation, respectively (Maurer et al. 2007). The pros and cons of statistical downscaling methods were described by Wilby et al. (2004). Although there are not currently sufficient regional climate model outputs available to analyze uncertainties in the WANA region, some impacts assessments may also benefit from increased investment in more computationally expensive dynamical downscaling approaches, as described by Mearns et al. (2003).

1.7.2 Regional Climate Changes

Figure 1.13 summarizes mid-century climate change projections for the WANA region under the A2 (relatively high) emissions scenario. Figure 1.13a shows the median annual temperature increase across the 16 CGCMs for the 2040–2069

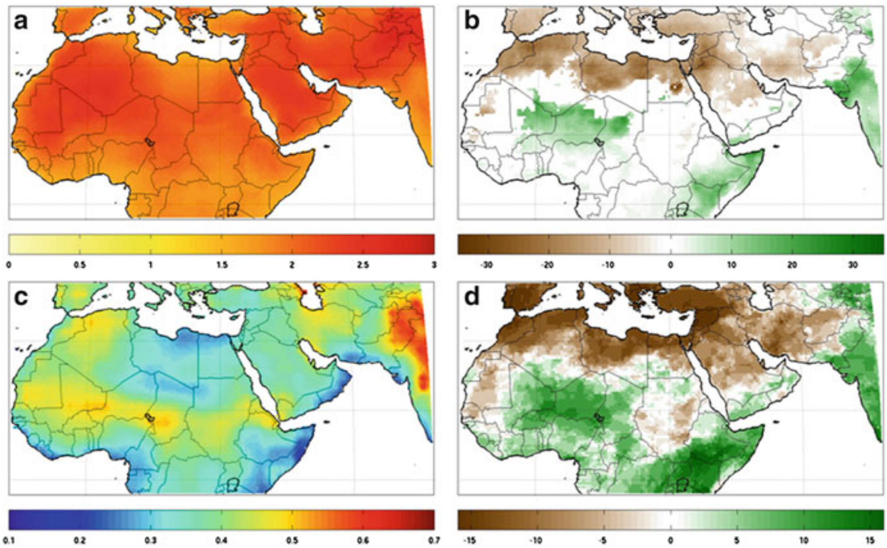


Fig. 1.13 Western Asia and Northern Africa median climate changes and model uncertainty (A2 2040–2069 period compared to 1980–2009 baseline period) from 16 downscaled GCMs. (**a**) Median annual temperature change (°C); (**b**) median annual precipitation change (%; displays only locations where two-thirds of CGCMs agree on sign of change); (**c**) standard deviation (across 16 GCMs) of annual temperature changes (°C); (**d**) number of models projecting wetter conditions minus number of models projecting drier conditions

period in comparison to 1980–2009. All areas are projected to warm, with most locations 1.5–2.5 °C hotter and higher temperature increases in arid lands and away from the coast. The areas with greatest projected warming are the border of Northern Pakistan and Afghanistan, the inland Saharan borders of Algeria and Mauritania, and the middle of the Arabian Desert. While all models project warming, the standard deviation of projected increases is displayed in Fig. 1.13c. Model uncertainty is generally proportional to the magnitude of change, with areas that warm the most also showing the largest spread between CGCM projections. Over Pakistan and portions of Afghanistan the spread is particularly large because of uncertainty in how the characteristics of the South Asian Monsoon's Western edge may change in the future climate.

The median projected changes in annual precipitation in Fig. 1.13b reveal a reduction in rainfall over the Mediterranean that extends across West Asia into Afghanistan. To account for the larger uncertainties in precipitation projections, Fig. 1.13b displays precipitation changes for locations where at least two-thirds of the CGCMs project the same sign of change. The drying feature is quite robust across models, as shown by the high level of agreement in the sign of CGCMs' precipitation changes in Fig. 1.13d. Simulations of the Arabian Peninsula and Eastern Africa indicate an increase in precipitation, however there is recent concern that this increase may reflect a model bias (see discussion in section below).

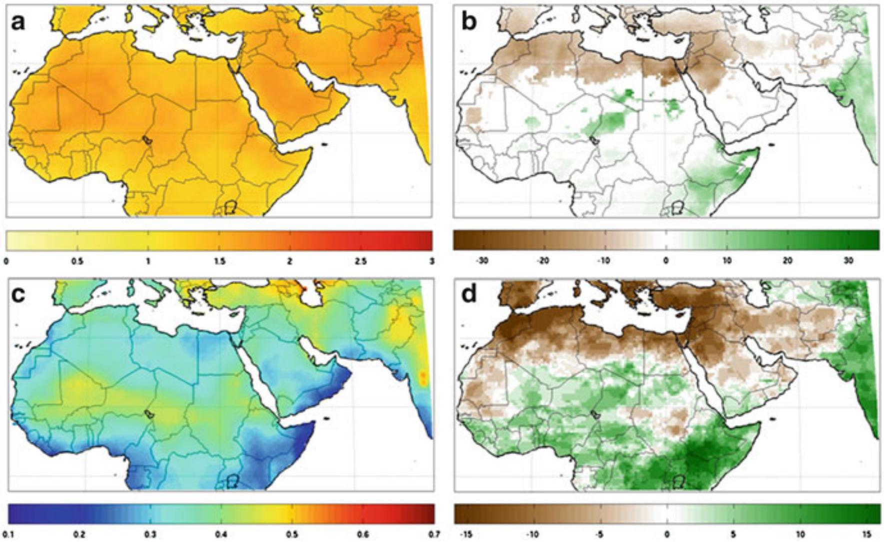


Fig. 1.14 As in Fig. 1.1, but for the B1 (relatively-low) emissions scenario

The similar summary of mid-century climate change projections for the WANA region, shown in Fig. 1.14 for the B1 (relatively low) emissions scenario, demonstrate that climate changes can be more muted if emissions are reduced. In this scenario median temperature change projections are generally between 1.1 °C and 1.7 °C, and precipitation changes have the same geographical pattern as the A2 projections but with a reduced magnitude.

1.7.2.1 Maghreb

Median projections of A2 mid-century temperature and precipitation changes for the Maghreb region show the substantial and robust impact of Mediterranean drying under future scenarios (Fig. 1.15). The higher heat capacity of the oceans reduces the rate of warming for the coastal regions that hold the bulk of the region's population, but these areas are also most dramatically affected by declines in precipitation. Median reductions of 25 % are projected for Northern Morocco, Algeria, and northeastern Libya. Mauritania and Western Sahara lie just outside of the reach of this Mediterranean drying, and wetter conditions in the central Sahara are only small percentage gains on a very low rainfall total. Embedded in the reduced annual rainfall along the Mediterranean coast are two other discouraging projections. First, Giorgi (2006) notes that interannual variability in Mediterranean precipitation is expected to increase, leading to an increased probability of droughts. Second, when rainfall does occur it is likely to have an increased intensity, leading to higher runoff and less groundwater storage (Alpert et al. 2002).

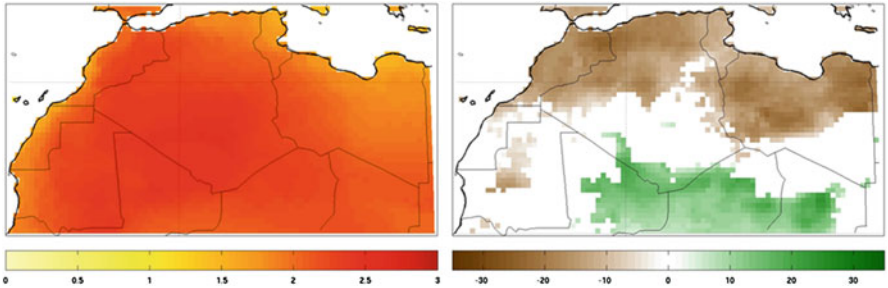


Fig. 1.15 Projected temperature (°C; *left*) and rainfall changes (%; *right*) for the Maghreb Region, as in Fig. 1.13a, b

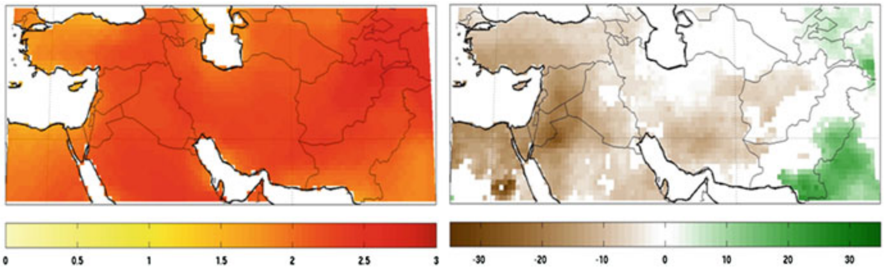


Fig. 1.16 Projected temperature (°C; *left*) and rainfall changes (%; *right*) for the Mashreq Region and the Western Asia Region, as in Fig. 1.13a, b

1.7.2.2 Mashreq

Figure 1.16 contains the median A2 mid-century temperature and precipitation changes for the Mashreq region. Warming increases west-to-east from a 1.5 °C rise in Lebanon to 2.5 °C in southeastern Iraq. The whole region is projected to become drier, with largest rainfall declines (20–30 %) inland over Jordan, southern Syria, western Iraq, and northeastern Saudi Arabia. Rainfall declines and CGCM agreement decrease in eastern Iraq, however, as the Mediterranean influence begins to fade.

1.7.2.3 Western Asia

Figure 1.16 also shows the median A2 mid-century temperature and precipitation changes for the Western Asia region. Warming is least (+1.7 °C) over the Adriatic coast of Turkey (and coasts in general), but amplifies toward the east over Iran, Afghanistan, and then Pakistan (where it peaks above +2.8 °C and is much more variable across CGCMs; recall Fig. 1.14c). Models are in full agreement that Turkey will become drier, particularly in the Southwest, however they agree less about

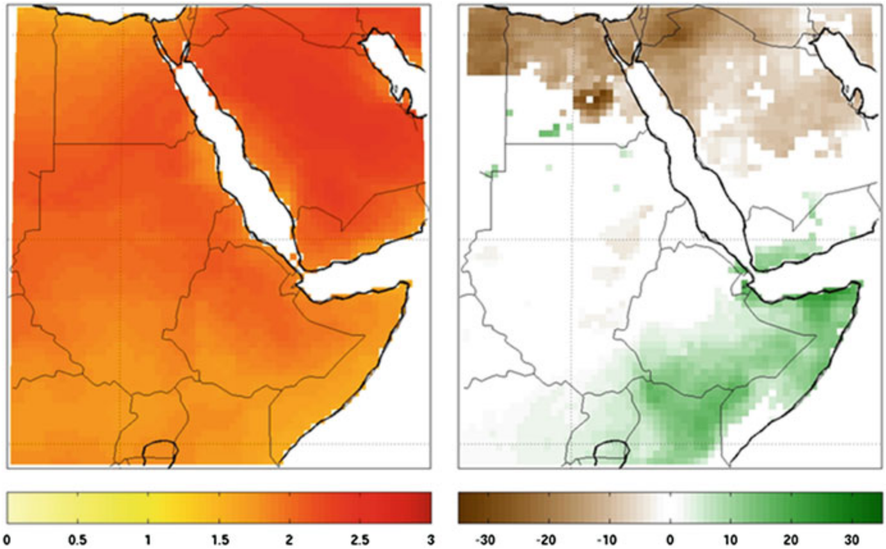


Fig. 1.17 Projected temperature (°C; *left*) and rainfall changes (%; *right*) for the Nile Valley and Red Sea Region, as in Fig. 1.13a, b

drying across Iran, Afghanistan and western Pakistan. Evans (2009) also notes that some models project shifts in the seasonal cycle of precipitation over Iran, leading to a longer dry season. The South Asian monsoon is projected to experience thermodynamic intensification while slowing down dynamically, however the end result is increased annual rainfall (Cruz et al. 2007). Increasing monsoonal precipitation therefore raises annual totals over Karachi (+24 %) and the agriculturally-vital Punjab Province (+18 %). Giorgi (2006) also identified an increase in interannual variability over the monsoon region, which seems to match the larger swings between floods and droughts that have affected Pakistan in recent years. Simulation of the monsoon region remains a substantial challenge for CGCMs, so even results with high model agreement in this region should be taken with precaution.

1.7.2.4 Nile Valley and the Red Sea

The Nile Valley and Red Sea region (Fig. 1.17) has mostly moderate temperature increases due to the proximity to water bodies, but includes a range of precipitation changes. Egypt is affected by Mediterranean drying, however in countries around the Gulf of Aden precipitation is projected to increase with substantial model agreement (between the two regions, Sudan changes are minor and inconclusive). In East Africa the CGCMs projections of wetter conditions have been called into question by recent droughts and observations of shifting Indian Ocean circulations (Funk et al. 2008; Williams and Funk 2010). Sea-surface temperature shifts in the Western

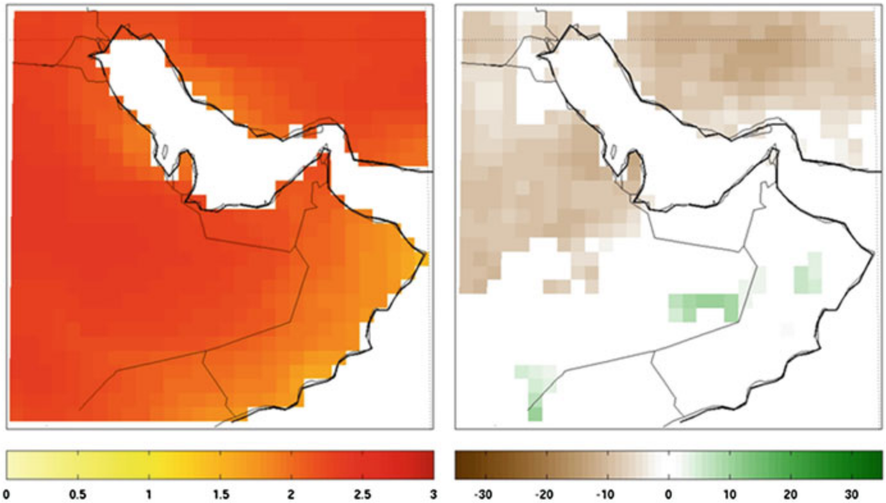


Fig. 1.18 Projected temperature (°C; *left*) and rainfall changes (%; *right*) for the Arabian Peninsula Region, as in Fig. 1.13a, b

Indian Ocean have drawn the region of storminess associated with the zonal Walker Circulation away from Africa, leading instead to drier conditions. It is not clear whether these changes are a characteristic of anthropogenic change or simply a part of decadal variability, so projections of wet conditions over Somalia, Yemen, and the Gulf of Aden are not nearly as robust as they first appear.

1.7.2.5 Arabian Peninsula

The Indian Ocean atmospheric circulation change may also affect rainfall over the Arabian Peninsula (Fig. 1.18). In the CMIP3 CGCMs there is little model agreement for precipitation changes in Oman or the UAE, however Qatar, Bahrain, and Kuwait are projected to be slightly affected by the West Asian extension of the Mediterranean drying signal (rainfall decreases of less than 10 %). Eastern Oman is projected to warm by the least amount in this region (+1.8 °C), with the largest increase in temperatures over inland Kuwait and western UAE (+2.2 °C).

1.8 Conclusions

The West Asia and North Africa (WANA) region is characterized by fragile ecosystems extended over vast semi-arid and arid areas. Analysis of land surface and sea surface temperature trends show that climate change is already occurring in WANA. Analysis of drought trends in different locations confirms that there is an increasing frequency and intensity of droughts, which can lead to increased land degradation. Future climate change analysis for WANA using an ensemble of 16 GCMs suggests that temperatures will warm between now and the 2050s, with temperature gains of 2–3 °C ± 0.5 °C over much of the region if global activities continue to track along the higher greenhouse gas emissions pathway. Projected changes in precipitation are less clear.

In order to pro-actively address the issue of climate change and food security in WANA it is important to:

- Improve collection and dissemination of weather- and agriculture-related information by improving weather station, field trial, irrigation supply and demand, and yield tracking networks to strengthen monitoring of extreme events and their impacts on food production and availability;
- Share information on climate change and related science, data, tools and methodologies in West Asia and North Africa;
- Establish a regional early warning system of climatic risks; and
- Create a Climate Change and Food Security in West Asia and North Africa Network (CCFSWANANet).

Acknowledgments We acknowledge the assistance of Drs. Byron Gleason and Tom Peterson with the analysis of land surface temperature trends; Dr. Kiyoharu Takano with the sea surface temperature trends; Drs. Don Wilhite, Brian Fuchs, Ray Motha and Harlan Shannon with the drought trends; and Dr. Cynthia Rosenzweig for her suggestions We acknowledge Daniel Bader and Soyee Chiu for their assistance in the generation of figures. We also acknowledge the modeling groups, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the WCRP's Working Group on Coupled Modelling (WGCM) for their roles in making available the WCRP CMIP3 multi-model dataset. Support of this dataset is provided by the Office of Science, U.S. Department of Energy.

References

Alpert P, Ben-Gai T, Baharad A, Benjamini Y, Yekutieli D, Colacino M, Diodato L, Ramis C, Homar V, Romero R, Michaelides S, Manes A (2002) The paradoxical increase of Mediterranean extreme daily rainfall in spite of decrease in total values. Geophys Res Lett 29. doi:10.1029/2001GL013554

Bates BC, Kundzewicz ZW, Wu S, Palutikof JP (eds) (2008) Climate change and water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva

Boko M, Niang I, Nyong A, Vogel C, Githeko A, Medany M, Osman-Elasha B, Tabo R, Yanda P (2007) Africa. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) From climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK, pp 433–467

Christensen JH, Hewitson B, Busuioc A, Chen A, Gao X, Held I, Jones R, Kolli RK, Kwon W-T, Laprise R, Magaña Rueda V, Mearns L, Menéndez CG, Räisänen J, Rinke A, Sarr A, Whetton P (2007) Regional climate projections. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Climate change 2007: the physical science basis.

Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK/New York

Cruz RV, Harasawa H, Lal M, Wu S, Anokhin Y, Punsalmaa B, Honda Y, Jafari M, Li C, Huu Ninh N (2007) Asia. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) From climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK, pp 469–506

Dai A, Trenberth KE, Qian T (2004) A global set of Palmer Drought Severity Index for 1870 to 2002: relationship with soil moisture and effects of surface warming. J Hydrometeorol 5:1117–1130

Evans JP (2009) 21st century climate change in the Middle East. Clim Chang 92:417–432. doi:10.1007/s10584-008-9438-5

Funk C, Dettinger M, Michaelsen JC, Verdin JP, Brown ME, Barlow M, Hoell A (2008) Warming of the Indian Ocean threatens eastern and southern African food security but could be mitigated by agricultural development. Proc Natl Acad Sci U S A 105:11081–11086

Giorgi F, Mearns LO (2002) Calculation of average, uncertainty range, and reliability of regional climate changes from AOGCM simulations via the “Reliability Ensemble Averaging” (REA) Method. J Climate 15:1141–1158

Giorgi F (2006) Climate change hot-spots. Geophys Res Lett 33, L08707. doi:10.1029/2006GL025734

Hoerling M, Eischeid J, Perlwitz J, Quan X, Zhang T, Philip P (2012) On the increased frequency of Mediterranean drought. J Climate 25:2146–2161

IPCC (2007a) Climate change 2007: synthesis report. Contribution of working groups I, II and III to the fourth assessment report of the intergovernmental panel on climate change. In: Core Writing Team, Pachauri RK, Reisinger A (eds). IPCC, Geneva

IPCC (2007b) Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. In Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds). Cambridge University Press, Cambridge, UK/New York

Ishii M, Shouji A, Sugimoto S, Matsumoto T (2005) Objective analyses of SST and marine meteorological variables for the 20th century using ICOADS and the Kobe Collection. Int J Climatol 25:865–879

JMA (2006) Monthly report on climate system separated volume no.12. Japanese Meteorological Agency, Tokyo

Maurer EP, Brekke L, Pruitt T, Duffy PB (2007) Fine-resolution climate projections enhance regional climate change impact studies. Eos Trans Am Geophys Union 88(47):504

McKee TB, Doesken NJ, Kleist J (1993) The relationship of drought frequency and duration to time scales. In: Eighth conference on applied climatology. American Meteorological Society, Boston

McKee TB, Doesken NJ, Kleist J (1995) Drought monitoring with multiple time scales. In: Ninth conference on applied climatology. American Meteorological Society, Boston

Mearns LO, Giorgi F, Whetton P, Pabon D, Hulme M, Lal M (2003) Guidelines for use of climate scenarios developed from regional climate model experiments. Data Distribution Centre of the Intergovernmental Panel on Climate Change, Geneva, 38 pp

Meehl GA, Covey C, Delworth T, Latif M, McAvaney B, Mitchell JFB, Stouffer RJ, Taylor KE (2007) The WCRP CMIP3 multi-model dataset: a new era in climate change research. B Am Meteorol Soc 88:1383–1394

Nakićenović N, Swart R (eds) (2000) Special report on emissions scenarios. Cambridge University Press, Cambridge, UK, http://www.grida.no/climate/ipcc/emission/

Narisma GT, Foley JA, Licker R, Ramankutty N (2007) Abrupt changes in rainfall during the twentieth century. Geophys Res Lett 34, L06710. doi:10.1029/2006GL028628

Palmer WC (1965) Meteorological drought. U.S. Weather Bureau, Washington, DC, Research paper no 45

Randall DA, Wood RA, Bony S, Colman R, Fichefet T, Fyfe J, Kattsov V, Pitman A, Shukla J, Srinivasan J, Stouffer RJ, Sumi A, Taylor KE (2007) Climate models and their evaluation.

In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) From Climate change 2007: the scientific basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK, pp 589–662

Raupach MR, Marland G, Ciais P, Le Quéré C, Canadell JG, Klepper G, Field CB (2007) Global and regional drivers of accelerating CO_2 emissions. Proc Natl Acad Sci U S A 104(24):10288–10293. doi:10.1073/pnas.0700609104

Rohde R, Curry J, Groom D, Jacobsen R, Muller RA, Perlmutter S, Rosenfeld A, Wickham C, Wurtele J (2011) Berkeley earth temperature averaging process. University of California, Berkeley

Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) (2007) Climate change 2007: the scientific basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK

Thomas RJ (2008) Opportunities to reduce vulnerability of dryland farmers in Central and West Asia and North Africa to climate change. Agric Ecosyst Environ 126:36–45

Vose RS, Schmoyer RL, Steurer PM, Peterson TC, Heim R, Karl TR, Eischeid J (1992) The Global Historical Climatology Network: Long-term monthly temperature, precipitation, sea level pressure, and station pressure data. ORNL/CDIAC-53, NDP-041, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, USA

Wilby RL, Charles SP, Zorita E, Timbal B, Whetton P, Mearns LO (2004) Guidelines for use of climate scenarios developed from statistical downscaling methods. Data Distribution Centre of the Intergovernmental Panel on Climate Change, Geneva, p 27

Williams AP, Funk C (2010) A westward extension of the warm pool leads to a westward extension of the Walker circulation, drying eastern Africa. Clim Dyn. doi:10.1007/s00382-010-0984-y

WMO (2011) WMO statement on the status of global climate in 2011. WMO-No. 1085, World Meteorological Organization, Geneva, Switzerland

World Water Council (2002) In: Abu-Zeid M, Hamdy A (eds) Water vision for the twenty-first century in the Arab World. World Water Council. Arab Countries Vision Consultations. 4–5 Aug 1999, Marselle, France

Chapter 2
Implications of Climate Change for Agriculture and Food Security in the Western Asia and Northern Africa Region

Ramasamy Selvaraju

Abstract Western Asia and Northern Africa (WANA) region is considered to be one of the most vulnerable regions to the impacts of climate change. In particular, dry areas characterized by low and unpredictable rainfall, long dry seasons, scarce water resources, rural poverty, dependence on agriculture, limited cropping/livestock options and low level of technological adoption contribute to vulnerability. Current vulnerabilities are likely to be exacerbated further by increasing climate variability and climate change. Agricultural productivity in the WANA region is likely to suffer losses because of high temperature, drought, and soil degradation, which, in turn will put the food security of many countries under threat. Many countries in the region are major food importers, and climate change impact may increase this dependence on imports. Food and Agriculture Organization of the United Nations estimates that a total of 25 million people are under-nourished in the Western Asia and Northern Africa region, and climate change may further exacerbate the food insecurity situation. Improving adaptation capacities through sustainable management and monitoring of rangelands, improved soil and water management and conservation as well as with non-structural measures such as crop insurance can reduce the impact of climate change on livelihoods. However, developing policies, legislation and action plans that integrate climate change considerations are the pre-requisite for enhancing adaptation in agriculture, sustainable livelihoods and improved food security.

Keywords Climate change impacts • Agriculture • Livelihoods • Extreme climate events • Adaptation • Resilience • Sustainability

---

R. Selvaraju (✉)
Climate, Energy and Tenure Division (NRC), Food and Agriculture Organization of the United Nations (FAO), Viale delle Terme di Caracalla, Rome 00153, Italy
e-mail: selvaraju.ramasamy@fao.org

M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_2,

2.1 Introduction

The Western Asia and Northern Africa (WANA) region is a vast zone of generally diverse climatic conditions, characterized by very low and highly variable annual rainfall and high degree of aridity. The climate of the region is mostly desert, arid and semi-arid with a long coast line and a variety of geographical features. Common cultural heritage and vastly different levels of development as well as the resource endowment is a characteristic feature of the region (FAO 2010).

The area of arable land and permanent crops in WANA is estimated at 93.1 million hectares. This accounts for 18 % of the total agricultural area (e.g. 3 % in Saudi Arabia; over 50 % in Egypt); 32 % of the arable land is irrigated, but contributes more than 50 % of the total agricultural production (FAO 2007a). Major cereal crops, mainly wheat and barley, with rice and sorghum in some countries contribute significantly to food production. Farming systems include: irrigated, highland mixed, rainfed mixed, dryland mixed, pastoral, sparse arid, coastal artisanal fishing and urban based agriculture (Dixon et al. 2001).

The WANA region is characterized as extremely scarce water resources with per capita Renewable Water Resources (RWR) of 1,215 m^3 $year^{-1}$ compared to world average of 23,803 m^3 $year^{-1}$ (FAO-AQUASTAT 2012). The irrigation efficiency is <50 % and water quality is currently deteriorating (FAO 2010). Continuous land degradation, extreme climatic conditions, over grazing, loss of biodiversity, over fishing, unsustainable cropping, salt accumulation, and pollution are the major challenges faced by the region. Tolba and Saab (2009) conducted an extensive review and prioritized water scarcity, land degradation and desertification, inadequate capacities for waste management, coastal and marine environment degradation, air pollution and global warming as major challenges.

Climate change, high population growth rates, and in some countries, rapid economic growth and urbanisation, all amplify the region's vulnerability to environmental challenges and constrain its ability to manage them. This paper aims to make a contribution to our understanding of the dynamics around climate change and its consequences for agriculture and food security in the WANA region.

2.2 Vulnerability of Agriculture to Climate Variability and Change

2.2.1 Rural Population and Dependence on Agriculture

Rural population, poverty and dependence on agriculture are the major underlying causes of vulnerability to climate change and related impacts. The proportion of rural population has declined from 48 % in 1980s to 30.4 % in 2010 in Western Asia and from 59.8 % to 44.6 % in Northern Africa (Fig. 2.1).

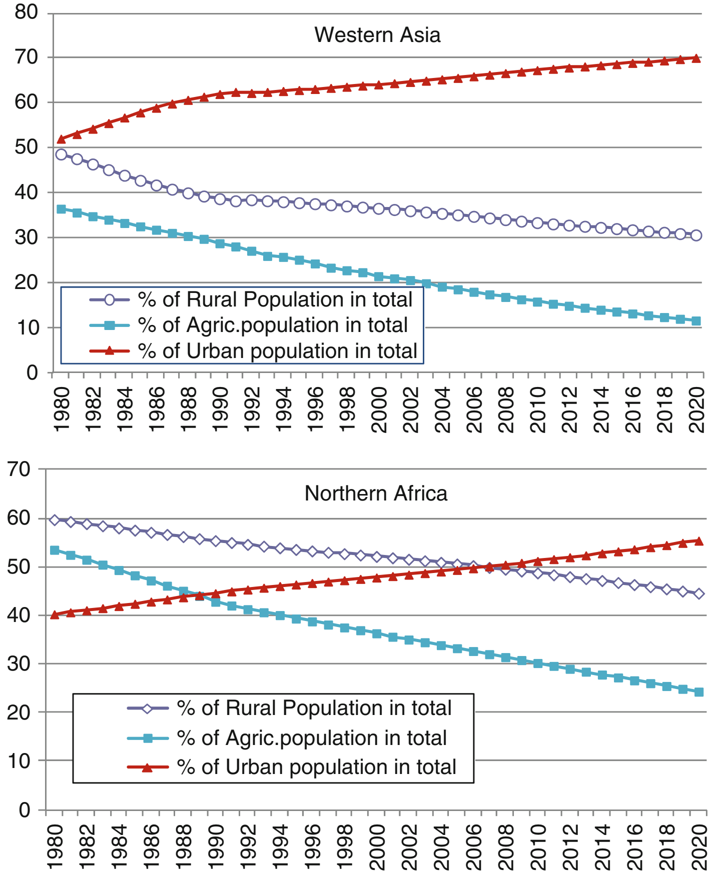


Fig. 2.1 Proportion of rural, agricultural and urban population to the total population in Western Asia and Northern Africa (Source: FAOSTAT)

The widening ratios between agriculture, rural and urban populations to the total population indicate that the population previously engaged in agriculture has either migrated to urban areas or stayed in the rural areas, but diverting to non-agriculture works. Overall, significant proportion (over 30 % in Western Asia and 45 % in Northern Africa) reside in rural areas and primarily depend on agriculture and related activities (FAOSTAT 2012).

The Arabian Peninsula holds 20.8 % of its population in the rural areas with a maximum proportion in Yemen (68.2 %) and followed by Oman (27 %). The proportion of rural population living in Northern Africa (44.6 %) is more than Western Asia (30.4 %) with a maximum of 60 % in Sudan (former) and 57 % in Egypt.

Extreme poverty is associated with agriculture production systems in highland mixed system of Yemen and Morocco and dryland mixed and pastoral systems of

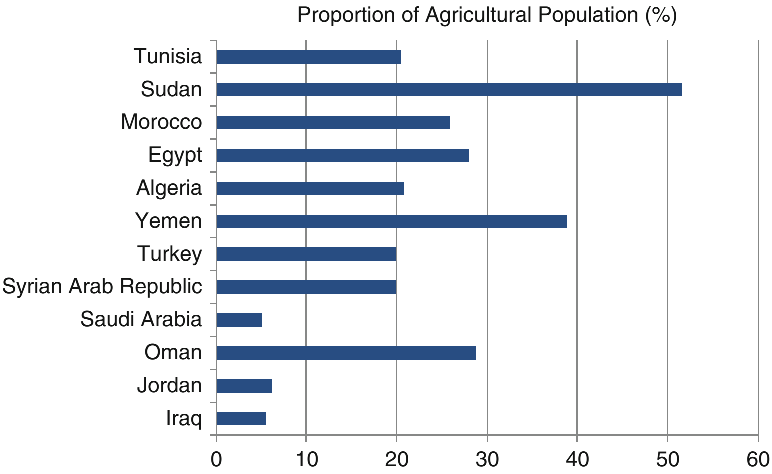


Fig. 2.2 Proportion of agricultural population to total population in selected countries of Western Asia and Northern Africa (Source: FAOSTAT)

other countries of the region. Around 25 % population is under poverty line, with large variations between countries (FAO 2010). Poverty translates into under nutrition in coexistence with food-related chronic diseases. Increased migration of males to the cities, leaving rural women without adequate access to productive assets also adds to the vulnerability of women to climate fluctuations.

Agriculture is the primary source of livelihoods and revenue for significant population in many countries in the region (Fig. 2.2). The proportion of agricultural population to the total is 15.5 % in Western Asia and 30.2 % in Northern Africa (2010) and contributes significantly to the rural population. On average, the agricultural population in the region is 18 % (51.5 % Sudan (former); 38.8 % Yemen) (FAOSTAT 2012).

Rainfed agriculture is practiced by 18 % of the agricultural population, but occupies only 2 % of the land area. This employs 21 % active population and contributes to over 10 % of the regional GDP (2001–2008). The land share per capita is decreasing annually as a result of rapid population growth and urbanization.

By 2007, the average agricultural land share in the Arab region was about 0.23 ha per capita, which is slightly lower than the world average of 0.24 ha per capita (Medany 2008). Forests occupy 39.3 million ha (3.2 % of total land area). Nearly 70 % of the land area is covered by rangelands and supports traditional livestock, which is the major support for livelihoods.

Marine capture fisheries grew six fold since 1950s, and aquaculture production, which was almost non-existent till the 1980s, showed a significant increase that has been particularly remarkable from the late 1990s. The sector contributes to the

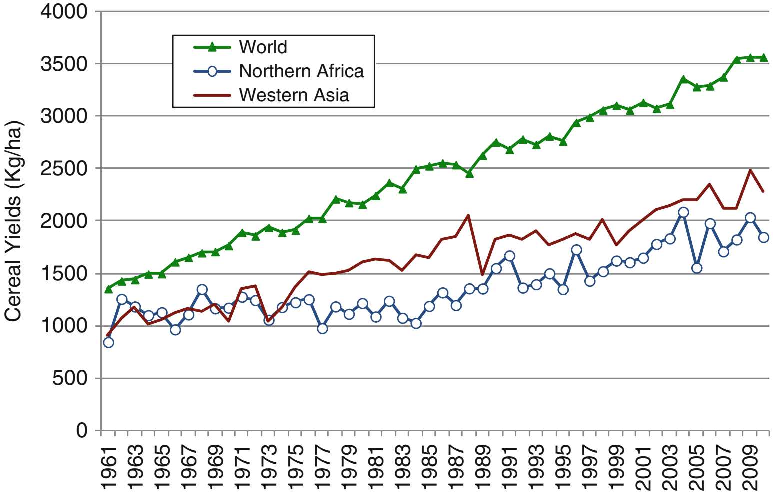


Fig. 2.3 Average cereal yields in Western Asia and Northern Africa in comparison to World average (1961–2010) (Source: FAOSTAT)

economy and employment. For example, in Morocco, fisheries contribute to 2–3 % of GDP and provide direct employment to 1.5 % of the active population and sources of income for three million people (FAO 2011).

2.2.2 Marginal Production Environments

Most of the lands in WANA region are classified as hyper-arid, semi-arid and arid land zones. The major climatic factors that affect crop yield stability in Northern Africa and Western Asia are inter-annual and intra-seasonal rainfall variability and temperature extremes (Cooper et al. 1989). The inter-annual, monthly and daily distribution of climate variables (e.g., temperature, radiation, precipitation, water vapour pressure in the air and wind speed) affects a number of physical, chemical and biological processes that drive the productivity of agriculture, forestry and fisheries.

The dominant agricultural system in the countries of the region is rainfed agriculture and the proportion of irrigation covers less than 28 % of the agriculture area (FAO 2008). Therefore, annual agricultural productivity and food security are highly correlated to the annual variability of precipitation, which has exhibited major changes in recent decades (Abou-Hadid 2006). The marginal production environments and variety of factors including climate variability lead to low cereal yields compared to global average yields and slow rate of growth (Fig. 2.3) in this region.

Agricultural production systems suffer varying degrees from problems associated both with subsistence production (isolated and marginal location, informal

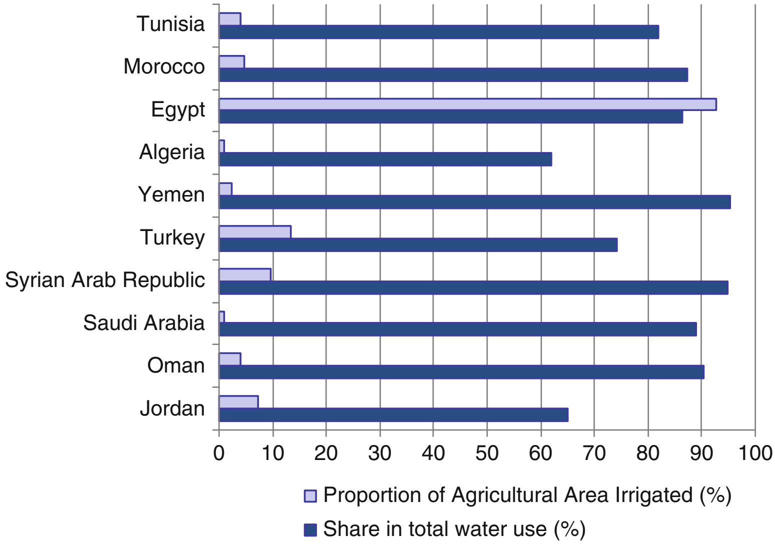


Fig. 2.4 Proportion of agricultural area irrigated and share of water use in selected countries of Western Asia and Northern Africa (Source: FAOSTAT)

land tenure and low levels of technology), and with uneven and unpredictable rainfall pattern. Climate related risks are also diverse (droughts, floods and crop and animal diseases) and often felt by individual households.

2.2.3 Scarce Water Resources and Limited Cropping Options

Most WANA countries are characterized by limited water resources and high water demands. The total annual Renewable Water Resources in the Arab world are about 460 km^3, or about 0.9 % of the global annual renewable water resources (Abou-Hadid 2009). Based on annual water resources per capita, all WANA countries are facing a vulnerable water situation, except Iraq and Turkey which has renewable water resources of 2,387 m^3 and 2,892 m^3 capita^{-1} year^{-1}, respectively. Lebanon (1,065 m^3 capita^{-1} year^{-1}) and Syria (822 m^3 capita^{-1} year^{-1}) are currently facing water stress (Mengu et al. 2008; FAO-AQUASTAT 2012). Jordan has world's lowest renewable water resources per capita, e.g., less than 150 m^3 year^{-1} (World Water Council 2002).

The agriculture sector uses over 80 % of the total water resources in many countries in the region (Fig. 2.4), but the water use efficiency of the agriculture sector is low (Montazar et al. 2007). The water availability and water use efficiency in the region is threatened by both environmental and socio-economic pressures.

Many negative impacts of climate variability on freshwater systems are observed in recent times. These impacts are mainly due to the increases in temperature, evaporation, and precipitation variability. Decreases in precipitation predicted by more than 90 % of climate models by the end of the twenty-first century for the region (IPCC 2007a) might aggravate the situation in the future.

The agricultural productivity of most crops exhibited noticeable increases during recent years. This increase was observed in limited areas due to irrigation and improving management practices. On the other hand, the majority of the countries in WANA have serious problems in increasing cropping options and crop diversification largely due to water scarcity; and to some extent agricultural diversification as a result of limited economic resources, low levels of technology, and environmental limitations (Abou-Hadid 2009). Problems related to infectious disease, conflicts and other societal factors also contribute to decrease the capacity to improve cropping options.

2.3 Increasing Climate Variability and Extreme Climate Events

The risks associated with extreme climate events are already posing number of threats to agriculture and livestock enterprise in the region. The International disaster database (EM-DAT) from Centre for Research on the Epidemiology of Disasters (CRED) indicates that the extreme climatological, hydrological and meteorological events (drought, extreme temperature, flood, mass movement wet, storm and wild fire) are increasing during the past six decades both in Western Asia and Northern Africa region (Fig. 2.5).

Studies using data from 75 weather stations of 15 countries in the region showed significant increases in number of warm days and decreases in number of cold days, and revealed ample evidence of hotspots of vulnerability to climatic variability and extreme climate events (Zhang et al. 2005; Celis et al. 2007; De Pauw 2008). The region also witnessed varying degree of extreme events such as droughts, floods, and sand and snow storms. For example, Cyclone Gonu in 2007 was the strongest tropical cyclone on record in the Arabian Sea. This event led to heavy rainfall near the eastern coastline, reaching up to 610 mm, which caused flooding and heavy damage. The cyclone caused about $4 billion in damage and nearly 50 deaths in Oman, where this was considered the nation's worst natural disaster (Azaz 2010). Extreme climate events often lead to large-scale mortality of livestock, loss of crops and degradation of natural resources.

Droughts are recurring climatic events, which often hit the region, bringing significant water shortages, economic losses and adverse social consequences (UN-ISDR 2010). Most of the countries in the region fall within the Hyper arid, arid and semi-arid zones receiving average rainfall of up to 400 mm with a winter growing season of 60–120 days. Drought is considered the major disaster occurring in the Arab region. The total people affected between 1970 and 2009, by drought

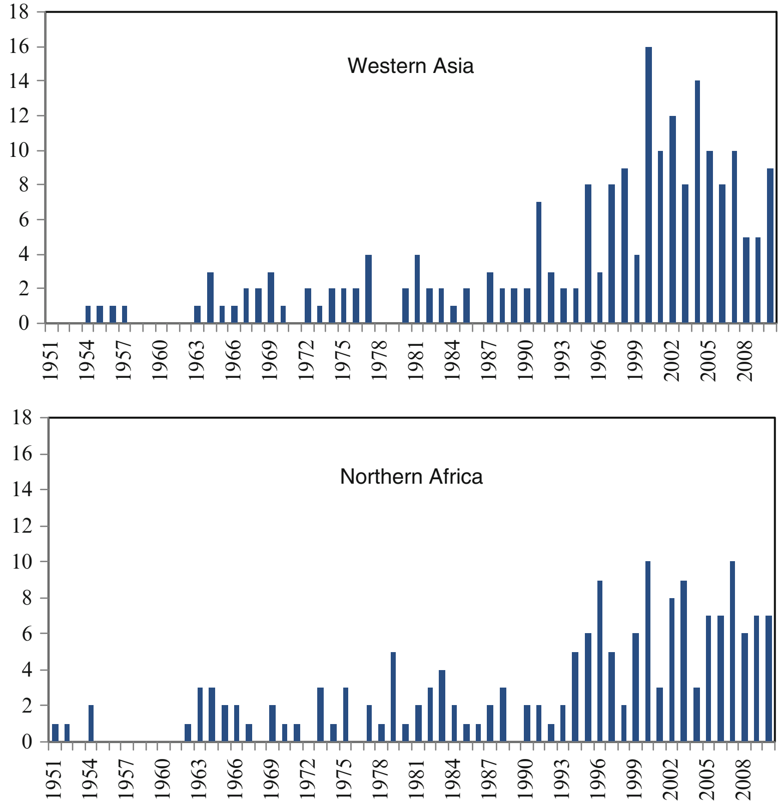


Fig. 2.5 Number of extreme climate related events occurred in a year in Western Asia and Northern Africa (1951–2010) (Source: EM-DAT)

were about 38.09 million (Abu Swaireh 2009). Drought causes serious water scarcity, crop failures, land degradation, depletion of forage, large-scale mortality of livestock, desperate sale of productive assets and out-migration.

On the other hand, extreme rainfall events are also causing widespread damage. For example, heavy rainfall in November 2001 in Algeria with wind speeds of more than 120 km per hour caused damage estimated at US$300 million. Similarly, Morocco experienced some of the worst flooding in its history in November 2002 with hundreds of hectares of agricultural land were damaged and hundreds of heads of livestock swept away. This wet, rainy year followed several dry years. The notable recent extreme climate events include excessive rain in Saudi Arabia (November 2009), floods in Jeddah, Saudi Arabia (January 2011) and Morocco (December 2010).

Recurrent natural disasters such as droughts, floods and outbreak of plant and animal pests such as desert locust, and trans-boundary animal diseases cause much suffering, deplete the natural resources base and damage the infrastructure.

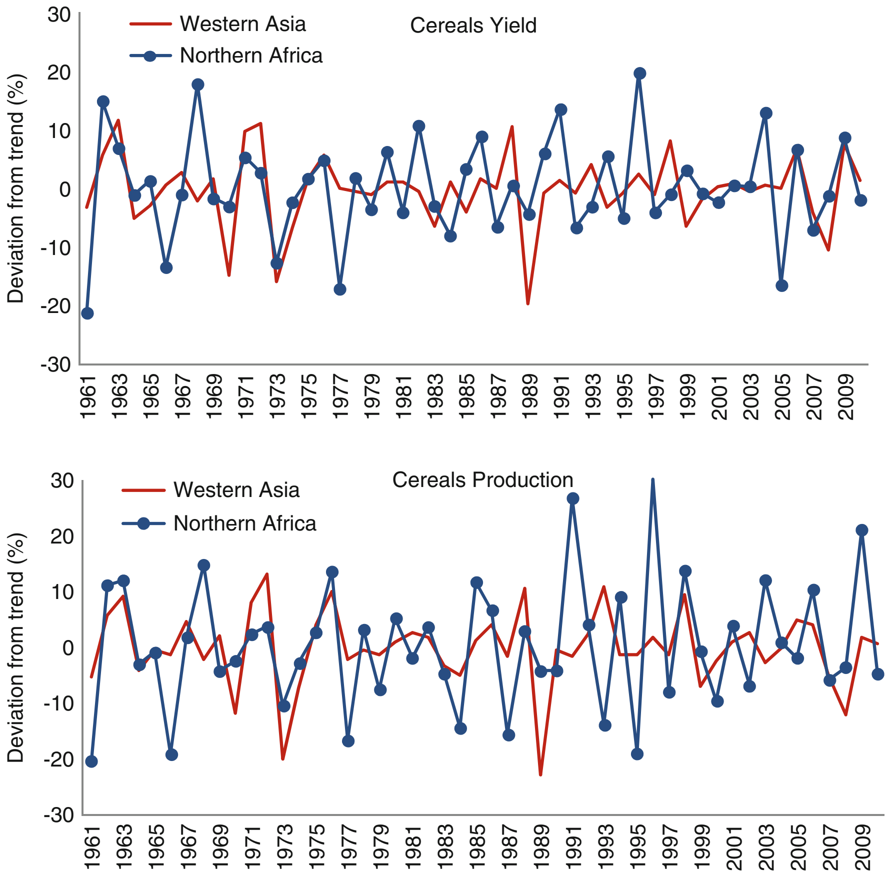


Fig. 2.6 Interannual variability (deviation (%) from trends) of cereal yields and production in Western Asia and Northern Africa (1961–2010) (Source: Detrended data from the original yield and production data from FAOSTAT)

These extremes cause large inter-annual crop yield and production variability. The deviation of cereal yield and production (de-trended using a low pass filter to remove technology trend) from the long-term (1961–2010) trend shows significant inter-annual variability in cereal yield and production (Fig. 2.6).

Impacts of climate variability and extreme climate events are large at country level. In Iran, losses inflicted by the 1998–1999 droughts on wheat production nationwide are estimated at about 1.05 million tons of irrigated wheat and 2.54 million tons of rainfed wheat (Amiri and Eslamian 2010). In the north-eastern Syria, for example, herders lost almost 85 % of their livestock due to repeated droughts since 2005. In the Mediterranean, a rise in sea surface temperature (SST) produced shifts in the distribution and abundance of fish species. Coral bleaching has been witnessed in the region and in 1998; El-Niño induced coral bleaching and mangrove loss in parts of the Gulf of Aden and Red Sea.

2.4 Implications of Climate Change on Natural Resources

Climate change projections show overall deterioration of climatic conditions. The range of temperature increase is projected to be 2–3 °C in much of region by 2050. Reduction of precipitation of 10–20 % (IPCC 2007a) is expected and runoff by 40 % in many areas (FAO 2010) is predicted.

Medany (2008) reported that the Arab region would face an increase of 2–5.5 °C surface temperature by the end of the twenty-first century and this increase would be coupled with a projected decrease in precipitation from 0 % to 20 %. These projected changes mean shorter winters, dryer and hotter summers, a higher rate of heat waves, a higher level of climate variability and more frequent extreme climate events.

The nature of the impacts of sea level rise will vary from place-to-place and is due to a variety of factors, depending on local conditions such as elevation of the land and geological land subsidence. River deltas and low-lying coastal urban areas have the highest exposure to sea level rise. A 1 m sea level rise would affect six million people in Egypt, where under this scenario 12–15 % of agricultural land in the Nile Delta region would be lost (Medany 2008). Adel El-Beltagy and Madkour (2012) reported that nearly 1,800 km of land on the north coast of Egypt and the Nile delta will be under seawater if there is a rise of 50 cm in the sea level, affecting 3.8 million people.

Poor land management and increasing pressure on the land in the WANA region are leading to widespread land degradation. Climate change can enhance land degradation risks in agricultural areas, soil erosion and contamination (Shahbazi and Rosa 2010). Climate change is expected to affect water resources and will exacerbate water scarcity. Likely decrease in surface water flows, reduced aquifer recharge and seawater intrusion and increased demand and conflicts are expected to increase.

Reduced precipitation and number of precipitation days in a year will place additional stress on the already scarce water resources in many countries, and shift arable land into more arid rangelands. Projected changes between now and 2100 show some consistent runoff patterns with some exceptions. For example, a long term run-off model applied to 30 basins in Iran showed that the temperature rise increases the runoff volume during winter and decreases it during spring as rising temperature melts snowfall (Amiri and Eslamian 2010). Runoff is projected to increase under different emission scenarios in Saudi Arabia (Al Zawad 2008).

Higher temperatures and reduced precipitation will increase the occurrence of droughts, an effect that is already a concern in North Africa. An additional 80–100 million people are estimated to be exposed to water stress by 2025, which is likely to result in increased pressure on ground water resources already being extracted in most areas beyond the aquifers' recharge potential (Verner and Biroscak 2010). Declines in water availability are therefore projected to affect some of the areas currently suitable for rain-fed crops.

Climate change will increase water use in key sectors in the future, especially in countries that have limited water resources and high population growth

(Medany 2008). Magano et al. (2007) point out that irrigation demands will increase due to accelerated demand for evaporation and supplementary irrigation under projected climate changes. For example, the total annual reference irrigation demands of Egypt are projected to increase by 6–16 % by the 2,100 s, due to the increase in reference evapotranspiration values (Medany 2008). Al Zawad (2008) used projections of soil water balance (precipitation – evaporation) using high resolution climate scenarios for Saudi Arabia and reported that soil water balance is expected to increase by 3.0 % (6.2 mm year^{-1}) under A2 scenario of IPCC, while it is expected to decrease by 16.4 % under B2 scenario.

Climate change will increase the interdependence of countries in respect to the access and use of genetic resources for food and agriculture. The impacts could result in further deforestation and range degradation, thus undermining forest and range ecosystem services that are essential to livelihoods and food security. Climate change is also predicted to increase the risk of wildfires, cause shifts in species' ranges and increase the risk of genetic erosion and species extinctions, and, through sea level rise, affect negatively mangroves and other coastal ecosystems.

In dryland agro-ecosystems with low inherent levels of biological productivity, coping with climate change presents significant problems. The effects will manifest not only through increased temperature per se but rather through changes in hydrological cycles characterized by increased droughts. Amiri and Eslamian (2010) described key impacts of climate change and climate variability on dryland agro-ecosystems. These include: reduction in crop yields and agricultural productivity, more erratic rainfall patterns and difficulties in determining the timings of sowing and harvesting, the selection of suitable crops with varying durations, reduced availability of water in already water scarce regions, complete loss of crops resulting from extreme events such as prolonged droughts, slow pervasive loss of soil fertility, lower livestock productivity from heat dissipation and reduced availability of feed and fodder, alternate pest and disease risks and increased vulnerability to pastoralists because of erratic rangeland production, through shifts in rainfall pattern and loss of vegetative cover.

2.5 Impact of Climate Change on Crops, Livestock and Fisheries

2.5.1 Crops and Cropping Systems

Climate change is likely to affect crop agriculture through changes in temperature, precipitation, extreme climate events, and raising sea levels. These may result in such adverse effects as further deterioration of water scarcity, land degradation, crop failures, loss of rangeland and other vegetation covers. Agricultural yields, especially in rainfed areas, are expected to fluctuate more widely, ultimately falling to a significantly lower long-term average (Verner and Biroscak 2010).

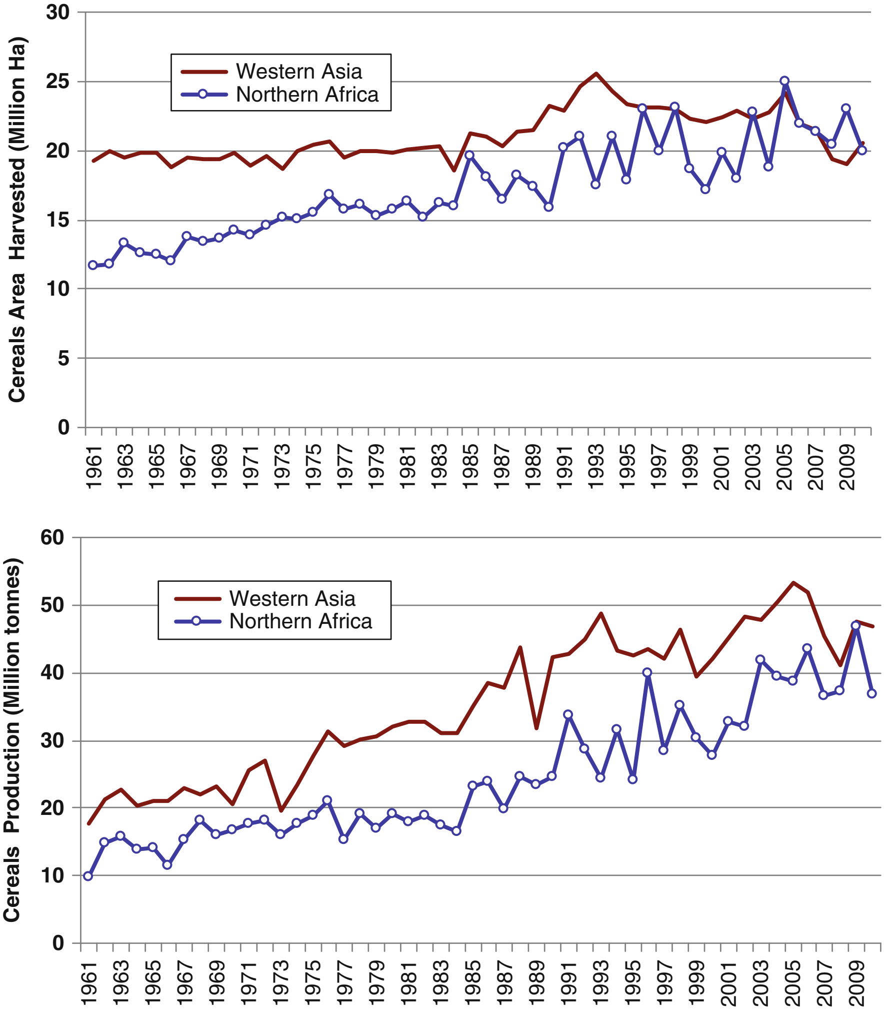


Fig. 2.7 Harvested area and production of cereals in Western Asia and Northern Africa (1961–2010) (Source: FAOSTAT)

The high level of production fluctuations on an inter-annual time-scale may reverse the long-term trend for cereals during the past six decades (Fig. 2.7). Reduced productivity induced by changes in climatic patterns is expected. Crop yields in the arid and semi-arid regions of Northern Africa and the Middle East are expected to decrease by as much as 10–30 % by the 2080 (IPCC 2001).

FAO (2009) and World Bank vulnerability study in Morocco reported 15 % yield loss by 2050 for rainfed wheat and barley in favourable ecological zones. The study further concluded that up to 30 % yield loss by 2050 for sugar beet in favourable zone and for barley in intermediate ecological zone could occur. A study by Eid and El-Marsafawy (2002) for Egypt projected a decrease in rice production by 11 % and soybean production by 28 %. Further, the results of the analysis showed a reduced production of maize and barley by 19 % and 20 %, respectively.

The predicted increases in temperature due to climate change may lead to spikelet sterility in rice, loss of pollen viability in maize, reversal of verbalization in wheat and reduced formation of tuber bulking in potato for the areas near the threshold (Amiri et al. 2009). Cakmak et al. (2010) reported that a 3–4 °C increase in temperature in Turkey will lead to a 25–35 % fall in crop yields, and mainly because of the close relationship between rainfall and crop yields. Similarly, Yano et al. (2007) reported that shortened growth duration with a higher temperature reduced the biomass accumulation of crops. Eid et al. (2007) assessed the economic impacts of climate change in Egypt using Ricardian approach and concluded that high temperatures will constrain agricultural production and warming may affect water resources and that would pose additional problem for agricultural production.

Regardless of CO_2-fertilization and increased temperature, the model projections showed increases in wheat yield by 16–36 % and decreases in maize yield by 25 %. Shahbazi and Rosa (2010) projected an average rainfed wheat yield reduction of 18 % and 24 % for 2025 and 2050, respectively. The yield reduction will be related to rainfall deficit and shortening of the wheat growth period (8–36 days). In addition to yield reduction, the cultivated land used for rainfed wheat production under climate change scenarios may be reduced by 15–40 %. In the coastal zones of Egypt, the key impacts on agriculture will in fact be indirect – mediated by salinization of prime agricultural land and reduced irrigation supplies from the river systems (Agrawala et al. 2004).

Breisinger et al. (2011) reported that the yield in all agroecological zones of Syria is projected to decrease over time due to climate change. The model based analysis results indicate that yields of rainfed crops in general are hit the hardest and a reduction of 39 % in rainfed wheat is predicted from 2010 to 2050 compared with yields in perfect mitigation. The projected yield reductions of irrigated wheat, maize and potatoes are −16.9 %, −4.8 % and −27.5 %, respectively. The yields for irrigated crops are projected to significantly fall, mainly due to higher temperature. Table 2.1 provides some examples from impact assessment studies conducted for some countries.

In particular, since more than 80 % of total agricultural land, and close to 100 % of pasture land, is rainfed, changes in precipitation will often shape both the direction and magnitude of the overall impacts. For the WANA region, the overall conclusion of most studies indicates a general trend of reduction for most major field crops. El-Shaer et al. (1997) concluded that climate change could do severe damage to agricultural productivity if no adaptation measures were taken.

By the year 2050, climate change could increase water needs by up to 16 % for summer crops but decrease them by up to 2 % for winter crops (Eid and El-Mowelhi 1998). Further understanding of links between increased frequency of extreme climate events and ecosystem disturbance (fires, pest outbreaks, etc.) is particularly important to quantify impacts (Hogg and Bernier 2005).

Table 2.1 Impact of climate change on yield of major crops in WANA region by 2050

Country	Crop	2050	Source
Egypt	Maize	−14 %	Hassanein and Medany (2007)
	Wheat	−4.8 to 17.2 %	Abou-Hadid (2009)
	Rice	−11 %	Eid and EL-Marsafawy (2002)
	Soybean	−28 %	Eid and EL-Marsafawy (2002)
Iran	Rainfed wheat	−24 %	Shahbazi and Rosa (2010)
Morocco	Rainfed wheat	−15 %	FAO (2009)
Syria	Rainfed wheat	−39.0 %	Breisinger et al. (2011)
	Irrigated wheat	−16.9 %	Breisinger et al. (2011)
	Irrigated maize	−4.8 %	Breisinger et al. (2011)
	Irrigated potato	−27.5 %	Breisinger et al. (2011)
Turkey[a]	Wheat	16–36 %	Yano et al. (2007)
	Maize	−25 to 2 %	Yano et al. (2007)

[a]This study covered the period of 2070–2079 relative to the baseline period of 1994–2003

Furthermore, CO_2 -temperature interactions are recognized as a key factor in determining plant damage from pests in future decades, though few quantitative analyses exist to date; CO_2 -precipitation interactions will likewise be important (Zvereva and Kozlov 2006). For instance, the impact of climate change on pests and diseases was studied for some important diseases at the national level, such as pear early blight, potato late blight (Fahim et al. 2007), and wheat rust diseases (Abo Elmaaty et al. 2007).

Dasgupta et al. (2009) analyzed the potential impacts of increasing frequencies and severities of storm surges based on the data of human population, socioeconomic conditions, the pattern of land use and coastal elevation data. The results indicated that storm surge intensification would cause additional GDP losses (above the current 1-in-100-year reference standard) in the Middle East and North Africa of $12.7 billion. The increase in impact on agricultural areas is significant for the region, mainly because Egyptian and Algerian cropland in surge zones would increase from the existing estimated 212 km^2 to approximately 900 km^2 with Sea Level Rise (SLR) and intensified storm surges.

2.5.2 Livestock and Rangelands

Native pasture or rangeland is still the most important livestock feed source for several countries in the region. The majority of drylands are occupied by rangelands with some 828 Mha in West Asia and North Africa (Thomas 2008). Overall degradation of rangelands is expected largely resulting from water stress and frequent and extreme climate events. In general, overall productivity decline in livestock nomadic system is stemming from erratic rainfall and moisture decline. The marginal areas are most vulnerable due to steady increase in livestock population in the WANA region (Fig. 2.8).

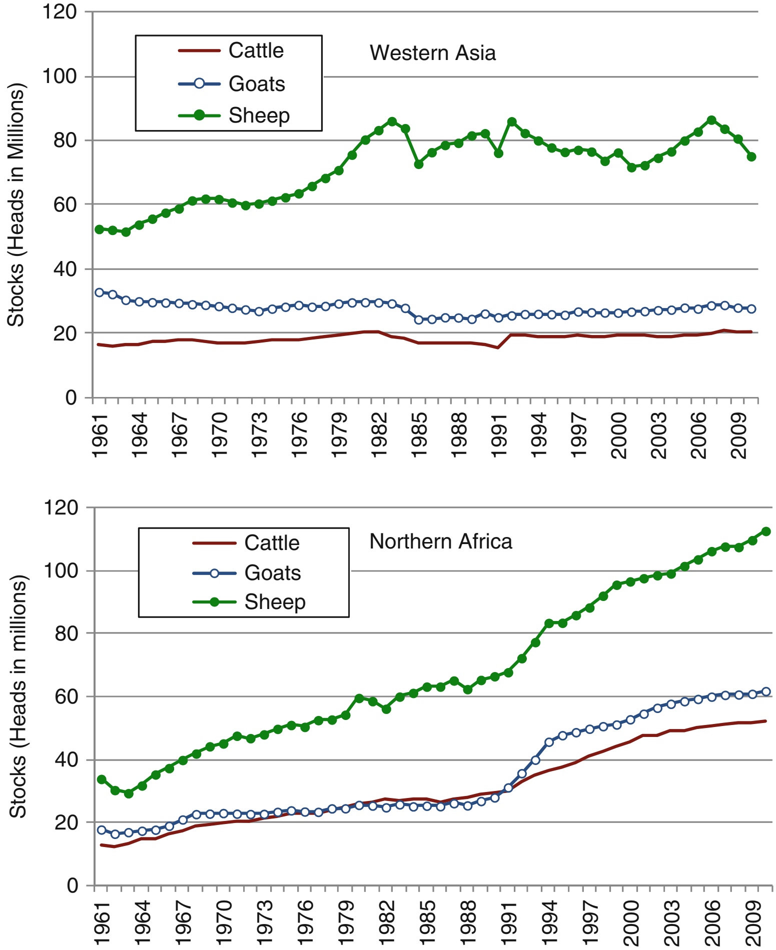


Fig. 2.8 Livestock population in Western Asia and Northern Africa (1961–2010) (Source: FAOSTAT)

Increased livestock pest and diseases and epidemic outbreaks are common. Disappearance of fragile ecosystems in desert and arid/semiarid areas is expected due to frequent drought and over grazing. Forced shifts in species habitats and increased risk of wildfire are expected to have negative effects on the health of herds. Increased probability of trans-boundary animal diseases may result impacts on prices, conflicts and food security.

For the drylands of West Asia and North Africa it is not the effects of increased temperature per se that are of major concern but rather the expected changes in precipitation, storm events, snow fall and snowmelt, evapotranspiration, run-off and soil moisture, that will disturb the hydrological cycles. These cycles are already stressed in the region by excessive water withdrawals (Thomas 2008).

2.5.3 Fisheries and Aquaculture

Fisheries and aquaculture dependent livelihoods are expected to be affected through alteration of marine and freshwater fish species. Adverse impacts on ecosystems (coral reefs, wetlands, rivers, lakes and estuaries) are largely due to acidification and changes in water temperatures. Increased risk of species invasions and spread of vector-borne diseases may cause further deterioration of the sub-sector. Principal impacts for aquaculture in Near East are from deteriorating water quality and extreme climatic events. This affect livelihoods as changes in distribution, species composition and habitats will require changes in fishing practices and aquaculture operations. Location of landing and other post-harvest activities are expected to face risks (FAO 2011).

Vulnerability of aquaculture is related to ownership, control of inputs, diseases and predators, and use of land and water. Capture fisheries depend on the productivity of natural ecosystems and are therefore vulnerable to climate change induced impacts affecting production in natural aquatic ecosystems (Abou-Hadid 2009). IPCC (2007b) reports a number of key negative impacts of climate change on aquaculture and freshwater fisheries, including (i) stress due to increased temperature and oxygen demand and increased acidity (lower pH); (ii) uncertain future water supply; (iii) extreme weather events; (iv) increased frequency of disease and toxic events; (v) sea level rise and conflict of interest with coastal protection needs; and (vi) uncertain future supply of fishmeal and oils from capture fisheries.

Temperature increases may cause seasonal increases in growth, but they may affect fish populations at the upper end of their thermal tolerance zone. Increasing temperature interacts with other changes, including declining pH and increasing nitrogen and ammonia (Morgan et al. 2001). Abou-Hadid (2009) in his review concluded that changes in primary production and transfer through the food chain will have a key impact on fisheries. Climate change has been implicated in mass mortalities of many aquatic species, including plants, fish, corals and mammals, but a lack of standardized epidemiological data and information on pathogens generally makes it difficult to attribute causes (Harvell et al. 1999).

The impact of climate change on the fisheries and aquaculture sectors will contribute to availability of aquatic foods through changes in habitats, stocks and species distribution and diversity; stability of supply by changes in seasonality, increased variance in ecosystem productivity and increased supply variability and risks; access to aquatic foods by changes in livelihoods and catching or farming opportunities, landing sites and fish prices; and utilization of aquatic products which will also be impacted. While the fisheries sector on the whole has historically been adaptable, increasingly over-exploited and poorly managed fisheries in the region may have reduced its adaptive capacity. Climate change can bring negative as well as positive impacts (potential increased flow of the Nile and increased primary productivity in the Arabian Sea) on the fisheries and aquaculture sectors and the capacity to adapt to both of these will determine how they develop.

2.6 Implications of Climate Change on Food Security

Climate change will affect the four dimensions of food security: availability, accessibility, food utilization, food system stability. The impacts of climate change on subsistence and smallholder agriculture, pastoralism and artisanal fisheries will include, (i) the direct impacts of changes in temperature, CO_2 and precipitation on yields of specific food and cash crops, productivity of livestock and fisheries systems, and animal health; (ii) other physical impacts of climate change important to smallholders are decreased water supply for irrigation, effects of sea level rise on coastal areas, increased frequency of tropical storms, and rangeland degradation. All these impacts mean reduced food availability and subsequent impact on food security.

According to FAO (2012) estimates, a total of 25 million people are under-nourished in WANA, with the Western Asia accounting for 21 million and Northern Africa 4 million. The proportion of undernourished in total population has declined from 3.8 % to 2.7 % in Northern Africa between 1990 and 2012, while in Western Africa this proportion has increased from 6.6 % to 10.1 % during the same period. Over the past two decades, the number of undernourished population has increased from 8 million to 21 million in Western Asia and decreased from 5 million to 4 million in Northern Africa (Fig. 2.9) (FAO 2012).

Expanded land use and improved technology are the important reasons contributing to increased production during the past decades, and the same rate of production increase might not be expected in the future due to multiple constraints. The FAO (2007b) expects growth rates in world agricultural production to decline from 2.2 % $year^{-1}$ during the past 30 years to 1.5 % $year^{-1}$ for next 20 years and 0.9 % $year^{-1}$ between 2030 and 2050. Climate change is likely to add to the existing threats

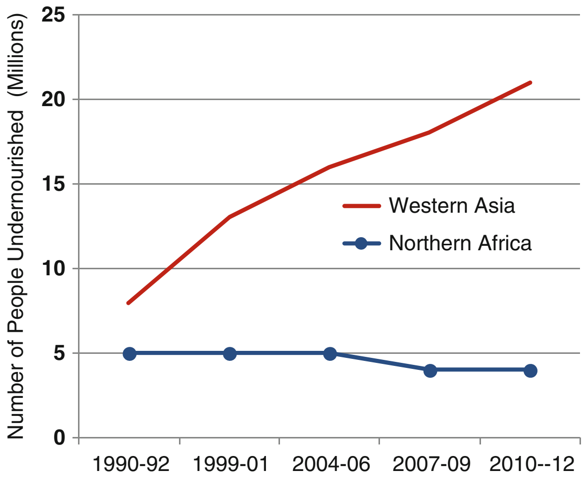


Fig. 2.9 Number of undernourished population in Western Asia and Northern Africa

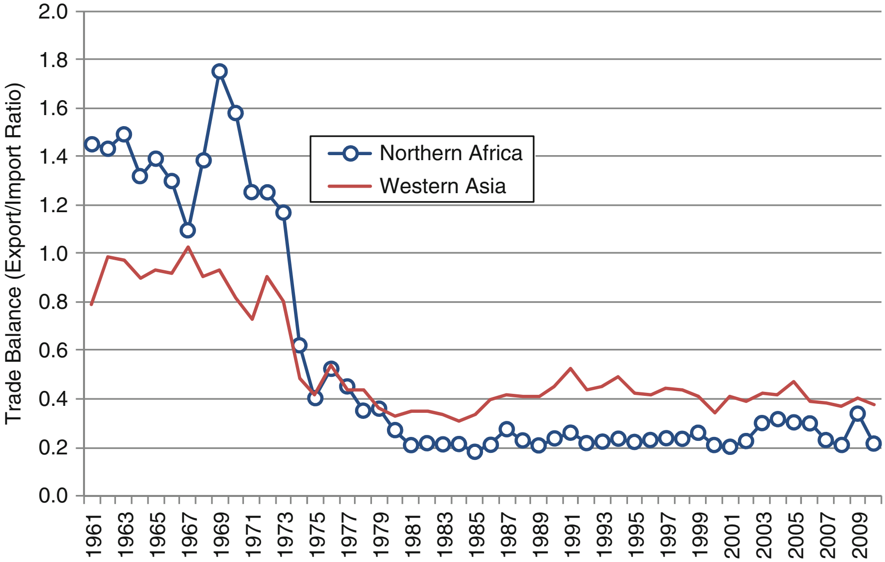


Fig. 2.10 Trade balance (Export/Import Ratio) calculated from export and import value of agriculture products in Western Asia and Northern Africa (1961–2010) (Source: FAOSTAT)

to food production and security from a number of converging trends such as high population growth rates, water scarcity, and land degradation.

As the WANA region is already the major grain/agriculture product importing region (Fig. 2.10) of the world and because of the predicted negative effects of climate changes on agricultural production, there is likely to be a worsening of regional food security. The food imports bill has rapidly increased over the past 30 years. For example, Libya's import bill increased from around US$ 100 million in 1970 to nearly 1,270 million in 2005. Cereals contribute the largest share of the bill with 35 % and wheat alone accounts for approximately 6 % of the total (FAO 2008).

Areas with high rates of population growth and natural resource degradation are likely to continue to have high rates of food insecurity. Cassman et al. (2003) emphasize that climate change will add to the dual challenge of meeting food demand while at the same time efforts of protecting natural resources.

2.7 Adaptation Priorities for the WANA Region

2.7.1 Enabling Policy Environment and Decision Support Systems

An important component of the work related to climate change is the support to policy planning of adaptation strategies. There is an urgent need to integrate climate change concerns into the establishment of unified national frameworks and the enhancement of cross-sectoral coordination. Medany and Attaher (2007) pointed out that designing an adaptation strategy for the agriculture sector should consider the simple and low cost adaptation measures that may be inspired from traditional knowledge to meet local conditions and to be compatible with sustainable development requirements. Addressing climate change adaptation in development means strengthening these strategies and increasing their efficiency and durability.

The region suffers from multiple challenges in addition to limited availability of natural resources, a situation expected to be exacerbated by climate change impacts. Thus, these challenges need to be tackled at multi-dimensional levels: micro, meso, and macro levels and adaptation strategies need to be developed in participation with stakeholders. Financial limitations to meet necessary investments at local level for addressing climate change agendas pose an important challenge. Global financial mechanisms for climate change adaptation which may provide additional resources need to be tapped, but eligibility criteria and complex mechanisms may limit the urgent investment priorities.

In addition to strengthening enabling policies, the decision support systems need to be enhanced at institutional level. Climate monitoring, early warning, weather index based risk insurance are some of the examples of decision support systems. It is a high priority for the region to install monitoring and early warning systems for impending disasters and to develop disaster preparedness plans for meeting any threat to food supplies and agriculture output. It is also important to enhance capacity for prevention of disasters and reduction of its impacts including trans-boundary plant and animal diseases. Enhancing institutional and technical capacities in monitoring and assessment of climate change impacts is another area of urgent action. Regional cooperation in data collection, exchange of information, and monitoring and assessment of impacts of climate change are the other priorities.

2.7.2 Crops and Cropping Systems

For cropping systems there are many potential ways to alter management to deal with projected climatic changes (Challinor et al. 2007). Altering inputs such as varieties, species, fertilizer, and amounts and timing of irrigation and other water management practices to prevent water logging, erosion and nutrient leaching in areas with excessive rainfall, altering the timing or location of cropping activities, diversifying income by integrating farming activities such as livestock raising, improving the effectiveness of pest, disease and weed management practices; and using seasonal climate forecasting to reduce production risk are some of the potential adaptation options to better manage crops and cropping systems.

These adaptation activities such as developing infrastructure or building the capacity to adapt in the broader user community and institutions are also the priority. Designing and applying national adaptation strategies for the agriculture sector faces multiple barriers. Including limitations of the existing scientific base, policy perceptions under current conditions and pressures, poor adaptive capacity of rural communities, lack of financial support, and the absence of an appropriate institutional framework should explicitly considered for successful and resilient adaptation.

Medany and Attaher (2007) recommended improving the scientific capacity, focusing on a bottom-up approach of planning and implementing adaptation strategies, developing community-based measures by stakeholders' involvement in adaptation planning, increasing the public awareness and improving adaptive capacity of the community to advance adaptation in the region. Attaher et al. (2009) studied the farmers' perception for adaptation planning in Nile Delta region, and concluded that farmers have a real initiative to act positively to reduce the impact of climate change. And, the study further concluded that although community engagement in adaptation planning is very important, the scientific evaluation should be taken into account to set a more practical adaptation measures.

2.7.3 Livestock and Rangelands

Reversing unsustainable forest and range management practices (e.g. excessive livestock numbers, overgrazing, illegal logging, over-harvesting of fuel wood and other products of rangelands) and applying best practices are fundamental for restoring ecosystem health and resilience. A review of the National Communications (NCs) submitted to the United Nations Framework Convention on Climate Change (UNFCCC) by the countries of the region provides a good indication of the types of adaptation measures the countries identify as most important for livestock sector.

Actions identified in the rangelands include restoration of degraded forests, afforestation and reforestation, use of drought tolerate species and varieties, watershed management, measures to reduce soil erosion and salinization, fire management, mangrove restoration and rangeland rehabilitation. Community-based management of natural resources and policy reform to increase peoples' access to grazing lands is important. Many countries listed improved forest/range monitoring, awareness raising, education, research, and institutional and policy reform as needed actions.

Integrating crop-livestock, herd diversity by using multi-species and multi-breed, herd splitting into smaller manageable groups and mobility are some of the commonly practiced adaptation strategies. Production and marketing strategies involve a range of husbandry adjustments to counteract heat stress that may suppress feed intake, production, fertility, and survival rates (Pilling and Hoffmann 2011). Livestock insurance scheme based on index which compensates clients for the loss of animals or reduced productivity because of drought has the potential to reduce the risks.

Unlike traditional insurance a payout is based on an external indicator which triggers a payment to all insured clients within a geographically defined space (Ouma et al. 2011). Adapted livestock breeds can survive, resist or tolerate diseases, drought, water scarcity and stresses from strong heat and solar radiation. They are also integral parts of their environment that help sustain biodiversity. Forecasting emerging infectious animal disease and early warning systems are crucial components for preparedness to extreme climate events.

2.7.4 Fisheries and Aquaculture

It has been increasingly recognized that reducing the vulnerability of fishing communities as a whole can help address poverty and resource degradation, and enhance adaptive capacity to a range of shocks, including those resulting from climate variability and extreme events. FAO (2011) proposes that options to increase resilience and adaptability should include the adoption, as standard practice, of adaptive and precautionary management within an ecosystem approach to fisheries (EAF) and an ecosystem approach to aquaculture (EAA).

Adaptation strategies at all levels (community, national and regional) will require and benefit from stronger capacity building, through awareness raising on climate change impacts on fisheries and aquaculture. The operational capacity (finance and human) is currently moderate to low, posing an important challenge that must be considered when designing adaptation strategies in fisheries sector.

2.8 Conclusions

The foregoing review clearly brings the fact that climate change will have far-reaching effects on the already stressed natural resources in all Western Asia and Northern Africa countries. Though the impacts of climate change on agriculture and food security vary considerably from location to location, the overall impacts are negative. Reduction in rainfall by up to 29 % and temperature increase by up to 4 °C will significantly reduce water available for food production. Degradation of forests, rangelands and soil will negatively impact food and feed production and biodiversity conservation.

Extreme climate events are evident (droughts, floods, sand storms). Increasing incidence of drought, new diseases and pests and scarcity of natural resources are the dominant factors affecting crop production. Disappearance of palatable rangeland species due to severe degradation of grazing lands, water shortage and recurrent crop losses due to droughts affects livestock dependent livelihood activities.

Food security will be threatened in all of it's four dimensions. Climate change impacts are highly location specific and thus future detailed assessment of implications on agriculture and food security should explicitly consider vulnerability profiles and adaptive capacities of most vulnerable communities. Several model based analysis predicted likely reduction in crop yields, rangeland degradation, livestock mortality and reduced fish production. But, scenario-based analytical approaches should be complemented with bottom up livelihood based approaches to define location specific adaptation strategies. In addition, policy relevant impact assessment considering medium term (10 years) time frame should be considered.

Appropriate policies and institutions are needed for assisting farmers and rural communities to manage droughts in dry areas. Policies need to provide strategic directions on agriculture trade (import and export) and supportive conditions for smallholder farmers and pastoralists through guaranteeing access to grazing land and water, and facilitating the provision of appropriate services and infrastructure.

References

Abo Elmaaty SM, Medany MA, ELHefnawy NN (2007) Influence of climate change on some rust diseases of wheat in Egypt. In: Procedures of the international conference on “climate change and their impacts on costal zones and River Deltas”, Alexandria, 23–25 Apr 2007

Abou-Hadid AF (2006) Assessment of impacts, adaptation and vulnerability to climate change in North Africa: food production and water resources. Assessments of Impacts and Adaptations to Climate Change, Washington, DC

Abou-Hadid AF (2009) Impact of climate change: vulnerability and adaptation (food production). In: Tolba MK, Saab NW (eds) Arab environment – climate change, impact of climate change on Arab countries. Arab Forum for Environment and Development (AFED) Published with Technical Publications and Environment & Development Magazine, Beirut

Abu Swaireh L (2009) Disaster risk reduction global and regional context, regional workshop on climate change and disaster risk reduction in the Arab Region “Challenges and Future Actions”. Organized by ISDR, WB, GFDRR, LAS, AASTM, Cairo, 21–23 Nov 2009

Agrawala S, Moehner A, El Raey M, Conway D, van Aalst M, Hagenstad M, Smith J (2004) Development and climate change in Egypt: focus on coastal resources and the Nile. Organisation for Economic Co-operation and Development, Syria, 68 p

Al Zawad FM (2008) Impacts of climate change on water resources in Saudi Arabia. In: The 3rd international conference on water resources and arid environment (2008) and the 1st Arab Water Forum, Riyadh, Saudi Arabia, 16–19 Nov 2008

Amiri MJ, Eslamian SS (2010) Investigation of climate change in Iran. J Environ Sci Tech 3:208–216

Amiri MJ, Ebrahimizadeh S, Amiri MR, Niakousari M (2009) Comparative evaluation of physico-chemical properties of corn flours through different water qualities and irrigation methods. J Appl Sci 9:938–943

Attaher SM, Medany MA, Abou-Hadid AF (2009) Possible adaptation measures of agriculture sector in the Nile Delta region, J Adv Sci Res, Special volume of EMS8/ECAC7 conference, 29 Sept–3 Oct 2008

Azaz LK (2010) Using remote sensing and GIS for damage assessment after flooding, the case of Muscat, Oman after Gonu tropical cyclone 2007: urban planning perspective. In: REAL CORP 2010 Proceedings/Tagungsband, Vienna, 18–20 May 2010

Breisinger C, Zhu T, Al-Riffai P, Nelson G, Robertson R, Funes J, Verner D (2011) Global and local economic impacts of climate change in Syria and options for adaptation. IFPRI Discussion Paper 01091, Development Strategy and Governance Division, International Food Policy Research Institute, Syria

Cakmak E, Dudu H, Saracoglu S (2010) Climate change and agriculture in Turkey. A CGE modelling approach. Econ Busin Fin 25:9–33

Cassman KG, Dobermann A, Walters DT, Yang H (2003) Meeting cereal demand while protecting natural resources and improving environmental quality. Annu Rev Environ Resour 28:315–358

Celis D et al (2007) Hot spots of land cover change and drought vulnerability. ICARDA, Aleppo, p 69

Challinor AJ, Wheeler TR, Craufurd PQ, Ferro CAT, Stephenson DB (2007) Adaptation of crops to climate change through genotypic responses to mean and extreme temperatures. Agr Ecosyst Environ 119:190–204

Cooper PJM, Harris HC, Goebel W (1989) Climate variability and food production in west Asia and North Africa. In: International symposium on climate variability and food security in developing countries, New Delhi, 5–9 Feb 1987. IRRI Los Banes, Laguna

Dasgupta S, Laplante B, Murray S, Wheeler D (2009) Sea-level rise and storm surges: a comparative analysis of impacts in developing countries. World Bank, Policy Research working paper 4901

Dixon J, Gulliver A, Gibbon D (2001) Farming systems and poverty – improving farmer's livelihoods in a changing world. Food and Agriculture Organization of the United Nations/The World Bank, Rome/Washington, DC

Eid HM, El-Marsafawy SM (2002) Adaptation to climate change in Egyptian agriculture and water resources. In: 3rd international symposium on sustainable Agro-environmental systems: new technologies and applications (AGRON 2002), Cairo, 26–29 Oct 2002

Eid HM, El-Mowelhi NM (1998) Impact of climate change on field crops and water needs in Egypt. In: African international environmental conference, Cairo, Oct 1998

Eid HM, El-Marsafawy SM, Ouda SA (2007) Assessing the economic impacts of climate change on agriculture in Egypt – a Ricardian approach, policy research working paper 4293. The World Bank Development Research Group, Sustainable Rural and Urban Development Team, Washington, DC

El-Beltagy A, Madkour M (2012) Impact of climate change on arid lands agriculture. Agr Food Sec 1:3

El-Shaer MH, Rosenzweig C, Iglesias A, Eid HM, Hellil D (1997) Impact of climate change on possible scenarios for Egyptian agriculture in the future. Mitig Adap Strat Glob Chang 1:233–250

Fahim MM, Aly HY, Medany MA, Fahim MM (2007) Effect of some climatic factors and the climate changes on the epidemiology of potato late blight disease in Egypt. In: Proceedings. of the international conference on "climate change and their impacts on costal zones and River Deltas", Alexandria, 23–25 Apr 2007

FAO (2007a) The State of Food and Agriculture (SOFA), paying farmers for environmental services. Food and Agriculture Organization of the United Nations, Rome

FAO (2007b) World agriculture: towards 2030/2050. Prospects for food, nutrition, agriculture and major commodity groups. Global Perspective Studies Unit Food and Agriculture Organization of the United Nations Rome, June 2006. Interim Report, p 71

FAO (2008) High-level conference on: water for agriculture and energy in Africa: the challenges of climate change, Sirte, Libyan Arab Jamahiriya, 15–17 Dec 2008. National Investment Brief, Libyan Arab Jamahiriya

FAO (2009) World Bank – Morocco study on the impact of climate change on agricultural yields in Morocco. Food and Agriculture Organization of the United Nations, Rome

FAO (2010) Regional priority framework for the Near East. Food and Agriculture Organization of the United Nations, Rome

FAO (2011) Adapting to climate change: the ecosystem approach to fisheries and aquaculture in the near east and North Africa region. In: Proceedings of the FAO/WorldFish workshop, Abbassa, Egypt, Nov 2009. Food and Agriculture Organization of the United Nations, Rome

FAO (2012) The state of food insecurity in the world 2012. Economic growth is necessary but not sufficient to accelerate reduction of hunger and malnutrition. Food and Agriculture Organization of the United Nations, Rome

FAO-AQUASTAT (2012) FAO's global information system on water and agriculture, Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/nr/water/aquastat/main/index.stm. Accessed 15 Sep 2012

FAOSTAT (2012) The FAO statistical database – an on-line multilingual database, Food and Agriculture Organization of the United Nations, Rome. http://faostat.fao.org/site/291/default.aspx. Accessed 15 Sep 2012

Harvell CD, Kim K, Burkholder JM, Colwell RR, Epstein PR, Grimes DJ, Hofmann EE, Lipp EK, Osterhaus ADME, Overstreet RM, Porter JW, Smith GW, Vasta GR (1999) Emerging marine diseases, climate links and anthropogenic factors. Science 285:1505–1510

Hassanein MK, Medany MA (2007) The impact of climate change on production of maize. In: Zea Mays L (ed) International conference on climatic changes and their impacts on coastal zones and river deltas: vulnerability, mitigation and adaptation, Alexandria, 23–25 Apr 2007, pp 271–288
Hogg EH, Bernier PY (2005) Climate change impacts on drought-prone forests in Western Canada. Forest Chron 81:675–682
IPCC (2001) In: Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson CA (eds) Climate change 2001: the scientific basis. Contribution of working group I to the third assessment report of the intergovernmental panel on climate change, Cambridge University Press, Cambridge,UK/New York, p 881
IPCC (2007a) Climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds). Cambridge University Press, Cambridge, UK
IPCC (2007b) Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds). Cambridge University Press, Cambridge, UK/New York
Magano T, Hoshikawa K, Donma S, Kume T, Onder S, Ozekici B, Kanber R, Watanabe T (2007) Assessing adaptive capacity of large irrigation districts towards climate change and social change with irrigation management performance model. In: Lamaddalena N, Bogliotti C, Todorovic M, Scardigno A (eds) Water saving in Mediterranean agriculture and future research needs. Proceedings of the international conference of WASAMED project, Valenzano, 14–17 Feb 2007. Option Mediterranean Series, CIHAM, B n. 56, pp 293–302
Medany M (2008) Impact of climate change on Arab countries. In: Tolba MK, Saab NW (eds) Arab environment – future challenges. Report of the Arab Forum for Environment and Development (AFED). Published with Technical Publications and Environment & Development Magazine, Beirut
Medany MA, Attaher SM (2007) Climate change and irrigation in Mediterranean region. In: Proceedings of the international conference on "climate change and their impacts on costal zones and River Deltas", Alexandria, 23–25 Apr 2007
Mengu GP, Sensoy S, Akkuzu E (2008) Effects of global climate change on agriculture and water resources. In: BALWOIS 2008, Ohrid, 27–31 May 2008
Montazar A, Nazari Far MH, Mardi E (2007) Optimal water productivity of irrigation systems in a semi-arid region. In: Lamaddalena N, Bogliotti C, Todorovic M, Scardigno A (eds) Water saving in Mediterranean agriculture and future research needs. Proceedings of the International Conference of WASAMED project, Valenzano, 14–17 Feb 2007. Option Mediterranean Series, CIHAM, B n. 56(3), pp 87–98
Morgan I, McDonald DG, Wood CM (2001) The cost of living for freshwater fish in a warmer, more polluted world. Glob Chang Biol 7:345–355
Ouma R et al (2011) Review of pastoral development – some innovations in risk management. Exp Agr 47:375–393
Pauw D (2008) Hot spots of vulnerability to climate change. ICARDA Caravan 25:43–44
Pilling P, Hoffmann I (2011) Climate change and animal genetic resources for food and agriculture: state of knowledge, risks and opportunities. Background study paper no. 53. FAO, Rome
Shahbazi F, Rosa D (2010) Towards a new agriculture for the climate change era in West Asia, Iran. In: Simard SW, Austin ME (eds) Climate change and variability. Sciyo, Janeza Trdine 9, 51000 Rijeka, p 486
Thomas RJ (2008) Opportunities to reduce the vulnerability of dryland farmers in central and west Asia and north Africa to climate change. Agr Ecosyst Env 126:36–45
Tolba MK, Saab NW (2009) Arab environment – future challenges. Report of the Arab Forum for Environment and Development (AFED). Published with Technical Publications and Environment & Development Magazine, Beirut
UN-ISDR (2010) Drought vulnerability in the Arab region: case study–Drought in Syria, 10 years of scarce water (2000–2010) United Nations Strategy for Disaster Risk Reduction (UNISDR)–Regional Office for Arab States, Cairo, Egypt and Arab Center for Studies of Arid Zones and Dry Lands (ACSAD). Damascus, Syria, p 74

Verner D, Biroscak J (2010) Climate change and the middle East. Development horizons, The World Bank Group News Letter. First/Second Quarter 2010

World Water Council (2002) In: Abu-Zeid M, Hamdy A (eds) Water vision for the twenty-first century in the Arab World. World Water Council. Arab Countries Vision Consultations. Marselle, 4–5 Aug 1999

Yano T, Aydin M, Haraguchi T (2007) Impact of climate change on irrigated demand and crop growth in a Mediterranean environment of Turkey. Sensors 7:2297–2315

Zhang X et al (2005) Trends in Middle East climate extreme indices from 1950 to 2003. J Geophys Res 110, D22104

Zvereva EL, Kozlov MV (2006) Consequences of simultaneous elevation of carbon dioxide and temperature for plant-herbivore interactions: a meta analysis. Glob Chang Biol 12:27–41

Part II
Climate Change and Environment

Chapter 3
Climate Change and Soil Quality in the WANA Region

Rattan Lal

Abstract The term soil quality refers to capacity of the soil to render ecosystem services of interest to humans, and relevant to other ecological functions. Soil quality in the West Asia North Africa Region (WANA) depends on a range of properties and processes. Principal soil properties include physical (i.e., texture, structure, available water holding capacity or AWC, water infiltration rate, bulk density, soil strength, effective rooting depth), chemical (i.e., pH, cation exchange capacity or CEC, nature of exchangeable cations, intensity and capacity of plant available nutrients, electrical conductance and the concentration of soluble salts), and biological (i.e., soil organic carbon concentration and stock, microbial biomass carbon, activity and species diversity of micro and macro flora and fauna). Among these, principal determinants of soil quality for agronomic land use are bulk density, aggregation, AWC, water infiltration rate, pH, CEC, electrical conductance, nutrient reserves, soil organic carbon, and microbial biomass C. Important processes affecting soil quality are: soil erosion, decomposition of soil organic matter, soil compaction, salinization and acidification, etc. These properties and processes can be strongly affected by climate change. The latter may include increase in temperature and decrease in the effective precipitation. These climatic changes can exacerbate risks of decline in aggregation and soil structure, increase in accelerated soil erosion by water and wind, and increase in the rate of mineralization of soil organic matter content, and secondary salinization. With increase in evaporation, the frequency and intensity of droughts may increase which may reduce the use efficiencies of water and nutrients, and also adversely affect agronomic yield and net primary production. With increase in population, and the demands for food and other basic necessities, adaptation to climate change is an important strategy. The goal of sustainable soil

R. Lal (✉)
Carbon Management and Sequestration Center, School of Environment and Natural Resources, The Ohio State University, 2021 Coffey Road, 422B Kottman Hall, Columbus, OH 43210, USA
e-mail: lal.1@osu.edu

M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_3,

management is to alter cropping/farming systems, crops and varieties, and timings of farming operations (i.e., planting, harvesting). Adaptations may also involve adoption of new and innovative irrigation methods such as micro-irrigation (drip sub-irrigation), shift to integrated nutrient management involving use of organic fertilizers (i.e., compost, manure, biological N fixation), and conversion to conservation tillage based on mulch farming and complex rotations. Improved grazing and low stocking rate, and integration of pastures with forage trees (agroforestry) is another useful option. While some scientific information on the recommended management practices is available for the WANA region, appropriate policies must be implemented to promote the adoption of new and innovative technologies to enhance and sustain soil quality in a harsh and changing climate.

Keywords Global warming • Principal soils of WANA region • Climate change adaptation • Climate change mitigation • Soil resilience • Carbon sequestration

3.1 Introduction

The problem of hunger and malnutrition persists in the West Asia North Africa (WANA) region inspite of numerous strategies being proposed. Child malnutrition (percentage of children under 5 year who are underweight) is estimated at 18.6 in Algeria, 14.5 in Egypt, 5.3 in Libya, 32.2 in Mauritania, 10.8 in Morocco, and 4.6 in Tunisia (Atinmo et al. 2009). The total number of under nourished population in the WANA region increased up to 132 million who are in the poverty category (Breisinger et al. 2010). Economic decline, poverty and human insecurity are interlinked to political stability, population growth and environmental degradation (Joekes 1994). In addition, the grain reserves have declined in the WANA region because of global income growth and use for biofuel production (Wright and Cafiero 2011). While food security is closely linked with the economic development (Breisinger et al. 2010), the importance of agricultural improvement and especially that of soil and water conservation and management cannot be overemphasized. Among numerous issues with regards to soil quality which require an immediate attention, the impact of projected climate change cannot be ignored. The strategy is to promote adoption of improved agriculture to reduce poverty and hunger (Wiggins and Leturque 2010).

There is a strong link between soil quality, agronomic productivity, and economic development. The Law of Marginality (Lal 2009) states that “Marginal soils, cultivated with marginal input produce marginal yields and support marginal living”. Furthermore, the biophysical process of soil degradation is driven by social, economic and political factors. The fact remains that when people are poverty stricken and desperate, they pass on their sufferings to the land (Lal 2009). Therefore, a prudent strategy is to restore soil quality for making agriculture as an integral component of increasing the economic growth while also advancing food security. Thus, the objective of this chapter is to describe the possible impact of the projected climate change in the WANA region on soil quality and the food security.

3.2 Soil Quality

Soil quality, the capacity of a soil to produce goods and services of economic and ecologic significance, has been of interest to humanity ever since the dawn of agriculture. For example, Ibn-Al-Awan, a Moorish Philosopher of the twelfth century, wrote about the importance of soil quality in a book "Kitab-Al-Felaha": "The first step in the science of agriculture is the recognition of soils and of how to distinguish that which is of good quality and that which is of inferior quality…One must take into consideration depth of the soil, for it often happens that its surface may be black". Indeed, soil quality has four distinct but inter-related components (Fig. 3.1). Soil physical quality comprises of physical attributes (texture, structure, biopores, soil temperature, erodibility, available water holding capacity or AWC) and processes (aggregation, infiltration, erosion, runoff etc.), soil chemical properties (pH, cation exchange capacity or CEC, base saturation, nutrient contents) and processes (leaching, volatilization, salinization, mineralization etc.), soil biological properties (microbial biomass carbon or MBC, biodiversity etc.) and processes (bioturbation, decomposition, nitrification, methanogenesis etc.), and ecological properties (water quality, net primary production or NPP, carbon pool etc.) and processes (sedimentation, non-point source pollution etc.), and the interaction among these components. Soil organic matter (SOM) or humus is an important component and a key determinant of soil quality.

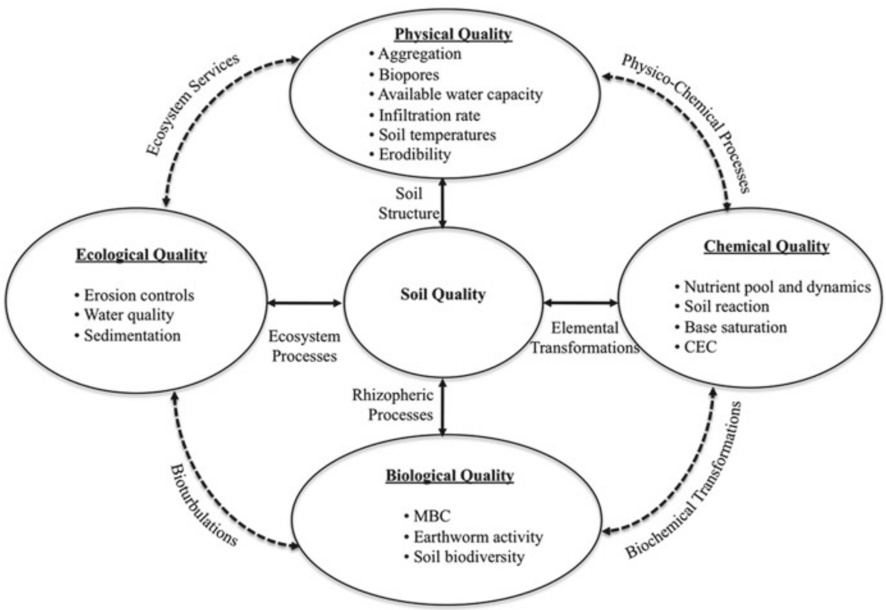


Fig. 3.1 Inter-connected components of soil quality

3.3 Global Warming

Acceleration of the natural greenhouse effect by anthropogenic activities (i.e., fossil fuel combustion, deforestation, cement production) causes global warming leading to a rate of increase in temperature of >0.1 % °C/decade, and the ecosystems are unable to adjust. Some reports indicate that human-induced global warming is already evident in the WANA region (Sowers and Weinthal 2010). The projected global warming can impact soil quality through alterations of numerous interacting factors (Fig. 3.2). Quantity and quality of SOM contents are the key determinants of soil quality, and the SOM and its attributes are strongly affected by mean annual temperature (MAT) and the mean annual precipitation (MAP) (Jenny 1941, 1980). Therefore, alterations in MAT and MAP because of the projected change in climate of the WANA region can alter quantity and quality of SOM. Further, the SOM is derived from the residues of crops and pastures. The biomass or NPP is also determined by the CO_2 fertilization effect (Grünzweig and Körner 2000). The magnitude of any CO_2 fertilization effect is governed by an adequate supply of essential plant nutrients (i.e., N) and water. Alterations in pedological and edaphological characteristics can strongly impact SOM concentration and its turnover rate, aggregation and aggregate stability, erodibility and the erosion hazard, frequency and intensity of drought, species composition and NPP, relative

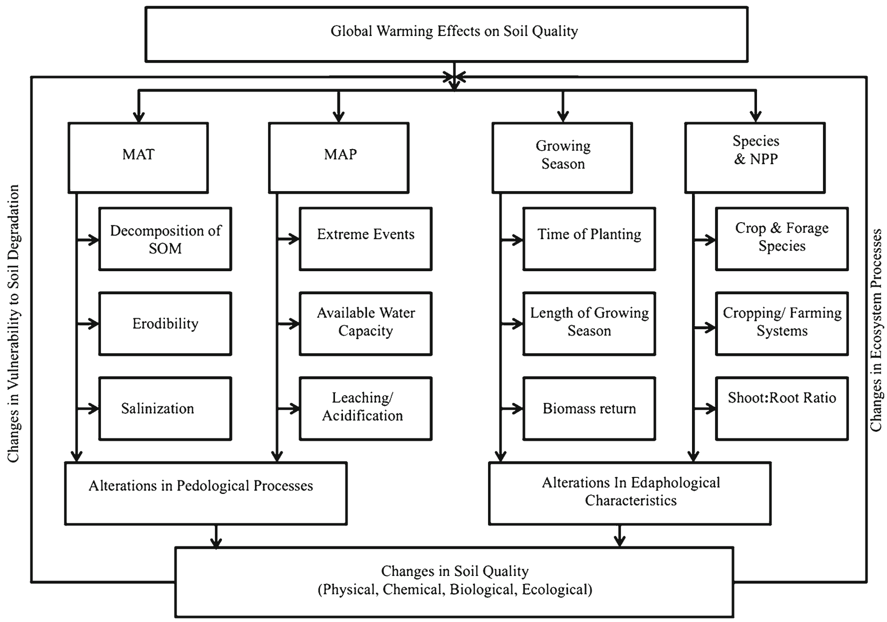


Fig. 3.2 Global warming effects on soil quality. Effects of anthropogenic global warming (accelerated greenhouse effect) on soil quality (*MAT* mean annual temperature, *MAP* mean annual precipitation)

Table 3.1 Principal soils of WANA (USDA-NRCS 2006, Courtsey Dr. Paul Reich)

Order	Area (10^6 ha)	% of total
Entisols	657	43.4
Aridisols	409	27.0
Inceptisols	79	5.2
Alfisols	58	3.8
Vertisols	65	4.3
Mollisols	31	2.1
Oxisols	16	1.1
Ultisols	14	0.9
Andisols	1	0.06
Shifting sands	149	9.9
Rock	28	1.8
Salt	7	0.5

appropriation of NPP into shoot and root and the proportion of fine versus coarse roots which affect the turnover rate, frequency of extreme events which can alter soil's susceptibility to erosion, salinization and other degradation processes.

3.4 Principal Soils of the WANA Region

The climate-induced changes in soil quality depend on soil type, the parent material, the profile attributes, and their interaction with the environment. The data in Table 3.1 show that principal soils of the WANA region are young and relatively less weathered, and comprising of Entisols (43.4 %), Aridisols (27.0 %) and Inceptisols (5.2 %). Relatively fertile soils (fine texture, high SOM concentration etc.) are scarce, and include Vertisols (4.3 %), Alfisols (3.8 %), Mollisols (2.1 %), Oxisols (1.1 %), Ultisols (0.9 %) and Andisols (0.06 %). In contrast, some problem soils (e.g., shifting sands, rocks and salt crusted) occupy about 12 % of the WANA region (Table 3.1). Therefore, predominant soils (e.g., Entisols, Aridisols, Inceptisols) are relatively coarse-textured, have low SOM concentration, low inherent soil fertility, low structural stability and low AWC. Thus, these soils are prone to both natural and anthropogenic perturbations, have low resilience, are easily degraded, and are prone to drought stress.

3.5 Adaptation to Climate Change

Adaptation to climate change involves any activity that reduces the negative impacts of climate change and/or takes advantage of new opportunities that may be presented. It implies adjustment in natural or human systems in response to actual or expected climatic change or its effects, which may moderate the adverse effects and explores beneficial opportunities. Thus, adaptation consists of strategies

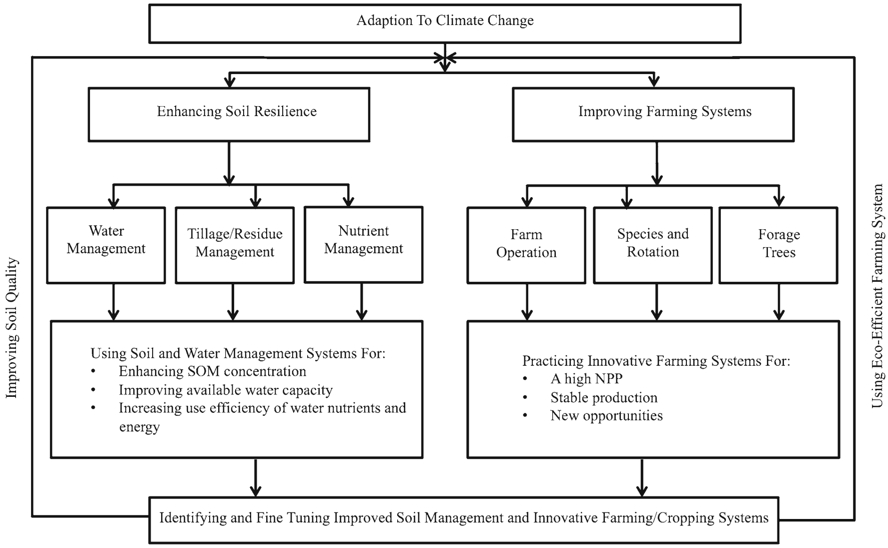


Fig. 3.3 Adaption to climate change. Adaption to climate change by enhancing soil resilience and converting to innovative and improved farming systems

(anticipatory or reactive) by which agricultural and forestry systems can become better adapted to the projected climate change in the WANA region such that adverse effects are minimized. Two principal strategies of adaptation are: (i) enhancing soil resilience, and (ii) improving farming systems (Fig. 3.3). Soil resilience can be enhanced by water management, tillage/residues management, and nutrient management. Enhancement of soil resilience can lead to increase in SOM concentration, plant AWC, and use efficiency of inputs (e.g., water, nutrients and energy) through improvement in soil quality. Adaptation strategies for innovative farming systems are appropriate adjustments in dates of farming operations (e.g., time of planting), choice of crop/forage species, rotations with the goal of using eco-efficient farming system (Fig. 3.3).

3.6 Mitigation of Climate Change

Rather than reducing the adverse impacts of climate change, mitigation involves specific soil and plant (crops, forages, tree) management activities which reduce the magnitude of climate change by off-setting anthropogenic emissions through sequestration of atmospheric CO_2 in the terrestrial ecosystems (e.g., soils and biota) (Fig. 3.4). The strategy of mitigation is to enhance C sink capacity of soils and biota, and reduce emissions from agricultural (industrial) activities by improving efficiency and decreasing losses.

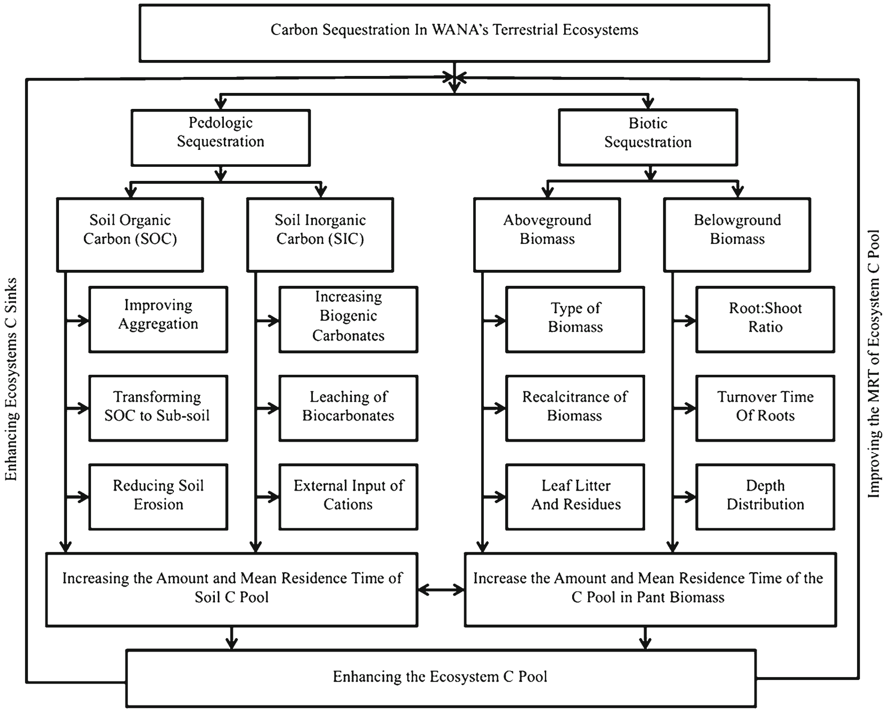


Fig. 3.4 Carbon sequestration in WANA's terrestrial ecosystems. Mitigation of climate change by off-setting anthropogenic emissions through carbon sequestration in soils and vegetation and enhancing the mean residue time (*MRT*) with in the terrestrial biosphere

3.7 Synergisms Between Adaption and Mitigation Strategies

To be effective, adaptive and mitigation strategies must be implemented to promote integration and explore synergisms. In general, adaptation strategies are primarily technological, involving for example, sustainable land management (SLM) options, policies towards risk management, and decision making such as choice of crops or cropping systems, aerobic vs. flooded rice, no-till vs. plow tillage, cover crops vs. continuous cropping etc. The adaptive strategies involve: plan → implement → evaluate → adjust → replan. Similarly, mitigative strategies include: recycle → restore → revalidate → reduce → recycle more. Adaptation strategies (making adjustments in decisions, activities and thinking to moderate adverse effects and take advantage of new opportunities) are linked with the moderation options (reducing the magnitude and intensity of gaseous emissions by sequestering emissions in the terrestrial and aquatic/wetland ecosystems) through appropriate policy interventions. The goal is to identify, fine-tune (validate) and adopt complementary and synergistic resource management options with specific reference to soil, water, vegetation and livestock. In addition to management of biophysical options, policy interventions also need to focus on the human dimensions (e.g., property rights, gender issues, social equity). The common goal of adaptation and mitigation strategies is to enhance production per unit of land area, time and inputs.

3.8 Enhancing Resilience of Soils in the WANA Region

Important properties pertinent to soil resilience and soil quality are SOM concentration, CEC, aggregation and stability, AWC etc. A key soil parameter that moderates all of these properties is the SOM concentration and its quality. The magnitude and turnover of SOM are controlled primarily by MAP and MAT, but modified by clay content and soil depth, input of biomass C into the soil, along with tillage methods and nutrient management. The amount of SOM depends on the input of biomass C and its rate of decomposition. Thus, SOM can be moderated through input of biomass and factors which control its decomposition (Johnston et al. 2009). Pedological factors which reduce the rate of mineralization are the amount of clay and the predominant clay minerals, and nature of exchangeable cations (Oades 1988). Given these characteristics, soil C sink capacity can be enhanced by conversion to a restorative land use, adoption of best management practices (BMPs), and creation of a positive ecosystem C budget (Lal 2000, 2001, 2002). Croplands and grasslands of the WANA region have a large C sink capacity through combating of soil degradation and restoration of degraded soils (Batjes et al. 2004; Lal 2002). Persistence of SOM as an ecosystem property depends on a range of environmental and biological controls (Schmidt et al. 2011). In the WANA region climatic factors limit input of the biomass C and yet accentuate mineralization of what ever is returned to the soil. The SOM concentration is also extremely low because of the centuries of cultivation by extractive practices, and the losses through accelerated erosion by wind (Masri et al. 2003) and also water (Lal 2000). Thus, increasing the SOM pool remains to be a major challenge in the soils of WANA region. Recognizing that an adequate level of SOM concentration is essential to all soil processes that impact agronomic productivity and the environment, it is important to identify systems of soil and crop/vegetation management which improve and sustain concentration of SOM above the threshold level. Rather than the conventional methods of adding biomass-C into the soil, Turgay et al. (2011) assessed the stimulatory effects of coal-derived humic substance on key properties of some soils in Cukurova, Adana, Turkey. The data showed that single and multiple applications of humic substances positively affected soil quality.

Some examples of management systems to enhance and sustain SOM pool and improve soil quality are briefly described below:

3.8.1 Tillage/Residue Management

Conservation tillage with no-till (NT) farming practices was initiated during early 1960s in response to the serious problems of accelerated soil erosion in row crops systems cultivated by plow tillage (PT) method of seedbed preparation. When combined with the crop residue management and legume-based rotation, the NT was designated as conservation tillage (CT) during 1990s. Since 2000s, CT system has evolved into conservation agriculture (CA) with four key components: (i) elimination of any mechanical seedbed preparation, (ii) retention of crop residue mulch, (iii) adoption of complex crop rotations, and (iv) use of integrated nutrient management (INM) options involving a judicious use of chemical fertilizers in conjunction with biological nitrogen fixation (BNF) and organic amendments (e.g., compost, manure). Furthermore, the concept of Sustainable Land Management (SLM) has been used by the development organizations. The SLM is defined as a knowledge-based combination of technologies, policies and practices that integrate land, water, biodiversity, and environmental concerns (including the input and output externalities) to meet the rising food and fiber demands while sustaining ecosystem services and livelihoods (World Bank 2006). Similar to CA, SLM also has several components: (i) maintaining or enhancing production and services, (ii) reducing the level of production risks, (iii) protecting the potential of natural resources and preventing degradation of soil and water quality, and (iv) enhancing economic viability and social acceptability (Wood and Dumanski 1994).

NT farming with crop residues mulch (CA) is an important option for improving soil quality. Despite its potential, NT farming has not been adopted in the WANA region (Thomas 2008). Presence of residues mulch can reduce wind erosion (Stewart and Koohofkan 2004) and improve nutrient cycling (Zöbisch 1998). Several field experiments in Morocco have demonstrated that NT farming with crop residues mulch can be effectively used for soil and water conservation and improving agronomic productivity even in regions with rainfall of 270–358 mm year^{-1} (Bouzza 1990; Mrabet et al. 2001, 2003). Bessam and Mrabet (2003) reported that the SOC pool in 0–25 cm layer increased by NT farming at the rate of 1.4 and 0.66 Mg C ha^{-1} year^{-1} after 6 and 11 years, respectively. Experiments conducted in Morocco on tillage system showed that NT farming enhanced buildup of particulate organic carbon (POC) and total SOC concentration in the surface layer. There was some improvement in soil quality of the surface 0–2.5 cm layer (Namr and Mrabet 2004). Similar studies conducted at ICARDA in Syria, however indicated little effects of NT farming on soil water storage or yield of barley (*Handeum vulgare*) (Pala et al. 2000). A low SOM concentration in plowed land is also caused by severe losses through soil erosion. A study conducted in the Khanasser Valley, northwestern Syria, showed that SOM concentration of the airborne sediments exceeded the amount in the parent soil (Masri et al. 2003). For a Vertisol in northwestern Iran with rainfall of 375 mm year^{-1}, Hemmat and Eskandari (2004) reported that grain yields of wheat (*Triticum aestrivum*) with reduced tillage (chisel plow) were consistently higher (35 %) than those from conventional tillage. Furthermore, grain yields under direct drilling were also similar to those obtained with reduced tillage. The 3-year experiment indicated that reduced tillage and direct drilling are appropriate practices for wheat production on Vertisols in northwestern Iran. A 10-year study conducted in a semi-arid area of Castile-Leon, Spain, by Sombrero and Benito (2010) indicated that conversion of PT to minimum or NT can enhance soil structure and increase SOC sequestration. The rate of SOC sequestration differed among tillage and crop

Table 3.2 The rate of increase of SOC pool, of a Typic Calcixerolls in 0–0.3 m depth between 1994 and 2004 by minimum and no-till systems in a semi-arid area of Castile-Leon, Spain (Recalculated from Sombrero and Benito 2010)

Rotation	Ten year mean rate of SOC sequestration (MgC/ha/year)		SOC pool in conventional tillage (MgC/ha)
	Minimum tillage	No-till	
1. Cereal-Cereal-Legume-Cereal	1.14	1.53	38.2 c
2. Fallow-Cereal-Legume-Cereal	0.92	1.36	38.3 c
3. Cereal-Legume-Cereal-Cereal	1.16	1.50	40.0 bc
4. Legume-Cereal-Cereal-Cereal	0.51	1.23	41.0 ab
5. Cereal-Legume-Cereal-Cereal	0.53	0.95	42.7 a

rotation treatments (Table 3.2). With reference to conventional tillage as the base line, the mean rate of SOC sequestration over 10 year period ranged from 0.51 to 1.16 Mg C ha^{-1} $year^{-1}$ for minimum tillage compared with 0.95–1.53 Mg C ha^{-1} $year^{-1}$ for NT farming. For each of the five rotation cycles, the rate of SOC sequestration was always more under NT than that under minimum tillage. A 2-year study conducted on a clay loam soil in semi-arid north-western Turkey indicated that in comparison with the original level, the SOC concentration in 0–0.2 m depth was 1.15 % in shallow tillage, 0.88 % in mouldboard tillage, and 0.95 % in the double discing treatment. Several experiments conducted in Central Asia have also shown agronomic benefits of adopting CA, especially when used in conjunction with soil fertility management and appropriate crop rotations (Suleimenov and Akshakov 2004; Thomas 2008).

A major constraint to adopting NT farming in the WANA region is the competing uses of crop residues (e.g., fodder, fuel, construction). The benefits of NT farming towards SOC sequestration, soil water storage, soil aggregation, nutrient cycling and erosion control are directly proportional to the amount of crop residues and other sources of biomass returned.

3.8.2 Soil Fertility Management

Low inherent soil fertility is a major constraint in cultivated soils of WANA. Prior to 1970, a little if any chemical fertilizers were used in croplands. However, use of chemical fertilizers, especially N and P, increased by 10–20 times between 1978 and 2008 (Ryan 2008). Increasing production to meet the food demands necessitates use of chemical fertilizers. However, it is important to use the chemical fertilizers in a balanced manner, through soil analysis and establishment of empirical relations between the soil test value and plant uptake of the specific nutrient (e.g., N, P, or K). These relations are used to establish critical values and the fertilizer response curve (Ryan 2008). Soil and plant test laboratories were established at ICARDA and other regional institutions to provide guidelines for the use of chemical fertilizers (Ryan et al. 1999).

Soil fertility management and fertilizer use strongly interact with tillage method/residue management, cropping/farming systems, and water management or irrigation. In a 14-year cropping system study conducted in the medium rainfall zone (300–400 mm $year^{-1}$) of northern Syria, Ryan et al. (2008b) observed a strong effect of the rate of N fertilizer (0, 30, 60, 90 kg ha^{-1}) on grain and straw nitrogen percentages and total N uptake. The use of N fertilizer, along with the legume-based rotations (vetch and medic), improved nutritional quality of the grains.

While the necessity of using N fertilizer is widely recognized, it is important to maximize the use efficiency and avoid excessive use. The latter, adversely affects water quality and exacerbates emission of N_2O. In addition to soil test, tissue testing of the growing crop is also important. Korkmaz et al. (2008) conducted a 2-year field trial to assess the potential of tissue testing of rainfed wheat in the Curkova region of southern Turkey. They observed that using the combined approach of soil and tissue nitrate resulted in lowering the rate of N fertilizer recommendation while maintaining the agronomic yield. A similar study conducted on sweet corn in Sanliurfa, Turkey, indicated that fresh ear yield and protein content (and micronutrient contents) of kernel were affected by N rate, and that the nitrogen use efficiency increased up to the application rate of 320 kg N ha^{-1}.

Adopting an INM strategy is also important to reducing the use of chemical fertilizers, and improving soil physical and biological quality. In Egypt, Mahmoud et al. (2009) observed that the addition of rice straw compost, in conjunction with that of water treatment residual (WTR), decreased soil salinity, increased concentration of Ca^{2+} and K^+, and enriched SOM concentration. In addition to N, a judicious use of P is also important to enhancing yield and quality of grains, fruits and vegetables. In Anatolia Turkey, Günes et al. (2009) assessed the effectiveness of P-solubilizing bacteria (*Bacillus* FS-3) and fungi (*Aspergillus* FS9) on strawberry (*Fragaris ananasa*) yield and mineral content of fruits and leaves. Use of P solubilizing bacteria and fungi resulted in P-fertilizer savings of 100–150 kg P ha^{-1}. Further, microorganism inoculation increased fruit and leaf nutrient concentrations.

3.8.3 Cropping Systems

Selection of appropriate crop species and the rotation cycle is important for adapting to any global warming because of their effects on soil resilience and agronomic productivity. Adaptation also involves adjustment in farm operations such as date of sowing, selection of short-duration crops/varieties, and those tolerant to heat/drought and salinity (Iglesias and Minguez 1997; Mendelsohn and Dinar 1999). Several long-term cropping systems experiments conducted by ICARDA and other institutions have indicated the usefulness of suitable rotations in improving SOC pool, enhancing soil quality, and increasing agronomic productivity. A long-term experiment (1983–2005) at Tel Hadya, Syria showed that soil physical properties indicated parallel trends with increasing concentration of SOM (Masri and Ryan 2006). Further, cereal-legume rotations, while being biologically and economically attractive, also improve soil quality and advance agronomic sustainability in the harsh dryland conditions of the WANA region (Masri and Ryan 2006). Kapur et al. (2007) assessed the impact of several cereal-based rotations on soil quality in Aleppo, Syria. The SOM concentration in the surface and sub-soil respectively, was 1.4 % and 1.1 % in medic (*Medicago* spp.) based rotations compared with 0.8 % and 0.6 % in the fallow rotations. There existed a strong relation of SOM concentration with aggregate stability, water infiltration rate, permeability and dispersion coefficient. Using both polarizing and electron microscope indicated inconsistent trends at micro level and macro level (wet sieving) structural properties, probably because of differences in age of the SOM and the degree of mixing to effectively form the organo-mineral complexes. Kapur and colleagues emphasized the importance of micro-scale approach to understanding the processes of development of microstructure. Based on a 14-year rotation experiment involving durum wheat in northern Syria (MAP of 340 mm) Ryan et al. (2008a) observed that SOM concentration was in the order of fallow < continuous wheat < lentil (*Lens culinaris*) < chick pea (*Cicer arietinum*) < vetch (*Vicia sativa*) < medic. Further, SOM concentration increased with application of N fertilizers and decreased with the intensity of grazing. In another study, Ryan et al. (2008b, c) observed that rotations with medic and vetch enriched the N concentration in grains and straw. In addition to the long-term effects, crop rotations can also induce seasonal changes in SOM concentration, especially in the labile fraction of SOM, because of the addition of biomass-C during a specific season. Ryan et al. (2009) observed that the SOM concentration decreased from 1.48 % in February to 1.151 % in August after cropping. Concentration of the labile SOM fraction followed a similar pattern with a large drop between May and August sampling. The labile fraction decreased from 1,746 mg kg^{-1} in February to 1,275 mg kg^{-1} in August, and the MBC from 107 mg kg^{-1} in February to 71 mg kg^{-1} in August (Ryan et al. 2009). All three forms of SOM (total, MBC, and the labile) were the highest in the zero-grazing in the fallow and the medic-based rotations.

3.8.4 Grazing, Forages and Fodder Trees

In general, no grazing of stubbles or forages has a positive effect on SOM concentration (Masri and Ryan 2006). Thus, the more the biomass-C directly returned to the soil the more is the SOM concentration. In this context, the beneficial impact of controlled grazing at low stocking rate with improved pastures cannot be overstated. It is precisely in this mode that fodder trees can also play a significant role in improving soil quality and enhancing the SOM concentration. Le Houérou (2000) emphasized the positive effects of deliberate plantation of fodder trees and shrubs since 1920s and 1930s in the WANA region. In the Sidi Bouzid region of Tunisia, early settlers were required to establish spineless cactus (*Opuntia ficus indica* f. *intermis*) on 2 % of their allocated land during the initial years of occupancy. Similarly, wattles (e.g., *Acacia saligna*) were introduced into Algeria in the 1870s, and into Libya in 1916. Saltbushes (*Atriplex* spp.) are also adapted to the WANA region. Other native species (e.g., *Chenopediacae*, *Fabaceae*, *Oleaceae*, *Elaegnaceae*, *Rhalnaceae*, *Anacardiaceae*, *Asclepiadaceae*, *Polygonaceae*, *Asteraceae*) are relevant for the region (Le Houérou 2000). Some exotic species of interest are *Atriplex*, *Acacia*, *Cactaceae*, *Myoporceae*, *Vitaceae*, *Agavaceae* etc. Ben Salem et al. (2010) used oldman saltbush (*Atriplex nummularia* Lindl) as livestock forage and as a revegetation species on marginal saline lands in the WANA region. Ben Salem and colleagues reported that oldman saltbush produces important consumable biomass in areas where other crops cannot grow. The management strategy is to integrate fodder trees and shrubs into production systems for restoration of degraded lands, multipurpose production systems, livestock grazing, and landscaping etc. Cereals can be grown in association with fodder trees and shrubs as agroforestry systems. In addition to soil quality improvement, there are also beneficial impacts on microclimate and moisture regime. Rather than single species, diverse species can also be used. Among multiple functions, other uses of fodder trees and shrubs include their establishment for land partitioning (boundary), fencing (*Acacia senegalia*), fuel wood, fruits, bee culture, erosion control etc. Establishing fodder trees have the following benefits (Le Houérou 2000): drought tolerance, fodder reserves during drought, facilitate transhumance to sedentary husbandry, high rain use efficiency (RUE) and WUE, high NPP (three to five times the rangeland), microclimate buffer, erosion/desertification control, ecosystem C pool, nature conservancy-biodiversity and soil quality improvement.

3.8.5 Soil Water Conservation and Supplemental Irrigation

Agronomic drought is a major constraint to dryland farming throughout the WANA region. The problem is exacerbated by low rainfall (200–600 mm) during the wet season (late autumn to early spring), and soils of low AWC. Low SOM (Ryan 1998) and low clay contents are also factors which reduce the AWC. Water being the key factor towards the success of agriculture in the WANA region, its judicious management is a primary factor influencing agronomic yields. Water deficit can affect productivity of even olive trees (Ahmed et al. 2007). Use of crop residues mulches and NT farming can enhance soil water storage in the root zone while reducing losses by surface runoff and evaporation. In addition, supplemental irrigation can be important to reducing drought stress because rainfall is insufficient during the growing season. However, there is a scarcity of good quality water for irrigation. Thus, use of saline water, reusing marginal water, and using waste water are important considerations.

In the water-scarce WANA and other arid regions, with only 1 % of the world's freshwater resources (Heidarpour et al. 2007), the reuse of waste water is strategically important (Toze 2006; Qadir et al. 2007). Furthermore, the waste water increases with increase in population. Egypt produces approximately 2.4 km^3 of waste water every year. With some treatment of this water, it can be used for supplemental irrigation (El-Mowelhi et al. 2006). The major problems of using waste water are heavy metals, salt buildup, and soil pathogens. With treatment, waste water can be safely used for irrigation without significant negative impact on the environment (El-Mowelhi et al. 2006). In addition to the water, there are also plant nutrients present in the waste water. However, the risks involved in reuse of waste water must be reduced. For example, Mara (2000) proposed that use of waste stabilization pond is an efficient low-cost and a low maintenance process to treat waste water for crop irrigation. Mara also recommended that treatment in anaerobic and facultative ponds is required for restricted irrigation, with further treatment in maturation ponds for unrestricted irrigation. However, the latter treatment requires additional land area. Risks can be minimized by treatment, but also by the choice of method (surface vs. sub-soil), amount and frequency of irrigation, species grown, and soil profile characteristics. Irrigation with waste water can significantly affect electrical conductivity, and concentration of plant nutrients (N, P, K) in the surface layer (Heidarpour et al. 2007). Ryan et al. (2006) observed that water in Quake River (south of Aleppo, Syria) was rich in major and micro nutrients and, with normal irrigation amounts, was adequate to meet the crop nutrient demands even without irrigation.

The problem of secondary salinization on irrigated lands can be exacerbated when brackish water is used. In northern Egypt at Quesina, Menofia, Amer (2010) observed that soil salt accumulation was significantly increased by either irrigation salinity increase or amount decrease (Amer 2010). Saline water can be mixed with good quality water for use in irrigation. In Mile Delat, Egypt, Malash et al. (2005) used a ratio of 60 % fresh water with 40 % saline water for irrigation of tomatoes (*Salanum lycopersicum*) using drip irrigation.

Evaluation of humic substances fertigation through surface and sub-surface drip irrigation system has been done for potato (*Solanum tuberosum*) cultivation in some Egyptian sandy soils (Selim et al. 2009). Increasing humic substances application rates up to 120 kg ha^{-1} enhanced tuber yield, starch content and total soluble solids probably because of decrease of nutrients leaching. Selim and colleagues also observed that the sub-surface drip irrigation system was more efficient than the surface drip irrigation.

Assessment of water productivity on the on-farm water use efficiency (WUE) assessed by Shideed et al. (2005) in Aleppo, Syria, indicated that farmers over-irrigate their crops by 20–60 %, Thus, Shideed and colleagues developed a model and tested WUE on some farms in Egypt, Iraq, Jordan and Syria, and observed that undervaluing the water is the basic reason of its overuse. In addition to the waste of a limited resource, over irrigation is also principal cause of secondary salinization.

3.8.6 Salinity Management

The widespread process of soil salinization is one of the degradation mechanism which leads to desertification (Kassas 1987; Thomas and Middleton 1993; Schofield 2003). It can be exacerbated by inappropriate irrigation (secondary salinization), land misuse and soil mismanagement. In Tunisia, Schofield (2003) observed that the problem of secondary salinization was the most severe on intensely-flooded irrigated land. Rise in the ground water (such as due to river impoundment or floor irrigation without adequate drainage) can lead to accumulation of salts in the surface layer. Aeolian activities can also lead to redistribution of salt adjacent to lakes containing brackish water.

Biosaline farming, growing halophytes in saline soils and/or by irrigation with brackish water, has a large potential in the WANA region (Jaradat 2003). The wide ecogeographic diversity, indicated by highly diverse vegetation and species in WANA, can be used to grow halophytes covering a range of crops, forages, fodder trees and shrubs under saline conditions. Jaradat reported that as many as 211 halophytic species comprising of 29 families have been recorded in the WANA region. Domestication of these wild plants can increase and sustain agricultural production. There are three types of halophytes: (i) obligatory plants which are dependent on salt, (ii) preferential plants whose growth is improved in presence of salt (e.g., *Arthrocnemum* spp., *Aster* spp., and *Salicornia* spp.) and (iii) salt enduring spp. (e.g., *Suaeda monoica*). Jaradat (2003) recorded halophytes in the WANA region with the following potential or source of specific goods and services:

(i) Seed bearing halophytes as sources of grains. Several grain bearing halophytes include eelgrass (*Zostera marina*), palmer saltgrass (*Distichlis palmeri*), sacaton (*Sporobolus airoides*), pearl millet (*Pennisetum typhoides*), quinoa (*Chenopodium quinoa*), and seashore mallow (*Kosteletzkya virginica*). Seed quality of some of these grains is comparable to that of wheat.

(ii) Oil seeds: Halophytes with potential of producing oil seeds include *Acacia* spp. (*A. aneura*, *A. coriacea*, *A. cowleana*, *A. dictyophleba*), aragan (*Aragania spinosa*), and *Salicosnia* spp. (S. *herbacea*).

(iii) Fruits: Several halophytic plants bear fruits. Common among these are ber (*Ziziphus mauritiana*), sapodilla also called nispero, sapatia, sapotille and chickle tree (*Manilkara zapota*), salt bush also called toothbrush and pileu (*Salvadora persica*), wolf berry also called goji and matrimony vine (*Lycium* spp.), native peach or quandong (*Santalum acuminatum*), and seagrape also called baygrape (*Coccoloba uvifera*).

(iv) Fuel wood and biofuels: Several salt tolerant trees and shrubs produce large biomass which can be source of fuel wood. Important among these are mesquite (*Prosopis* spp.), gum tree (*Eucalyptus* spp.), whistling tree or beach sheoak (*Casuarina equisetifolia*). Sugar beet (*Beta vulgaris*) and nipa palm (*Nypa fruticans*) can be converted into liquid fuel (ethanol).

(v) Forages: Karnal grass or kallar grass (*Leptochloa fusca*) is a good fodder and also useful for conversion into cellulosic ethanol. Salt grass (*Distichlis septata*) and channel millet (*Echinochloa turnerana*) are also good forage grasses. Oldman salt bush (*Atriplex nummularia* Lindl.) is a good fodder for sheep and goat (Ben Salem et al. 2010).

(vi) Bioremediation: The large native biodiversity in the WANA region can also be used for bioremediation of contaminated and polluted soils. There has been a severe metal contamination of soils from the Gulf War activities (Sadiq et al. 1992).

Then there are drastically modified urban soils (called *Antrhosols* or *Technosols*). These soils receive a considerable pollution from industry, traffic and refuse (El Khalil et al. 2008). There are also petroleum contaminated soils (Ünlü and Demirekler 2000). Bioremediation by establishing appropriate plants (grasses, shrubs and trees) is a useful strategy to improve soil quality.

3.9 Soil Quality Management and Policy Interventions

Any anthropogenic disturbance of the soil and vegetation in the dryland ecosystems of the WANA region can adversely impact the quality of soil and environment. Conversion of native vegetation to agroecosystems (e.g., croplands, pasture land, horticultural land) can lead to depletion of SOM concentration and reduction in specific fractions, while also exacerbating the risks of soil erosion. An experiment conducted in northwestern Turkey by Kara and Bolat (2008) showed that levels of SOC, total N and soil moisture reserves decreased by deforestation. In contrast, however, pH, electrical conductivity and concentration of $CaCO_3$ increased. There were also strong differences in microbial community structure, especially in the MBC. Thus, only those methods of land clearance and development must be used which cause minimal disturbance to soil and ecosystem functions.

Use of biosolids, sewage sludge and waste water also requires appropriate policy measures. Similar precautionary measures are needed for management of contaminated soils, which pose serious health risks. In addition to any adverse effects on plant and livestock, human health risks involved must be carefully assessed (Kentel et al. 2011).

3.10 Carbon Sequestration and Climate Change

With a total land area of 1.7 billion ha (B ha), WANA region has a large potential of C sequestration in soils and vegetation (Lal 2000, 2002). The rangeland, with a total area of ~830 Mha, can be resotred and managed to sequester C. In addition, restoration of degraded and desertified soils can promote C sink capacity in soils and the vegetation. With an historic C loss of 6–12 Pg C, these soils have a C sink capacity of 3.5–7 Pg or 0.2–0.4 Pg C year^{-1} over 20 year (Lal 2002). In addition to SOC, soils of the dry regions also have a capacity to sequester inorganic C as secondary carbonates.

Trading C credits and payments for ecosystem services is an option to promote the adoption of restorative land uses and best management practices. Benefits generated by improved management of drylands (carbon sequestration, water quality, biodiversity) are common goods, justifying the payments to land manager for their restoration.

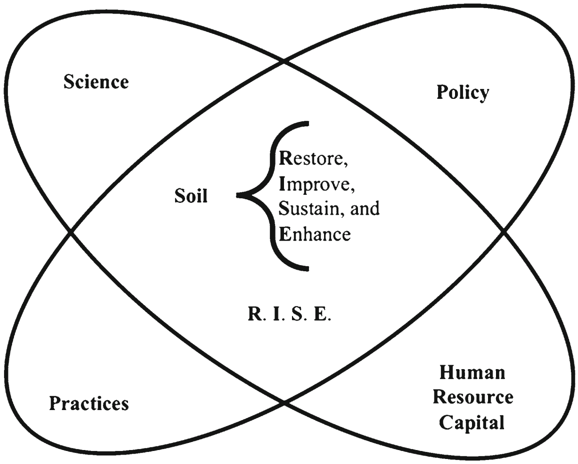


Fig. 3.5 Integrating science, practices and policy for sustainable soil management and restoration

There is a strong need for integration of science, practices and policy for sustainable soil use and management (Fig. 3.5). Amid perpetuating hunger and poverty, degrading and desertifying soils, and ever depleting the soil resource base, it is the right time to develop and implement science-driven programs based on basic principles of soil management and eco-efficient approaches.

3.11 Conclusions

The strategy is to produce more from less land, more crop per drop of water, more yield per unit input of fertilizers and pesticides, more food per unit of energy, and more biomass per unit C and the environmental foot print. In this regards, we must go back to the roots of human civilization, and combine scientific principles with concepts described in various scriptures. Albert Einstein stated "Science without religion is lame; religion without science is blind". The importance of clay and soil is clearly stated in the Quran as "He created the man of clay like the potters" (Surah Al-Rhman, verse, 14). Khalil Gibran emphasized the importance of trees in his verse "Trees are poems that earth writes upon the sky, We fell them down and then turned them into paper, That we may record our emptiness". The value of water is most appropriately stated in the word of prophet Mohammed: "Do not overuse water even if you are on a running river". The importance of wasting not by excessive use is stated in Quran (6:141) "It is He who produced gardens. With trellises and without, and dates, and cultivated land with produce of all kinds, and olives and pomegranates, similar (in kind) and different (in variety): Eat of these fruits in their season, but render the dues that are proper on the day that the harvest is gathered. But waste not by excess: For God loves not the wasteful".

References

Ahmed CB, Rouina BB, Boukhris M (2007) Effects of water deficit on olive trees cv. Chemlali under field conditions in arid region in Tunisia. Sci Hortic-Amsterdam 113:267–277

Amer K (2010) Corn crop response under managing different irrigation and salinity levels. Agric Water Manag 97:1553–1563

Atinmo T, Mimiran P, Oyewole OE, Belahsen R, Serra-Majem L (2009) Breaking the poverty/malnutrition cycle in Africa and the Middle East. Nutr Rev 67:40–46

Batjes N, Bernoux M, Cerri C (2004) Soil data derived from SOTER for studies of carbon stocks and change in Brazil. ISRIC, Wageningen

Ben Salem H, Norman HC, Nefzaoui A et al (2010) Potential use of oldman saltbush (*Atriplex nummularia* Lindl.) in sheep and goat feeding. Small Rumin Res 91:13–28

Bessam F, Mrabet R (2003) Long-term changes in soil organic matter under conventional and no-tillage systems in semi-arid Morocco. Soil Use Manag 19:139–143

Bouzza (1990) Water conservation in wheat rotations under several management and tillage systems in semi-arid areas. PhD thesis, University of Nebraska, Lincoln

Breisinger C, van Reheenen T, Ringler C et al (2010) Food security and economic development in the Middle East and North Africa: current state and future perspectives. IFPRI Discussion Paper 00985, pp 1–52

El Khalil H, Schwartz C, Elhamiani O et al (2008) Contribution of technic materials to the mobile fraction of metals in urban soils in Marrakech (Morocco). J Soil Sediment 8:17–22

El-Mowelhi NM, Abo Soliman SMS, Barbary SM et al (2006) Agronomic aspects and environmental impact of reusing marginal water in irrigation: a case study from Egypt. Water Sci Technol 53:229–237

Grünzweig JM, Körner C (2000) Growth and reproductive responses to elevated CO_2 in wild cereals of the northern Negev of Israel. Glob Change Biol 6:631–638

Günes A, Ataoğlu N, Turan M et al (2009) Effects of phosphate-solubilizing microorganisms on strawberry yield and nutrient concentrations. J Plant Nutr Soil Sci 172:385–392

Heidarpour M, Mostafazadeh-Fard B, Koupai J (2007) The effects of treated wastewater on soil chemical properties using subsurface irrigation methods. Agric Water Manag 90:87–94

Hemmat A, Eskandari I (2004) Conservation tillage practices for winter wheat-fallow farming in the temperate continental climate of northwestern Iran. Field Crop Res 89:123–133

Iglesias A, Minguez MI (1997) Modelling crop-climate interactions in Spain: vulnerability and adaption of different agricultural systems to climate change. Mitig Adapt Strat Glob Change 1:273–288

Jaradat AA (2003) Halophytes for sustainable biosaline farming systems in the Middle East. In: Alsharhan AS, Wood WW, Goudie AS et al (eds) Desertification in the third millennium. Swets & Zeitlinger Publishers, Lisse

Jenny H (1941) Factors of soil formation. McGraw-Hill, New York

Jenny H (1980) The soil resource, origin and behavior. Springer, New York

Joekes S (1994) Population and reproductive rights. Focus Gend 2:13–18

Johnston AE, Poulton PR, Coleman K (2009) Soil organic matter: its importance in sustainable agriculture and carbon dioxide fluxes. Adv Agron 101:1–57

Kapur S, Ryan J, Akça E et al (2007) Influence on Mediterranean cereal-based rotations on soil micromorphological characteristics. Geoderma 142:318–324

Kara Ö, Bolat Ï (2008) Soil microbial biomass C and N changes in relation to forest conversion in the northwestern Turkey. Land Degrad Dev 19:421–428

Kassas M (1987) Seven paths to desertification. Desert Control Bull 15:24–26

Kentel E, Aksoy A, Büyüker B et al (2011) Challenges in development and implementation of health-risk-based soil quality guidelines: Turkey's experience. Risk Anal 31:657–667

Korkmaz K, Ibrikci H, Ryan J et al (2008) Optimizing nitrogen fertilizer-use recommendations for winter wheat in a Mediterranean-type environment using tissue nitrate testing. Commun Soil Sci Plan Anal 39:1352–1366

Lal R (2000) Carbon sequestration in drylands. Ann Arid Zone 39:1–10
Lal R (2001) Potential of desertification control to sequester carbon and mitigate the greenhouse effect. Clim Chang 51:35–72
Lal R (2002) Carbon sequestration in dryland ecosystems of West Asia and North Africa. Land Degrad Dev 3:45–49
Lal R (2009) Ten tenets of sustainable soil management. J Soil Water Conserv 64:20A–21A
Le Houérou HN (2000) Utilization of fodder trees and shrubs in the arid and semiarid zones of West Asia and North Africa. Arid Soil Res Rehab 14:101–135
Mahmoud E, Mahmoud I, Robin R et al (2009) Rice straw composting and its effect on soil properties. Compost Sci Land Ut 17:146–150
Malash N, Flowers TJ, Ragab R (2005) Effect of irrigation systems and water management practices using saline and non-saline water on tomato production. Agric Water Manag 78:25–38
Mara DD (2000) The production of microbiologically safe effluents for wastewater reuse in the Middle East and North Africa. Water Air Soil Poll 123:595–603
Masri Z, Ryan J (2006) Soil organic matter and related physical properties in a Mediterranean wheat-based rotation trial. Soil Till Res 87:146–154
Masri Z, Zöbisch M, Bruggeman A et al (2003) Wind erosion in a marginal Mediterranean dryland area: a case study from the Khanasser Valley, Syria. Earth Surf Proc Land 28:1211–1222
Mendelsohn R, Dinar A (1999) Climate change, agriculture, and developing countries: does adaption matter? World Bank Res Obs 14:277–293
Mrabet R, Saber N, El-Brahi A et al (2001) Total particulate organic matter and structural stability of a Calcixeroll soil under different wheat rotations and tillage systems in a semi-arid areas of Morocco. Soil Till Res 57:225–235
Mrabet R, El-Brahi A, Lahlou S et al (2003) No-tillage technology: research review of impacts on soil quality and wheat production in semiarid Morocco. In: Cantero-Martinez C, Gabina D (eds) Mediterranean rainfed agriculture: strategies for sustainability. CIHEAM-IAMZ, Zaragoza
Namr KI, Mrabet R (2004) Influence of agricultural management on chemical quality of a clay soil or semi-arid Morocco. J Afr Earth Sci 39:485–489
Oades JM (1988) The retention of organic matter in soils. Biogeochemistry 5:35–70
Pala M, Harris HC, Ryan J et al (2000) Tillage systems and stubble management in a Mediterranean-type environment in relation to crop yield and soil moisture. Exp Agric 36:223–242
Qadir M, Sharma BR, Bruggeman A et al (2007) Non-conventional water resources and opportunities for water augmentation to achieve food security in water scarce countries. Agric Water Manag 87(1):2–22
Ryan J (1998) Changes in organic carbin in long-term rotation and tillage trials in northern Syria. In: Lal R, Kimble JM, Follet JM, Stewart RF (eds) Management of carbon sequestration in soils. Advance Soil Science CRC Press, New York
Ryan J (2008) A perspective on balanced fertilization in the Mediterranean region. Turk J Agric For 32:79–89
Ryan J, Garabet S, Rashid A et al (1999) Assessment of soil and plant analysis laboratories in the West Asia – North Africa region. Commun Soil Sci Plan 30(5–6):885–894
Ryan J, Masri S, Qadir M (2006) Nutrient monitoring of sewage water irrigation: impacts for soil quality and crop nutrition. Commun Soil Sci Plan 37:2513–2521
Ryan J, Masri S, Ibrikiçi H et al (2008a) Implications of cereal-based crop rotations, nitrogen fertilization, and stublle grazing on soil organic matter in a Mediterranean-type environment. Turk J Agric For 32:289–297
Ryan J, Pala M, Masri S et al (2008b) Rainfed wheat-based rotations under Mediterranean conditions: crop sequences, nitrogen fertilization, stubble grazing in relation to grain and straw quality. Eur J Agron 28:112–118
Ryan J, Singh M, Pala M (2008c) Long-term cereal-based rotation trials in the Mediterranean region: implications for cropping sustainability. Adv Agron 97:273–319

Ryan J, Masri S, Singh M (2009) Seasonal changes in soil organic matter and biomass and labile forms of carbon as influenced by crop rotations. Commun Soil Sci Plan 40:188–199

Sadiq M, AlThagafi KM, Mian AA (1992) Preliminary evaluation of metal contamination of soils from the Gulf war activities. Bull Environ Contam Toxicol 49:633–639

Schmidt MWI, Torn MS, Abiven S et al (2011) Persistence if soil organic matter as an ecosystem property. Nature 478:49–56

Schofield R (2003) Soil salinity as a degradation process in Spain and Tunisia. In: Alsharhan AS, Wood WW, Goudie AS et al (eds) Desertification in the third millennium. Swets & Zeitlinger Publishers, Lisse

Selim EM, Mosa AA, El-Ghamry AM (2009) Evaluation of humic substances fertigation through surface and subsurface drip irrigation systems on potato grown under Egyptian sandy soil conditions. Agric Water Manag 96:1218–1222

Shideed K, Oweis TY, Gabr M et al (2005) Assessing on-farm water-use efficiency: a new approach. ICARDA, Aleppo

Sombrero A, de Benito A (2010) Carbon accumulation in soil. Ten-year study of conservation tillage and crop rotation in a semi-arid area of Castile-Leon Spain. Soil Till Res 107:64–70

Sowers J, Weinthal E (2010) Climate change adaptation in the Middle East and North Africa: challenges and opportunities. The Dubai initiative, working paper #2. Harvard Kennedy Center, Harvard, 29 pp

Stewart BA, Koohofkan P (2004) Dryland agriculture: long neglected but worldwide importance. In: Rao SC, Ryan J (eds) Challenges and strategies for dryland agriculture. CSSA Spec. Pub. 32, CSSA/ASA, Madison, Wisconsin

Suleimenov M, Akshakov K (2004) Issues of transition from grain-fallow rotations to no fallow crop rotations. In: Loshakov V (ed) In proceedings of an international conference on crop rotation in modern farming practices. Moscow Agricultural Academy, Moscow, pp 33–39

Thomas RJ (2008) Opportunities to reduce the vulnerability of dryland farmers in Central and West Asia and North Africa to climate change. Agr Ecosyst Environ 126:36–45

Thomas DSG, Middleton NJ (1993) Salinisation: new perspectives on a major desertification issue. J Arid Environ 24:95–105

Toze S (2006) Reuse of effluent water – benefits and risks. Agric Water Manag 80:147–159

Turgay OC, Karaca A, Unver S et al (2011) Effects of coal-derived humic substance on some soil properties and bread wheat yield. Commun Soil Sci Plan 42:1050–1070

Ünlü K, Demirekler E (2000) Modeling water quality impacts of petroleum contaminated soils in a reservoir catchment. Water Air Soil Poll 120:169–193

USDA-NRCS (2006) Global soil regions and GLC 2000 land cover. USDA-NRCS Database. USDA, Washington, DC. (Courtsey Dr. Paul Reich)

Wiggins S, Leturque H (2010) Helping Africa to feed itself: promoting agriculture to reduce poverty and hunger. Future Agric Occas Pap 002:1–31

Wood RC, Dumanski JC (1994) Sustainable land management for the 21st century. In: proceedings of the international workshop, University of Lethbridge, Lethbridge, 20–26 June 1993

World Bank (2006) Sustainable land management: challenges, opportunities and tradeoffs. Agriculture and rural development. The World Bank, Washington, DC

Wright B, Cafiero C (2011) Grain reserves and food security in the Middle East and North Africa. Food Secur 3:61–76

Zöbisch MA (1998) The West Asia and North Africa region: some underlying factors of wind erosion and perspectives for research and technology development. In: Sivakumar MVK, Zöbisch MA, Koala S, Maukanen T (eds) Wind erosion in Africa and West Asia: problems and central Strategies. ICARDA, Aleppa

Chapter 4
Conserving Green and Blue Water in the WANA Region

Hamed Daly-Hassen, Yves Birot, Carlos Gracia, and Marc Palahi

Abstract The WANA region is characterized by water scarcity with 14 countries ranked in the top 20 water scarce countries, with less than 500 m^3 of renewable water/year/capita. Despite this current situation, water availability per capita will be severely reduced due to climate change and the increase in water demand. On the other hand, woodlands cover only 13.1 % of the region in average, moreover, most countries (14) have very low cover rate (less than 4 %). In this context of water scarcity, the blue and green water approach has raised much interest over the last years, especially in dry areas, for analyzing water balance. The green water (evaporation and transpiration) is needed to sustain ecosystem processes and the goods and services they provide, while the blue water (surface runoff and groundwater recharge) plays a paramount role on water supply to urban populations, industry and irrigated agriculture. In such circumstances of conflicts and trade-offs, integrating hydrological, ecological and socio-economic management is a key approach towards sustainability. Mainly, the effects of the land use change on water resources and their distribution among stakeholders should be analyzed and economic instruments should be introduced when establishing a watershed management plan in a water-constrained environment.

Keywords Terrestrial ecosystems • Climate and land use change • Water use efficiency • Land management • Integrated water use

---

H. Daly-Hassen (✉)
INRAT, Tunis, Tunisia
e-mail: Daly@gnet.tn

Y. Birot
EFIMED, Avignon, France

C. Gracia
CREAF-UB, Barcelona, Spain

M. Palahi
EFIMED, Barcelona, Spain

M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_4,

4.1 Introduction

This chapter attempts to give an overview about the ecosystem/water interface in the context of water scarcity that characterizes the WANA region. It refers to a recent book published by the European Forest Institute (EFI) with the contribution of forty scientists (Birot et al. 2011).

The WANA region is permanently confronted with the scarcity of water. Population growth will further decrease water resources. Moreover, climate change (CC) is predicted to bring more frequent and severe droughts and floods (Croitoru and Young 2011). Also, WANA region has experienced a strong decrease of the forest and vegetation cover due to the anthropogenic pressure. Evolutions in land use have affected and are affecting biological processes, including the water cycle, as well as the water resources in quantity and quality. For example, water overuse or misuse induces environmental degradation that is estimated to 0.6 % of GDP in Tunisia and 2.8 % of GDP in Iran (Croitoru and Sarraf 2010).

First of all, this chapter presents a glance at water relations in terrestrial ecosystems; especially, linkages between green and blue water, secondly, the future constraints (climate change (CC), land use change) that could affect green and blue Water in the WANA region, thirdly, the contribution of green and blue water to human welfare. Following that, some recommendations for a sustainable management of water and ecosystems in the WANA region are presented.

4.2 A Glance at Water Relations in Terrestrial Ecosystems

Water is the foundation of all biological life on earth and one of the basic link between the biosphere and atmosphere (Birot and Gracia 2011). It is equally fundamental for humans and nature. The water cycle links ecosystems and human societies (Fig. 4.1).

The paradigm of green/blue water provides a valuable conceptual framework in water management at various scales (Fig. 4.2) (Falkenmark and Rockström 2006).

In the past, the blue water has dominated water perceptions. It was considered that food production (agriculture) is the main consumer of water, although, it represents only one third of the real freshwater resource, the rainfall over the continents. At the global scale, the traditional use of freshwater accounts only for about 3 % of the annual rainfall, and only 2 % is used for the production of food on irrigated areas (Table 4.1). In fact, the majority of available water is used for the maintenance of main ecosystems and the provision of goods and services, it benefits directly to the society by 22 %, or indirectly through water functions of ecosystems by 40 % (Mavsar 2011).

Water issues have been almost exclusively looked upon the angle of blue water. Blue water and green water are required and should be considered together to sustain the multiple ecosystem goods and services on which we heavily depend (MEA 2005) (Fig. 4.3). These are distinguished into four categories:

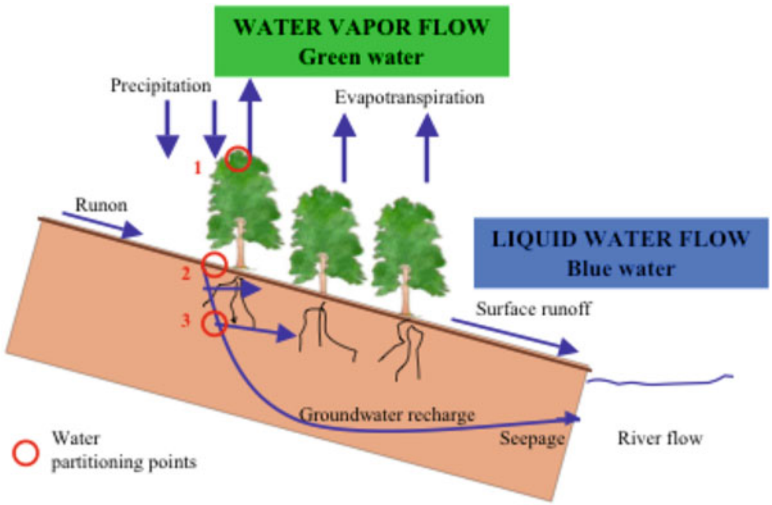


Fig. 4.1 The hydrological cycle for an ecosystem showing the partitioning of rainfall (Source: Falkenmark and Rockström 2006)

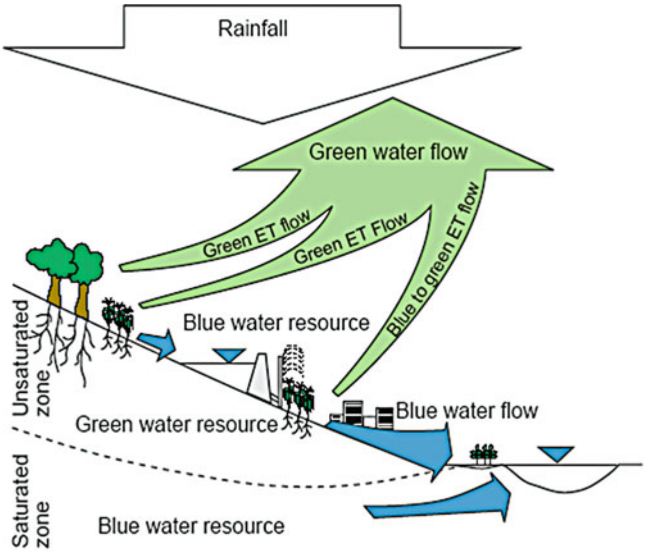


Fig. 4.2 The green/blue water approach (Source: Falkenmark and Rockström 2006)

- Provisioning services are the products people obtain such as food, water, wood and fuel
- Regulating services are the benefits people obtain from the regulation of ecosystem processes such as climate, erosion, water
- Cultural services are the non material benefits people obtain
- Supporting services are those that are necessary for the production of all other previous ecosystem services.

Table 4.1 Percentage of rainwater use to sustain water dependent human activities at the global level

Water	% of rainfall	Flow domain		Use	% of rainfall
Blue	38 %	Available	Used	Food (irrigated)	2 %
				Domestic and industry use	1 %
			Unused	Time-stable runoff (rivers)	8 %
		Unavailable		Flood runoff (non-utilizable)	27 %
Green	62 %	Direct		Food (rainfed)	4 %
				Permanent grazing	18 %
		Indirect		Grasslands	11 %
				Forests and woodlands	17 %
				Arid lands	5 %
				Wetlands	1 %
				Lake evaporation	1 %
				Unaccounted green flow	5 %

Source: Rockström et al. (1999)

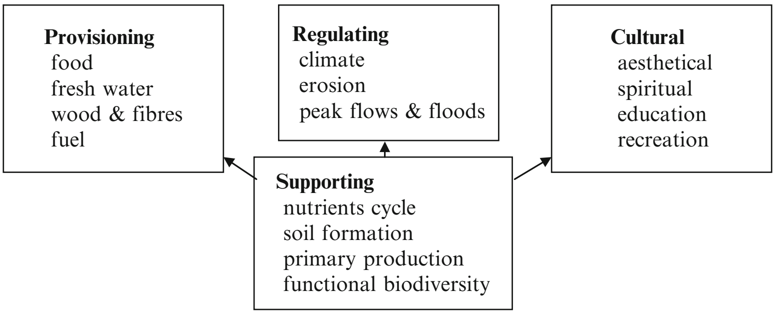


Fig. 4.3 Categories of goods and services provided by ecosystems (Source: Millennium Ecosystem Assessment 2005)

4.3 Green and Blue Water in the WANA Region in the Context of Climate and Land use Changes

Although, world temperature change scenarios vary regionally, they show clear trend towards warming. In some Mediterranean countries, the increment was 1.53 °C for the period 1971–2000. In addition, simulation of future climate scenarios tend to agree that higher GHGs emission levels could produce a temperature increase higher than the global average value, and further reduce precipitation (of up to 20 % by 2100), increase their inter-annual variability (+4 °C and –20 % to 50 % rainfall in summer) (Fig. 4.4), and induce extreme events such as droughts and heat waves and floods, that would have negative consequences on ecosystems (EFIMED 2009).

Consequently, it was predicted a marked decrease of runoff (20 %) with negative consequences for water and food supply (Fig. 4.5). In areas where rainfall and

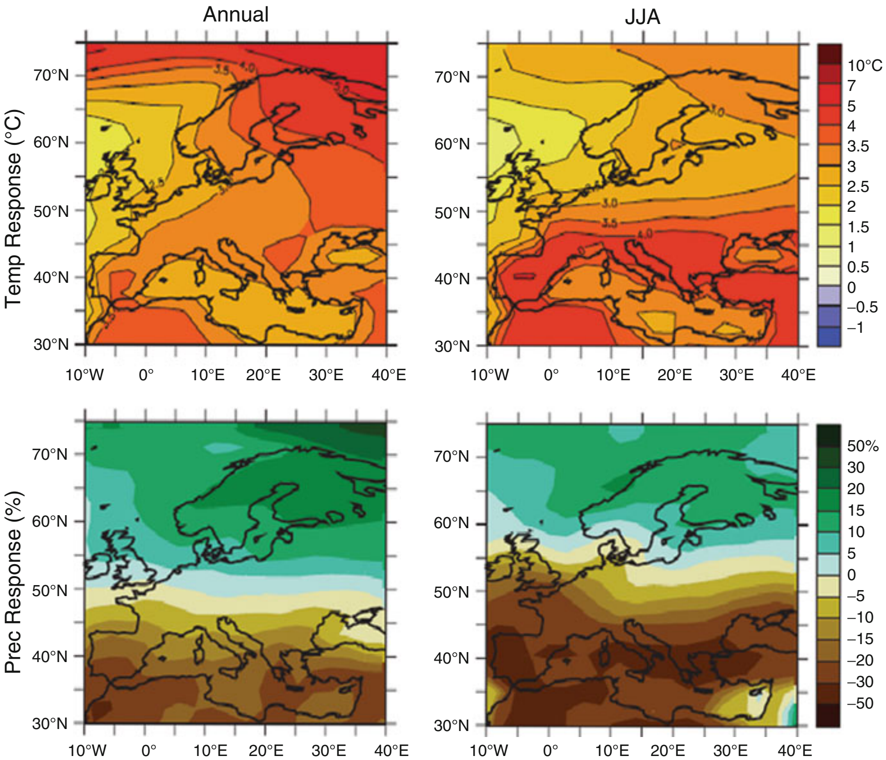


Fig. 4.4 Simulated temperature and precipitation changes over 2100 for the A1B scenario

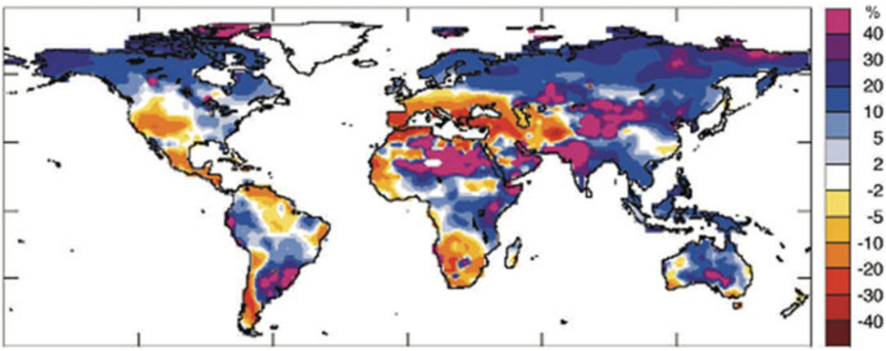


Fig. 4.5 Projection of changes in runoff by 2041-60 based on 12 models (Source: IPCC, AR4 2007)

runoff are very low, small changes can lead to large percentage changes. These changes are projected to have great impacts on ecosystem structure and functions, with dominantly negative consequences for ecosystem goods and services, water and food supply.

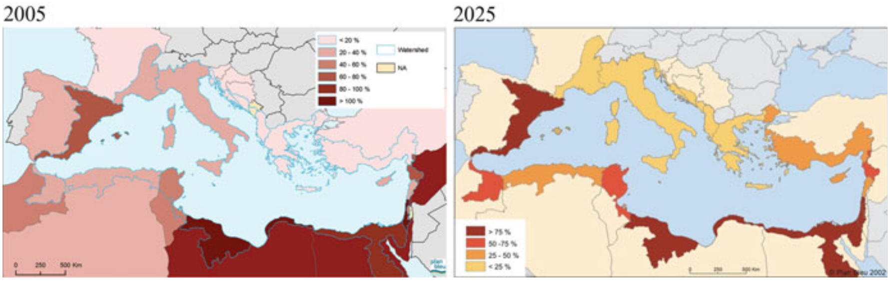


Fig. 4.6 Water exploitation index (Source: Hamdane 2002)

In addition to risks related to climate change, demographic growth and economic development will increase the pressure on water resources, expressed with the renewable natural water exploitation index (see Fig. 4.6). In the Mediterranean region, there are 60 % of the world's "water-poor"[1] countries (80 millions). This pressure on water uses may induce conflicts between population needs and ecosystem conservation requirements (Thivet 2011). Demographic growth increases the need for food, water, soil and energy, and accrues the pressure on natural resources. The surface of cultivated land has been multiplied (+40 % in Morocco, +28 % in Egypt 1960–2000), where land has been reclaimed with difficulty from pasturelands, forests and deserts (Thivet 2011). Deforestation occurs in several countries, the annual loss in forest area (2005–2010) is 1.95 % in Mauritania, 0.58 % in Algeria, 0.08 % in Sudan (FAO 2010). This pressure is expected to remain high at least until 2020, increasing deforestation and desertification, and aggravating resource degradation (Thivet 2011).

Changes in land use in rural or circum-urban areas, in plant cover, and in watershed management (e.g. soil and water conservation) will be major drivers of the share between green and blue water. Consumption of blue water already reaches an upper limit (80 % of the surface water is stored in dams in Morocco and Tunisia). In addition, climate change will lead to an increase of the evapotranspiration demand and reduce overland runoff. These concerns underline that new hydrological balances reflecting these changes need to be established, and the share between green and blue water should be assessed in the context of tradeoffs related to future uses of water, particularly in agriculture, wherever possible.

4.4 Conserving Green and Blue Water and Human Welfare

Water regulation is an important but not exclusive function of ecosystems. Many other ecosystem services (ES) are generated: biodiversity conservation, carbon sequestration and recreation. These services can be synergic (moisture retention, wood production) or opposite (carbon sequestration, water quantity). Water and

[1]Less than 500 m^3 $year^{-1}$ $capita^{-1}$

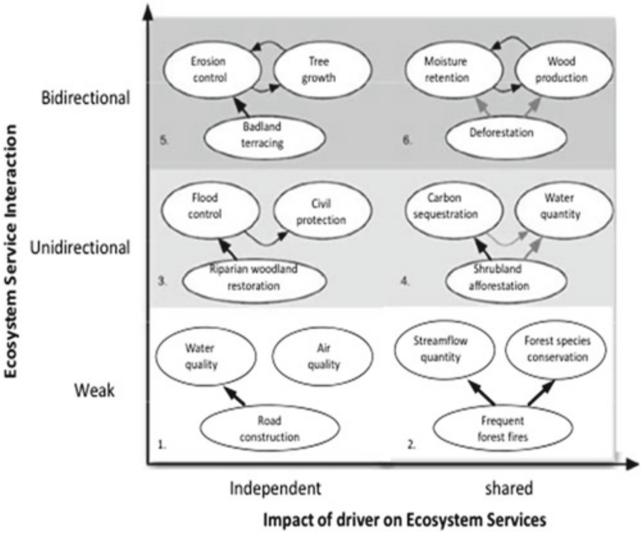


Fig. 4.7 Examples of possible interactions between water and other ecosystem services (Benett et al. 2009). *Black arrows* indicate positive effects, grey arrows negative effects

ecosystem management should be based on a better understanding on how water and other ecosystem services interact with each other (Fig. 4.7) (Muys et al. 2011).

Understanding ES trade off is an excellent basis for an integrated sustainable landscape management. Any management has an effect on the relative mix of ES provided.

Planting trees in an overall context of water scarcity should consider threats and opportunities. Many MENA countries are characterized by physical, climatic and socio-economic conditions that are particularly favorable to erosion which threatens the soil potential of the country. In this context, forest plantation can play an important role in watershed protection, sand dune fixation and, in some cases, combating desertification if water limitations are taken into account in the design of such projects. In addition to this protective role, planted forests offer a wide range of goods and services, including variety of wood (timber, fuel-wood), fodder production, fruits, etc. Regarding the role of plantation in watershed management, it is clear that forest cover maintains soil fertility, reduces sedimentation, and thus, contributes to conserve the watershed capacity of reservoirs and to improve water quality, and consequently, extends the life duration of reservoirs and reduce the cost of water treatment. However, plantations, especially of forest growing species, increase water infiltration and reduce the runoffs and thus reduce the quantity of water that reach reservoirs, and the total annual water flow due to evapotranspiration (Cossalter and Pye-Smith 2005). Forests are usually net consumers of water. Water footprint of forest products depends on tree species & growth conditions and, it is strongly dependent on the management regime. It is estimated to 2,073 m^3 of water/m^3 of wood for *Pinus halepensis*, and to 2,981 m^3 of water/m^3 of wood for *Quercus suber*

(Gracia et al. 2011). It is crucial to understand the responses of forests not just in terms of carbon and biomass but also in terms of water. Planting trees for wood or carbon sequestration is highly questionable because of the high cost of water (about 500 m^3 of water/t of carbon). Also, water scarcity can result in a marked alteration of ecosystem functions and reduce the provision of goods and services to human societies.

In addition, planting trees should take into account not only the multitude of marketed and non marketed goods and services that could be provided, but also, the large number of stakeholders at local and national level that could be affected and that have different and divergent perceptions regarding forest plantation and the use of natural resources. While public administration is more concerned by soil and water resources protection and economic development, private owner is interested by the private benefits at short term of the plantation. Also, the local population who lives in forest areas, especially in WANA region, would like to increase its private income for the current use of natural resources at short term. Another distinction could be made between the upstream and downstream users. The upstream users can benefit from the direct uses of forest plantation, while the downstream users of water resources would be affected by the effects of land management change upstream on the quantity and quality of the water reaching the reservoir. This mixed characteristic of forest services and their scale dimension stress the critical trade off between watershed protection and local benefits for forest owners or local users. The situation is still more complex given that some land use changes can have non reversible effects, at least in the short term, on the development of forests.

4.5 Recommendations for a Sustainable Management of Water and Ecosystems in the WANA Region

New and realistic policies offer options for progress through a sustainable management of water and ecosystems.

4.5.1 Improving Water use Efficiency Through Reduction of Losses, Leaks, Wastage and Better Irrigation Techniques

By acting on water demand, potential for progress is considerable as improved demand management could allow saving one fourth of the demand in the Mediterranean, or 85 km^3/year in 2025 (Fig. 4.8). Irrigated agriculture represents the largest potential for savings in volume, with nearly 65 % of total water savings identified in the Mediterranean. In this optimistic perspective, the total water demand would reach 140 km^3 $year^{-1}$ in the South and Near East, globally, equivalent to a reduction of 25 km^3 $year^{-1}$ of the current total demand.

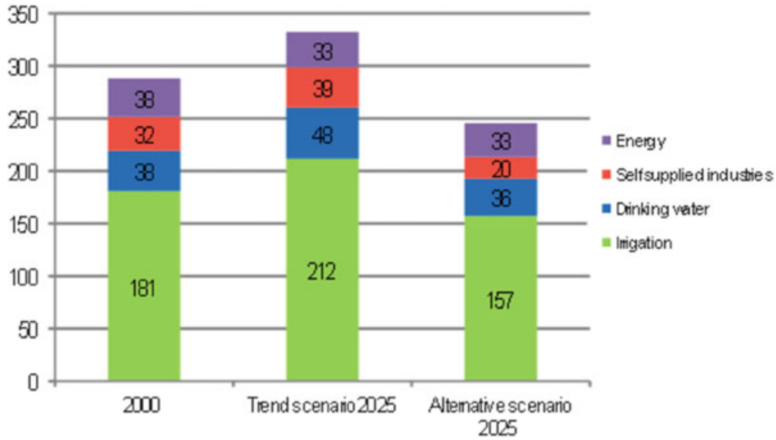


Fig. 4.8 Water demand per sector of use (km³ year⁻¹) in the Mediterranean region, trend and alternative scenarios (2025) (Source: Hamdane 2002)

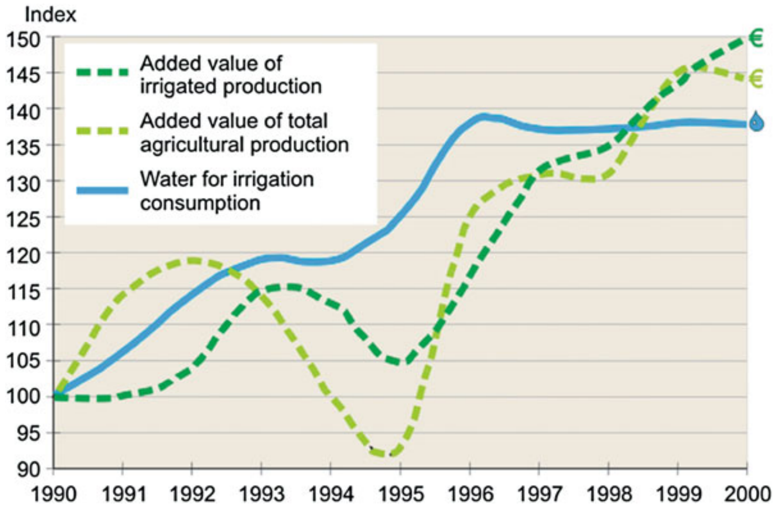


Fig. 4.9 Water consumption and added value of irrigation in Tunisia (Source: Hamdane 2002)

For example, Tunisia has implemented a national strategy for irrigation water savings based on the creation of user associations, a pricing system which has lead to gradual recovery of costs, and specific financial instruments to endow farms with water-saving technologies and to support farmer income. This policy has, since 1996, stabilized the demand for irrigation water despite the significant development of the farming sector and has secured the needs of the tourism industry -source of currency- and cities (Fig. 4.9).

4.5.2 Optimizing Land Management Water Oriented

For selecting the optimal land use, full costs of provision and value should be considered in valuing alternative uses. The effects of the land use change on water resources and their distribution among stakeholders should be analyzed when establishing a strategy of land management in a water-constrained environment. For example, before the conversion of shrubs to forest plantation, we should compare the situations with and without intervention: what would be the on-site effects at long term on direct uses (wood, fodder, fruits, etc.)?, but also what are the off-site effects on water flows, groundwater recharge, sediments, water quality? What are the net returns for the forest owner, local users, but also what are the net benefits at social perspective? Who are the gainers and the losers from this land use change? The plantation could be conducted only if it can be economically desirable at social perspective, i.e. the discounted net benefits of the plantation exceed those of the situation without intervention. The analysis should also consider the projected effects of climate change that, in some cases will severely reduce water availability.

The value of water is composed of the economic and intrinsic value. The economic value includes not only the value of water to users, but also, the net benefits of return flows (recharge of groundwater), the net benefits from indirect use (improvement in health), and adjustment for societal objectives (poverty alleviation, employment generation). Similarly, water pricing should reflect the scarcity of water. The recommended approach would be to define the water basis of the full cost of supply, it includes operating and management cost, capital charges, opportunity cost, economic and environmental externalities (Rogers et al. 2002). Nevertheless, in most countries, water is priced below its full cost. Such pricing system not only underestimates the price of water, it also fails to provide incentives for more efficient water use.

4.5.3 Tools for Integrated Water use

While water pricing and different water allocation systems help reduce water demand and overuse, they don't contribute to conserving the ecosystem that provides water services. Other mechanisms need to be devised to support the conservation of ecosystems such as payment of ecosystem services (PES), trading systems, etc. (Croitoru and Young 2011)

Usually, investments for ecosystem conservation and forest plantations induce lower direct returns compared to the current situation "*business as usual scenario*", but could generate higher benefits for the society, when local- and national-scale externalities such as increased soil fertility and water capacity, and global-scale externalities, such as biodiversity protection, carbon sequestration, are included (Daly-Hassen et al. 2010). Consequently, there is a need for offsetting the potential

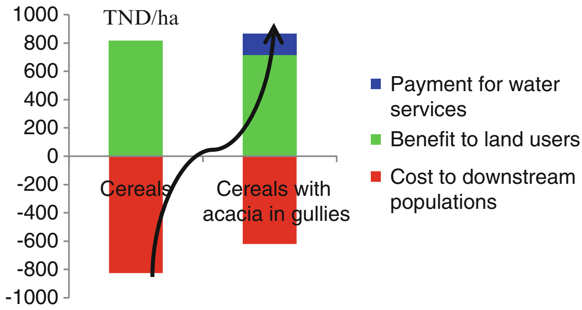


Fig. 4.10 PES scheme to convert cereals to cereals with acacia in gullies (Source: Croitoru and Daly-Hassen 2010)

income loss, if improvements in soil fertility and water capacity were undertaken. Non market benefits and off site effects are not usually considered because it remains difficult to measure the land use effects on soil erosion and water resources, especially for large basins (Achouri 2002). Usually, public intervention through subsidies, grants and compensation for income loss, is needed to fill the gap between private profitability and public utility (Daly-Hassen et al. 2010). Besides these traditional instruments, other market-based instruments were introduced, based on the payment by off-site beneficiaries for the services provided. Mostly applied for water provision services, these instruments were implemented through Payment for Environmental Services (PES) scheme i.e. direct negotiations between water users and landowners, trade of "credits" between companies and landowners for exceeding the requirements on water use, or public payments to farmers/forest owners for management practices that protect water quality (Perrot-Maitre and Davis 2001).

An illustrative example of potential PES scheme can be drawn from the management of Barbara watershed in North-Western Tunisia (Croitoru and Daly-Hassen 2010). Most land is privately owned and cultivated with cereals. In order to protect downstream water infrastructure, the government gives large subsidies (80 % of the investment costs) to protect gullies using acacia plantation and/or check-dams. But, these subsidies are not conditional and land owners are not compensated for the foregone income from grazing resources. Consequently, the survival rate of acacia is quite low. The economic analysis of different land use alternatives showed that all the protection measures are less profitable for farmers than producing cereals alone, and only one, cereals with acacia plantation in gullies, seems to be profitable at national perspective. In order to encourage acacia plantation in gullies, farmers should be compensated for the income loss incurred (100 TND ha^{-1}). This compensation could be covered by the reduced cost of sedimentation (200 TND ha^{-1}) (Fig. 4.10). The payment by water users beneficiaries could increase the budget available for conservation, contribute to a more efficient use of water and could increase the survival rate of acacia because payments would be conditional to success indicators.

Usually, forest and woodland cover important areas, covering the upper part of a watershed, and playing a crucial role in soil protection and water conservation, whose impact on water quality can be huge. Improving the conservation of water services is possible through the payment by downstream users to upstream land users for water services provided. For example, in the artificial lake of La Môle in a fully forested (cork oak) watershed supplying water to the tourist town of Saint-Tropez, Var, France, a water company is paying annual fees to the local forest owners (public & private) for maintaining the fuel-break network, and thus limiting the risk of wildfires, whose impact on dam siltation and water quality can be huge.

4.6 Conclusions

Ecosystems can undergo major changes in area due to global changes which can condition the future availability of water resources. Also, land use changes have a major impact on runoff and soil degradation. Green water flows sustain main ecosystem functions and the derived goods and services, and prevent major risks of unsustainability: desertification, rural poverty, silting of dams, biodiversity loss, degraded water resources and increased vulnerability to floods.

The sustainable management of water resources and demand must above all be based on an integrated approach at the level of catchment areas. Integrating ecological, socio-economic and hydrological management is a key approach towards sustainability. Predominantly supply-driven policies have led to the misuse or overuse of water. Reversing these trends is possible by acting on both the demand and the supply side through economic instruments. Innovative policies, acting on demand for water, do exist for coping with water shortage issues. Many new tools for trade-off analysis and land management optimization have become available to integrating water with other ecosystem services. Improving the conservation of ecosystems as water providers is possible through the payment by downstream users of clean water to upstream land users.

References

Achouri M (2002) Forests and water: towards effective watershed management. In: International expert meeting on forests and water, Shiga, 20–22 Nov 2002

Benett EM, Petrson GD, Gordon LJ (2009) Understanding relationships among multiple ecosystem services. Ecol Lett 12:1394–1404

Birot Y, Gracia C (2011) The hydrological cycle at a glance: blue and green water. In: Birot Y, Gracia C, Palahi M (eds) Water for forests and people in the Mediterranean: a challenging balance, vol 1, What science can tell us. EFI, Joensuu

Birot Y, Gracia C, Palahi M (eds) (2011) Water for forests and people in the Mediterranean: a challenging balance, vol 1, What science can tell us. EFI, Joensuu

Cossalter C, Pye-Smith C (2005) Fast-wood forestry: myths and realities. CIFOR, Bogor

Croitoru L, Daly-Hassen H (2010) Using payments for environmental services to improve conservation in a Tunisian watershed. Mt Forum Bull 10:89–91

Croitoru L, Sarraf M (eds) (2010) The cost of environmental degradation: case studies from Middle East and North Africa. The World Bank, Washington, DC

Croitoru L, Young M (2011) The economics of water and forests: issues and policy recommendations. In: Birot Y, Gracia C, Palahi M (eds) Water for forests and people in the Mediterranean: a challenging balance, vol 1, What science can tell us. EFI, Joensuu

Daly-Hassen H, Pettenella D, Jemal Ahmed T (2010) Economic instruments for the sustainable management of Mediterranean watersheds. For Syst 19:141–155

EFIMED (2009) A Mediterranean forest research agenda (MFRA) 2010–2020. EFIMED, Barcelona

Falkenmark M, Rockström J (2006) The new blue and green water paradigm: breaking new ground for water resources planning and management. J Water Res Pl-ASCE 132:129–132

FAO (2010) Global forest resources assessment 2010. Food and Agriculture Organization, Rome

Gracia C, Vanclay J, Daly H, Sabaté S, Gyenge J (2011) Securing water for trees and people: possible avenues. In: Birot Y, Gracia C, Palahi M (eds) Water for forests and people in the Mediterranean: a challenging balance, vol 1, What science can tell us. EFI, Joensuu

Hamdane MA (2002) Rapport Tunisie. Forum de Fiuggi "Avancées de la gestion de la demande en eau en Méditerranée". Plan Bleu. Octobre 2002

IPCC (2007) Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. In:Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds). Cambridge University Press, Cambridge, UK/New York

Mavsar R (2011) Balancing water for ecosystems, goods and services, and people. In: Birot Y, Gracia C, Palahi M (eds) Water for forests and people in the Mediterranean: a challenging balance, vol 1, What science can tell us. EFI, Joensuu

Millennium Ecosystem Assessment (MEA) (2005) Ecosystems and human well-being: wetlands and water. Island Press, Washington, DC

Muys B, Ceci P, Hofer T, Veith C (2011) Towards integrated ecological, socio-economic and hydrological management. In: Birot Y, Gracia C, Palahi M (eds) Water for forests and people in the Mediterranean: a challenging balance, vol 1, What science can tell us. EFI, Joensuu

Perrot-Maitre D, Davis P (2001) Case studies: developing markets for water services from forests. Forest Trends, Washington, DC. http://www.forest-trends.org

Rockström J, Gordon L, Folke C, Falkenmark M, Engwall M (1999) Linkages among water vapor flows, food production and terrestrial ecosystem services. Conservat Ecol 3(2):5

Rogers P, de Silva R, Bhatia R (2002) Water is an economic good: how to use prices to promote equity, efficiency and sustainability. Water Policy 4:1–17

Thivet G (2011) Coping with increased population and land use changes. In: Birot Y, Gracia C, Palahi M (eds) Water for forests and people in the Mediterranean: a challenging balance, vol 1, What science can tell us. EFI, Joensuu

Chapter 5
Climate Change and Land Use in the WANA Region with a Specific Reference to Morocco

Mostafa Ibrahim and Rattan Lal

Abstract West Asia and North Africa (WANA) region comprises of 22 countries (Algeria, Bahrain, Cyprus, Egypt, Eritrea, Ethiopia, Iran, Iraq, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, Sudan (formerly), Syria, Tunisia, Turkey, United Arab Emirates, and Yemen). Climate of the WANA region is generally arid and semi-arid with high temperature and low rainfall. Total population has increased from 192 million in 1965 to 564 million in 2009. The arable land area increased from 97 Mha in 1965 to 110 Mha in 2010. However, forest land area decreased slightly from 125 Mha in 1990 to 117 Mha in 2009. The land area under permanent pastures and meadows increased slightly from 425 Mha in 1990 to 453 Mha in 2009, but that under permanent crops doubled from 6.6 Mha in 1965 to 13.5 Mha in 2009. Furthermore, area under temporary crops also increased slightly from 75 Mha in 2001 to 84 Mha in 2009. With reference to Morocco as a case study, its total population increased drastically from 13.3 to 31.6 million between 1965 and 2009. The arable land area increased slightly from 6.8 Mha in 1965 to 8.1 Mha in 2009. The area under forest land increased slightly from 5.05 Mha in 1990 to 5.12 Mha in 2009. The land area under permanent pastures and meadows increased slightly from 16.4 Mha in 1961 to 21 Mha in 2009. However, the area under permanent crops doubled between 1965 and 2009 from 0.43 Mha to 1.0 Mha, respectively. Land area under temporary crops decreased from 6.7 Mha in 2001 to 4.3 Mha in 2008.

M. Ibrahim (✉)
Soil and Water Science Department, College of Agriculture,
Zagazig University, Zagazig, Egypt
e-mail: amostafa@zu.edu.eg

R. Lal
Carbon Management and Sequestration Center, School of Environment
and Natural Resources, The Ohio State University, 2021 Coffey Road,
422B Kottman Hall, Columbus, OH 43210, USA
e-mail: lal.1@osu.edu

M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_5,

Keywords Climate change • Land use • Drought • Soil properties • Agronomic yield

5.1 Introduction

Many countries in West Asia and North Africa (WANA) region, are linked by language (Arabic), religion (Islam), history (most of these countries were under the same rules during eras of different empires such as the Roman and Ottoman), and geographic features such as surface or ground water basins (Casas et al. 1999). The WANA region includes 22 countries comprising of Algeria, Bahrain, Cyprus, Egypt, Eritrea, Ethiopia, Iran, Iraq, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, Sudan (formerly), Syria, Tunisia, Turkey, United Arab Emirates (UAE), and Yemen. It extends from Morocco in the west to the Arabian/Persian Gulf in the east, and from the Mediterranean Sea in the north to Yemen and Ethiopia in the south (Fig. 5.1). Total area of the region comprises 10.6 % of the world's area or 1,595.7 million hectare (Mha), of which 97.4 % is land, and 2.6 % is inland

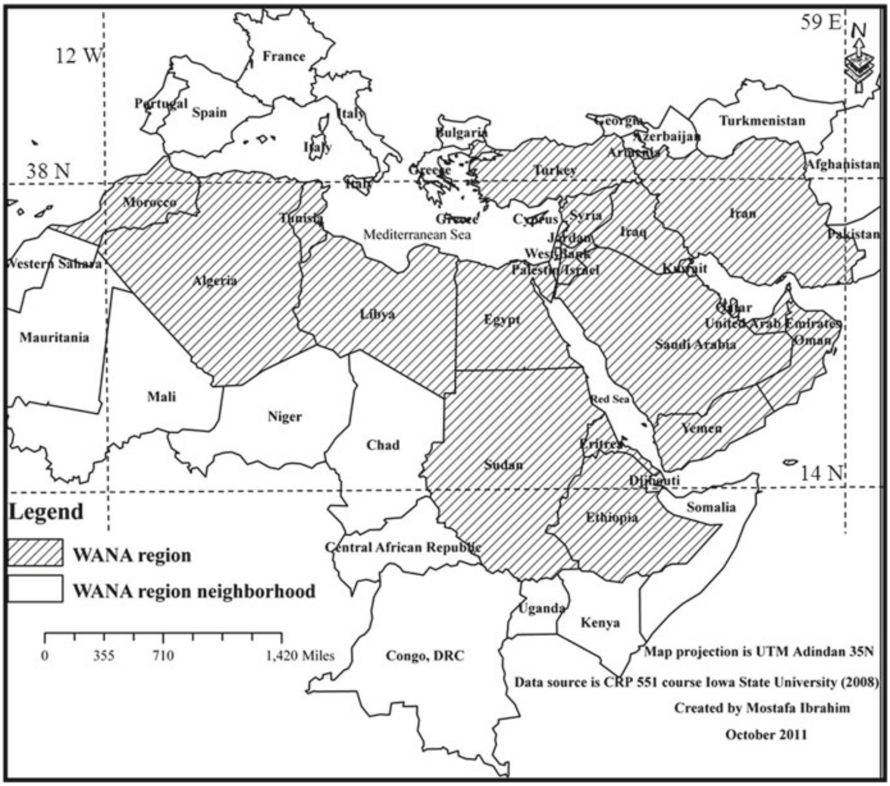


Fig. 5.1 Locations of the WANA countries

Table 5.1 General information about the WANA countries (WMO 2012; FAO 2012b, c)

Country	Total area[a] (×10^6 ha)	MAT[b] (°C)		MAP (mm)
		Min.	Max.	
Algeria	238.17	11.9	23.7	89
Bahrain	0.08	23.0	30.1	83
Cyprus	0.93	12.8	26.0	498
Egypt	100.15	15.8	27.7	51
Eritrea	11.76	15.9	23.2	384
Ethiopia	110.43	15.6	23.1	848
Iran	174.52	11.7	22.5	228
Iraq	43.83	14.9	30.6	216
Jordan	8.88	11.3	23.5	111
Kuwait	1.78	19.9	34.3	121
Lebanon	1.05	10.0	30.0	661
Libya	175.95	15.6	25.4	56
Morocco	44.66	13.5	27.8	346
Oman	30.95	23.9	33.0	125
Qatar	1.16	21.6	32.7	74
Saudi Arabia	214.97	19.7	32.9	59
Sudan	250.58	22.8	37.0	416
Syria	18.52	8.1	25.3	252
Tunisia	16.36	13.3	23.5	207
Turkey	78.36	6.0	17.7	593
UAE	8.36	20.2	33.7	78
Yemen	52.80	22.0	37.0	167
Total	**1,595.7**			–

[a]Total area information was obtained from FAO (2012c)
[b]Mean Annual Temperature was obtained from WMO (2012). Mean Annual precipitation was obtained from FAO (2012b)

water (Table 5.1). Total area of each individual country varies widely (e.g., the largest countries are Sudan (formerly) and Algeria, which occupy 250.6 and 238.2 Mha, respectively; and the smallest countries are Bahrain and Cyprus, which occupy 76,000 and 925,000 ha respectively).

The WANA countries can be divided into five geographical regions: the Nile Valley/Red Sea region (Egypt, Eritrea, Ethiopia, and Sudan (formerly)), North Africa region (Algeria, Libya, Morocco, and Tunisia), the Arabian Peninsula region (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, UAE and Yemen), West Asia region (Cyprus, Iraq, Jordan, Lebanon and Syria), and Highlands region (Iran and Turkey).

Most of the WANA countries are characterized by the Mediterranean climate, with hot and dry summer, and cold winter with little rains. The whole region can be categorized into four climatic sub-regions. The arid and semi-arid sub-regions comprise 68.5 % of the total land area, and receive <300 mm year^{-1} of mean annual precipitation (MAP); the semi moist sub-region comprises 19.7 % of the total land area with 300 to 500 mm year^{-1} of MAP; and the moist region comprises 12 % of the total land area with >500 mm year^{-1} of MAP. The region also has a wide range

Table 5.2 Change in total arable land in the WANA countries between 1965 and 2010 (FAO 2012b)

	Total arable land area (1,000 ha)					
Country	1965	1975	1985	1995	2005	2010
Algeria	6,203	6,845	6,910	7,519	7,511	7,500
Bahrain	1	1	2	2	2	1.3
Cyprus	100	100	103	99	123	87
Egypt	2,582	2,691	2,305	2,817	2,563	2,884
Eritrea	498	498	498	438	620	690
Ethiopia	11,995	13,000	11,850	9,940	12,923	13,948
Iran	15,020	15,850	14,900	17,388	16,533	17,205
Iraq	4,800	5,100	5,250	5,350	5,500	4,500
Jordan	276	291	277	252	185	200.8
Kuwait	1	1	3	5	11	11.3
Lebanon	206	234	204	180	142	145
Libya	1,715	1,740	1,787	1,870	1,750	1,750
Morocco	6,800	7,293	7,878	8,921	8,122	8,055
Oman	20	23	29	28	28	99
Qatar	1	2	8	13	13	12
Saudi Arabia	1,220	1,620	2,550	3,655	3,500	3,200
Sudan	11,172	12,115	12,600	16,157	19,434	20,160
Syria	6,342	5,125	5,038	4,799	4,675	4,670
Tunisia	3,180	3,410	3,070	2,842	2,730	2,707
Turkey	23,841	24,908	24,595	24,654	23,830	21,351
UAE	5	11	26	43	64	64
Yemen	1,305	1,363	1,372	1,633	1,287	1,171
Total	**97,283**	**102,221**	**101,255**	**108,605**	**111,545**	**110,411**

of temperatures, e.g., the mean annual temperature (MAT) ranges from 6 °C during winter in Turkey to 37 °C during summer in Sudan and Yemen (Table 5.2).

Although the climate of the most part of the region is hot and dry, it is projected to be hotter and drier in the future as a consequence of climate change (Cervigni and Dobardzic 2012). The latter is defined as any changes in climate over time due to both natural variability and human activity (IPCC 2007). Most projections indicate an increase in the mean annual surface air temperature in the WANA region by 3–4 °C between 2080 and 2099 compared with that between 1980 and 1999 (Nakicenovice et al. 2000). Some projections indicate a rise in the surface air temperature by as much as 9 °C in North Africa by 2070 (Ruosteenoja et al. 2003), and by 5 °C in Asia (Lal et al. 2001).

Increasing temperature causes the Arctic ice to melt, and the sea level to rise, which may submerge many coastal areas. The sea level is projected to increase by 0.1–0.3 m by 2050, and 0.1–0.9 m by 2100 (Dasgupta et al. 2007). Consequently, many low lying coastal areas in the WANA region (e.g., Tunisia, Qatar, Libya, UAE, Kuwait, and Egypt) might be at risk. For example, a rise of 0.5 m in the sea level may cause >2 million people in Alexandria, Egypt to evacuate due to land submergence by sea water (Cervigni and Dobardzic 2012). Similarly, some parts of the Nile delta in Egypt may be submerged by 2050 as a consequence of sea level rise and decreased sediments delivery. Consequently, >300,000 people may be directly affected (Parry et al. 2007). In the meanwhile, the MAP is expected to decrease by 20 % along the Mediterranean coast between 2080 and 2099 (Christensen et al. 2007).

The objectives of this study are: (1) studying population, land uses and their changes in the WANA region between 1960s and 2010, (2) investigating the climate change impacts on the land uses, and (3) studying drought and its management.

5.2 Population

The WANA region has experienced a substantial increase in total population since 1965, which increased from 191.6 million (or 5.8 % of the world's total) in 1965 to 564 million (or 8.2 % of the world's total) in 2009, with an annual growth rate of 2.5 %. Historically being an agrarian society, a large population lived in rural communities. In 1965, for example, the rural population was 130 million compared with an urban population of 60 million (FAO 2012a). However, both rural and urban communities have increased during the past few decades, albeit at different growth rates. Urban population increased drastically with an average yearly growth rate of 4.5 % (FAO 2012a). In contrast, the rural population increased at a lower annual rate of 1.6 %. Consequently, both rural and urban population was ~231 million in 2000 (Fig. 5.2). In 2009, urban population exceeded the rural, being 302.6 and 261.4 million, respectively. Rapid increase in urban population is due to the migration from rural communities.

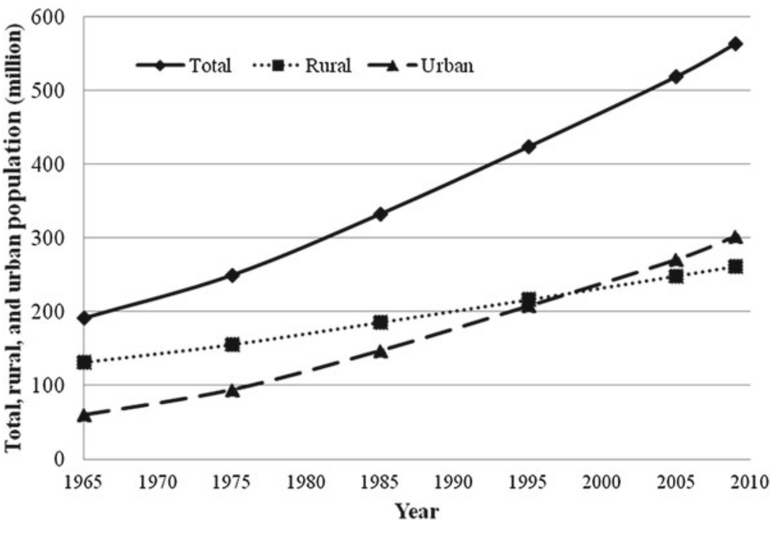


Fig. 5.2 Changes in total, rural and urban population between 1965 and 2010 (FAO 2012a)

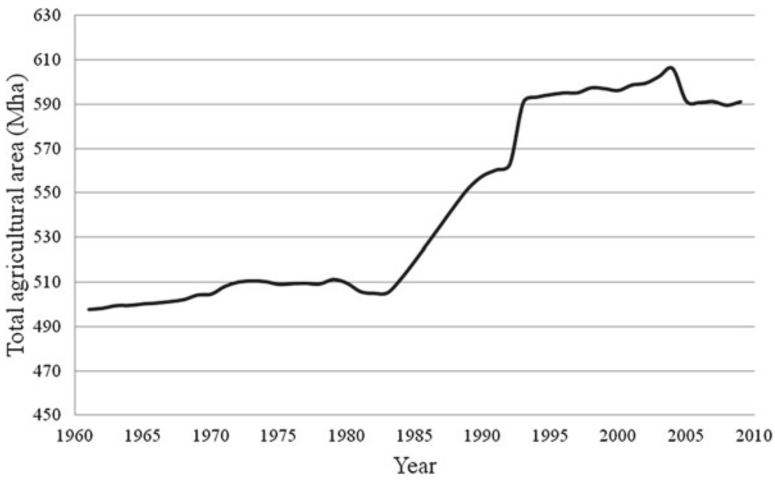


Fig. 5.3 Changes of agricultural land area in the WANA region between 1960 and 2010 (FAO 2012c)

5.3 Agricultural Land Use in the Region

The agricultural land refers to all areas used for agricultural purposes including crops and horticulture farms, grazing land, pasture land, meadows, fallow, livestock and fish farms, etc. Agricultural land has increased since the middle of the twentieth century, from 498 Mha (or 32 %) in 1961 to 606 Mha (or 38 % of the region's total land area) in 2004 (FAO 2012a). During this period, agricultural land area remained constant between 1961 and 1983; increased between 1984 and 2004, and has declined since 2004 (Fig. 5.3). Thus, natural resources were adequate for the population until 1983, and there was no need to increase the agricultural land. However, with the increase in total population and the demand for food, the WANA governments enlarged the agricultural area by reclaiming new lands and establishing livestock and fish farms.

5.4 Climate Change and Water Resources in the Region

Being arid and semi-arid, total renewable water resources of the WANA region are limited and estimated at 857.5 km^3 $year^{-1}$. Consequently, the per capita available water is below the minimum required amount of 1,000 m^3 $year^{-1}$ for many countries. Yet, the renewable fresh water resources may decrease because of the projected climate change, increasing temperature, decreasing rainfall, and increasing frequency and intensity of drought. Since 1980, most of the WANA countries have experienced severe droughts, with adverse effects on agricultural production. For example, the drought in 1999 reduced cereal grain production by 40 % in Syria, and red meat and milk production by 40 % in Jordan (Hamadallah 2001). Frequency and intensity of drought may increase in the coming decades.

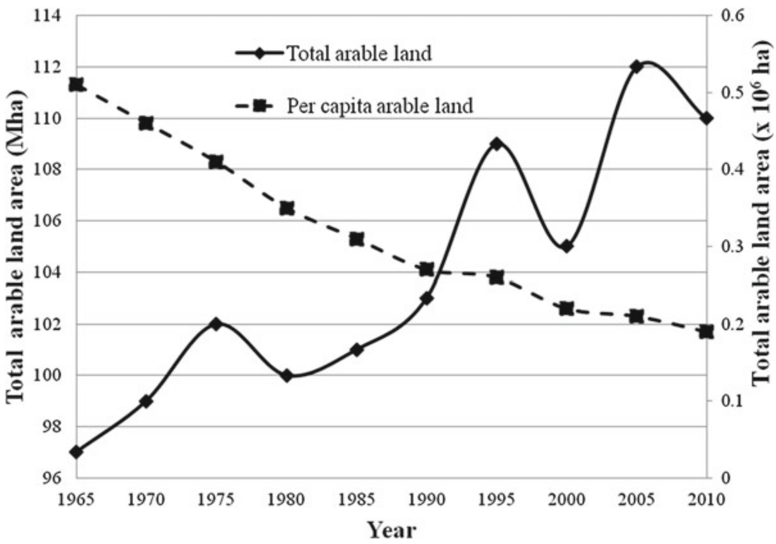


Fig. 5.4 Changes in total and per capita arable land area in the WANA region between 1965 and 2010 (FAO 2012a, c)

5.5 Arable Land

Arable land is defined as land under temporary crops (double-cropped areas are counted only once), temporary meadows for mowing or pasture, market and kitchen gardens, and temporary fallow (<5 years). The abandoned land resulting from shifting cultivation, and potentially cultivable lands are not considered arable (FAO 2012b). With a large area being desert, total arable land area is small, and unevenly scattered among countries of the region. In 2010, 4 of the 22 countries (Ethiopia, Iran, Sudan (formerly), and Turkey) accounted for ~66 % of the region's total arable land area. However, the region's arable land area increased from 97 Mha (or 6.2 % of the region's total land area; 7.5 % of the world's total arable land area) in 1965 to 110 Mha (or 7.1 % of the region's total land area; 8 % of the world's arable land area) in 2010 (Fig. 5.4; Table 5.2). The increase in total arable land area is associated even with a larger increase in total population. For example, the per capita arable land area declined from 0.51 ha in 1965 to 0.19 ha in 2010 (Fig. 5.4), probably due to: (1) the large increase in total population (which tripled between 1965 and 2010, but total arable land area increased by only 13 %), and (2) conversion of arable land to urbanization and the associated infrastructure.

Some increase in total arable land area since the middle of the twentieth century has been negated by: (1) drought and aridization caused by climate change, the low rainfall, limited water resources, and increase in evapotranspiration (Amin 2004), (2) encroachment by desert and sand dunes, which are prone to wind erosion, have low soil fertility, crops are prone to sand blasting, and the relatively fertile A horizon gets buried by aeolian deposition (Hagedorn et al. 1977; Sharif 1960), and (3) most of the irrigated arable land is prone to secondary salinization due to a combination of high evapotranspiration, low rainfall and poor water quality, which causes a decline in the agronomic productivity (Amin 2004).

Soils under arable land use are mostly young, and include Entisols (~33.6 %), Inceptisols, and Aridisols (44.5 %), Alfisols (e.g., Morocco, Sudan, Eretria, Jordan, Syria, Lebanon, Iraq, Turkey and Iran; 8.2 %), Vertisols (e.g., Morocco, Sudan, Egypt, Ethiopia, Eritrea, Iraq, Syria, and Turkey; 3.6 % of the region's arable land area), and ~10 % of other soil orders such as Mollisols, Ultisols, Andisols, etc. (Lal 2002; NRCS 2012). The projected increase in air temperature and decrease in precipitation may exacerbate the rate of decomposition of soil organic matter (SOM). Thus, Mollisols, which are the most fertile soils, may lose the Mollic horizon and be degraded to either Alfisols or Inceptisols (depending on the characteristics of the subsurface horizons), with reduced fertility.

Soil degradation can also be exacerbated by tillage, especially, the traditional or conventional plough-based tillage methods which pulverize the surface horizons, increase the decomposition rate of SOM, and increase the soil erosion hazard (Havlin et al. 1990; Wood et al. 1990). Top soil is also used as cattle bedding, and for brick making. Degradation effects of brick making and other extractive practices were in the past masked by use of manure and other organics, which at present are neither available nor adequate to enhance soil fertility. Since 1990, rather than using it as cattle bedding, compost or household fuel, crop residues are burnt in the field causing severe air pollution which also degrades soil fertility.

In order to enhance soil fertility and protect the environment, rather than burning crop residues, they must be retained as mulch in conjunction with conservation tillage. The latter with crop rotations increases SOM (e.g., SOM increased from 35 Mg h^{-1} to 40 Mg h^{-1}, under conventional tillage, versus 35 Mg h^{-1} to 53 Mg h^{-1} under no tillage, through 10 years (Sombrero and Benito 2010)), soil aggregates and their stability at the soil surface and subsurface, improves soil structure, and increases cereal yields (Mrabet et al. 2001; Masri and Ryan 2006). Conservation tillage moderates soil temperature, increases soil moisture, improves porosity, decreases bulk density, decreases runoff and evaporation, and minimizes soil erosion risks (Mrabet 2000).

5.6 Forest Land

The vegetation cover in the WANA region is patchy at best, and forested areas are relatively small and unevenly distributed among the WANA countries. Three countries (Ethiopia, Iran and the former Sudan) contain >83 % of the total forest area of the region. In contrast, some countries (Bahrain, Kuwait, Oman and Qatar) have <4,000 ha of forest land. The forest land area decreased from 124.8 Mha (or 8 % of the region's total land area, and ~3 % of the world's total forest area) in 1990 to 117.7 Mha (or 7.5 % of the region' total land area, and ~2.9 % of the world's total forest area) in 2009 (Fig. 5.5; Table 5.3). The WANA region lost 5.7 % of its forest land between 1990 and 2010, especially in Algeria, Ethiopia and the former Sudan.

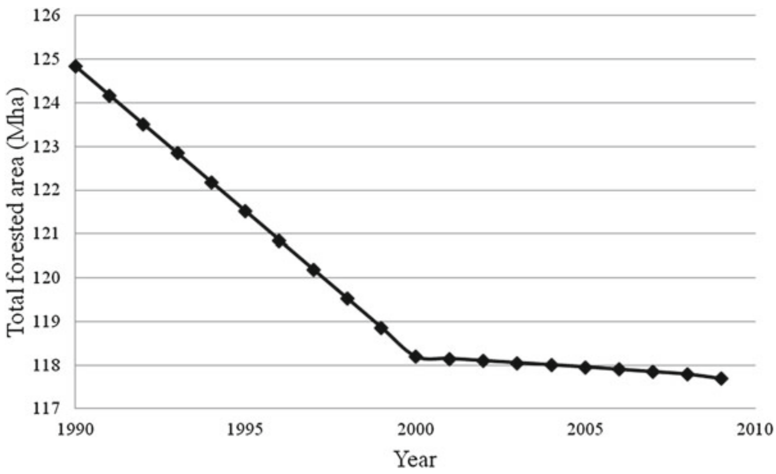


Fig. 5.5 Change in forested area in the WANA region between 1990 and 2010 (FAO 2012c)

Table 5.3 Change in forest area between 1990 and 2009 in the WANA region (FAO 2012c)

	Total forest area (1,000 ha)				
Country	1990	1996	2002	2005	2009
Algeria	1,667	1,614.2	1,561.8	1,536	1,500.8
Bahrain	0.2	0.3	0.4	0.5	0.5
Cyprus	161.1	167.41	172.11	172.85	173.1
Egypt	44	53	62.2	67	69.4
Eritrea	N/A	1,594	1,567.2	1,554	1,536.4
Ethiopia	16,735	14,268.6	13,423	13,000	12,436.8
Iran	11,075	11,075	11,075	11,075	11,075
Iraq	804	812.4	820.8	825	825
Jordan	97.5	97.5	97.5	97.5	97.5
Kuwait	3.5	4.3	5.1	5.6	5.97
Lebanon	131	131	133.2	136.5	136.8
Libya	217	217	217	217	217
Morocco	5,049	5,029.8	5,042.6	5,081	5,121
Oman	2.0	2.0	2	2.0	2.0
Qatar	0.0	0.0	0	0.0	0.0
Saudi Arabia	977	977	977	977	977
Sudan	76,381.4	72,847.1	70,382.6	70,220	70,003.2
Syria	372	408	443.6	461	485
Tunisia	643	759.4	871.8	924	940.4
Turkey	9,680	9,959.6	10,383.6	10,740	11,215.2
UAE	245	284	310.8	312	316.24
Yemen	549	549	549	549	549
Total	**124,833.7**	**120,850.61**	**118,098.3**	**117,953**	**117,683.4**

Morocco has lost ~5 Mha of its forest area since the Roman era to 1990 (Thirghood 1981), while Algeria lost ~2 Mha during the French occupation (Sari 1978) and ~650,000 ha of its forest was burnt during the Independence War between1954 and 1962 (RADP 1966; Zaimeche 1994). The remaining 18 countries have either preserved their forest areas or even slightly increased them.

With relatively low price of oil prior to 1970, the demand for charcoal as a source of power was also low. Furthermore, deforestation was prohibitively expensive, and the area of forest land in the region was almost constant. Since 1970, however, when oil price rose, charcoal became a cheaper alternative, and a competitive source of power throughout the WANA region. In addition to making charcoal, other causes of deforestation include timber harvest for furniture, and construction and industrial uses. Expansion of agriculture is another major cause of deforestation (Grove 1973; Elnagheeb and Bromley 1994), which has accelerated since 1970.

5.7 Permanent Pastures, Meadows, and Grazing Land

Permanent pastures and meadows are defined as a land used for >5 years to grow herbaceous and forage crops (FAO 2012b). Permanent pastures and meadows occupy an area of ~29 % of the region's total land area (FAO 2012c). Pasture land is mainly used for grazing horses and livestock. Permanent pastures and meadows cover ~79 % of the total land in Saudi Arabia (Table 5.4). The Rub'al-Khali, in addition to An-nafud desert, covers most of Saudi Arabia. With an exception of urban land, remainder of the land in Saudi Arabia is used for extensive grazing (Fig. 5.6).

Livestock is generally grazed on the crop residues remaining after the harvest (Rihawi 2012). Grazing by sheep has adverse effects on soil quality through the decrease of SOM and denudation of the soil surface. The former adversely affects physical, chemical and biological soil properties. For example, amount and stability of aggregates decreases, available water holding capacity is reduced, and permeability to water becomes faster in light-textured soils and slower in heavy-textured soils. Decline in SOM also reduces cation exchange capacity (CEC), decreases biotic activity, and diminishes soil fertility. Overgrazing denudes soil surface, increases soil erosion risks, and reduces productivity. Pasture and plant residues are insufficient for grazing. Consequently, livestock have to be stall-fed on crop residues, weed biomass, dry forage, and some grains (Fig. 5.7).

5.8 Permanent Crops

Permanent crops are those which are sown or planted once, then occupy the land for several years, and need not be replanted after each harvest (e.g., cocoa, coffee and rubber). Permanent crops include flowering shrubs, fruit trees, nut trees and vines, but exclude trees grown for wood or timber, and permanent meadows and pastures (FAO 2012b). Land area under permanent crops has increased since 1960s to meet

Table 5.4 Areas of permanent pasture and meadow in the WANA countries between 1990 and 2009 (FAO 2012c)

	Total area (1,000 ha)				
Country	1990	1995	2000	2005	2009
Algeria	31,041	31,620	31,829	32,848	32,890
Bahrain	4	4	4	4	4
Cyprus	5	4	2	1	4.3
Egypt	NA	NA	NA	NA	NA
Eritrea	NA	6,967	6,967	6,900	6,900
Ethiopia	44,900	20,000	20,000	20,000	20,000
Iran	45,000	45,500	46,600	29,524	29,524
Iraq	4,000	4,000	4,000	4,000	4,000
Jordan	791	791	791	742	742
Kuwait	136	136	136	136	136
Lebanon	300	300	325	370	400
Libya	13,300	13,300	13,300	13,500	13,500
Morocco	20,900	21,000	21,000	21,000	21,000
Oman	1,000	1,000	1,000	1,700	1,700
Qatar	50	50	50	50	50
Saudi Arabia	120,000	170,000	170,000	170,000	170,000
Sudan	110,000	113,370	115,225	116,340	116,340
Syria	7,869	8,287	8,359	8,266	8,244
Tunisia	3,793	4,470	4,561	4,928	4,853
Turkey	NA	NA	NA	NA	NA
UAE	230	300	305	305	305
Yemen	22,000	22,000	22,000	22,000	22,000
Total	**425,319**	**463,099**	**466,454**	**452,614**	**452,592.3**

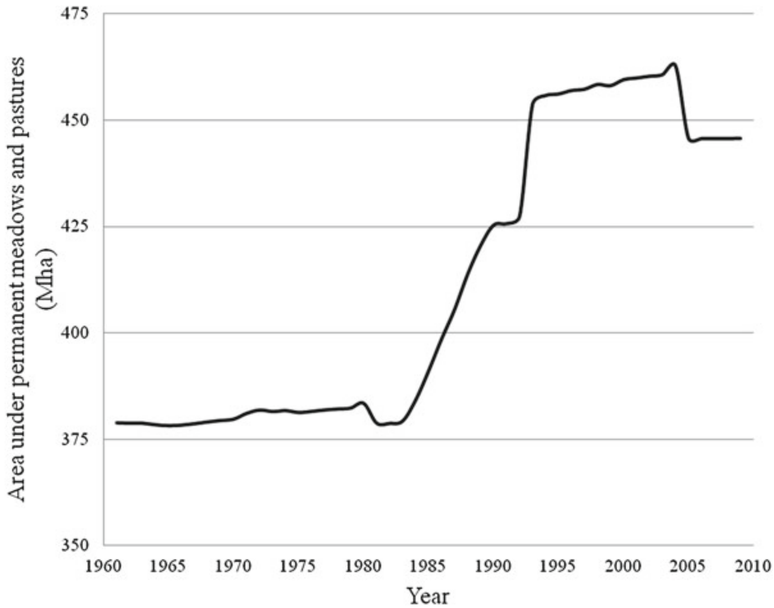


Fig. 5.6 Changes of area under permanent pastures and meadows between 1960 and 2010 (FAO 2012c)

Fig. 5.7 Feeding sheep in yards during shortage in pasture in the WANA countries (Courtesy Dr. Merwad)

Fig. 5.8 Changes in area under permanent crops in the WANA region between 1965 and 2009 (FAO 2012c)

the increase in nutritional, medical, and recreational demand by the increase in population. Total area of permanent crops doubled between 1965 and 2009 from 6.6 to 13.5 Mha (Fig. 5.8). The land area under permanent crops progressively increased except between 1990 and 1995 when there was a loss of 0.3 Mha mostly in Ethiopia and Turkey (FAO 2012c). In general, there has been an increasing trend in the land area under permanent crops.

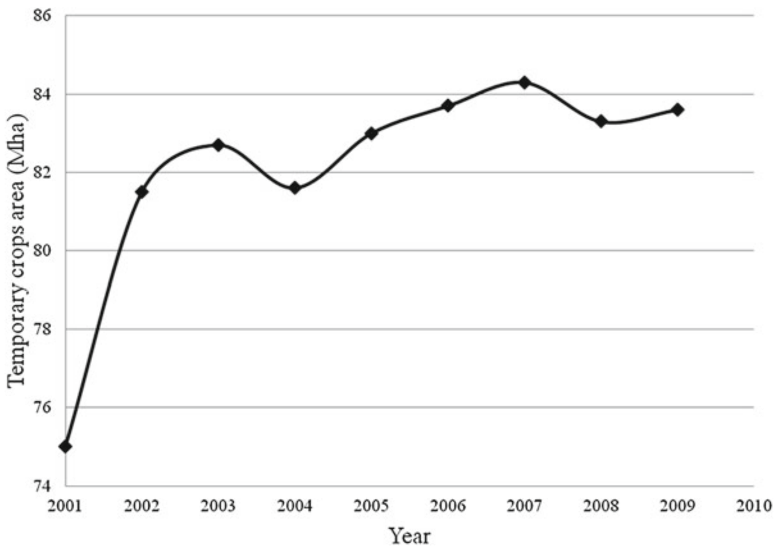


Fig. 5.9 Change in temporary crops area between 2001 and 2009 (FAO 2012c; AOAD 2009)

5.9 Temporary Crops

Temporary crops are planted and harvested every 1 or 2 years, and include cereals, vegetables, legumes, roots and tubers, etc. These crops are more important compared with permanent crops because people and livestock mainly depend on them. Thus, the area allocated to temporary crops is much larger than that to permanent crops, and was 75 and 83.6 Mha in 2001 and 2009 (FAO 2012c; AOAD 2009), respectively (Fig. 5.9). The area has been increasing slowly since 2001 because arable land is limited, and some is also converted to competing uses (i.e., urbanization).

5.10 Morocco: A Case Study

Morocco is located in the northwest corner of Africa and covers an area of 44.7 Mha (Fig. 5.1; Table 5.1). It is bordered by the Mediterranean Sea and Strait of Gibraltar in the north, Algeria in the south and east, and the Atlantic Ocean in the west. Its climate extends from the Mediterranean in the north to the Saharan subtropical desert with high mountains creating an altitudinal climate gradient (Lamb et al. 1989). Mean annual temperature ranges from 13.5 °C in winter to 27.8 °C in summer (Table 5.1). The presence of the Mediterranean Sea, the Atlantic Ocean, and the diverse geography (e.g., the Sahara Desert and Atlas Mountains) create diverse climatic regions. The MAP is 346 mm; however,

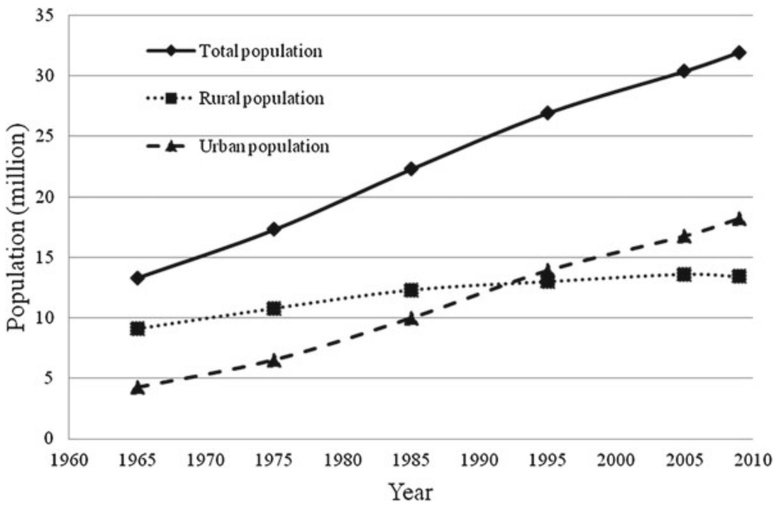


Fig. 5.10 Changes in Moroccan total, rural and urban population between 1965 and 2009 (FAO 2012a)

it differs drastically among the geographic regions. For example, it is <100 mm year^{-1} in the desert and coastal plains, and is 1,200 mm year^{-1} in the Rif and Atlas mountains (Nash et al. 2007). The diverse climate in different regions of Morocco also creates diverse land uses.

5.10.1 Population

Morocco is one of the populous countries in the WANA region. During the twentieth century, population of Morocco increased by >5 times, i.e., it increased from 5 million in 1910 to ~25 million in 1990 (Courbage 1994). Since 1960s, however, the Moroccan government adopted the family planning programs. Consequently, total population increased slowly from 13.3 to 32 million with an average annual growth rate of 2.3 % and 1.2 %, in 1965 and 2009, respectively (Fig. 5.10). The decline in population growth rate can be attributed to: (1) increase literacy and health awareness, especially among women, (2) improvement in standards of living, and (3) migration to Europe with a trend of having a small family (Courbage 1994).

Traditionally, Moroccan society has been primarily agrarian. Thus, rural population was twice as much as urban population (9.1 versus 4.2 million, in 1965). Since 1960s; however, rural population increased at a slower rate of 1.6 % and 0.4 % in 1965 and 2005, respectively. Furthermore, rural population decreased at an annual rate of −0.4 % between 2005 and 2009. In contrast, the urban population increased

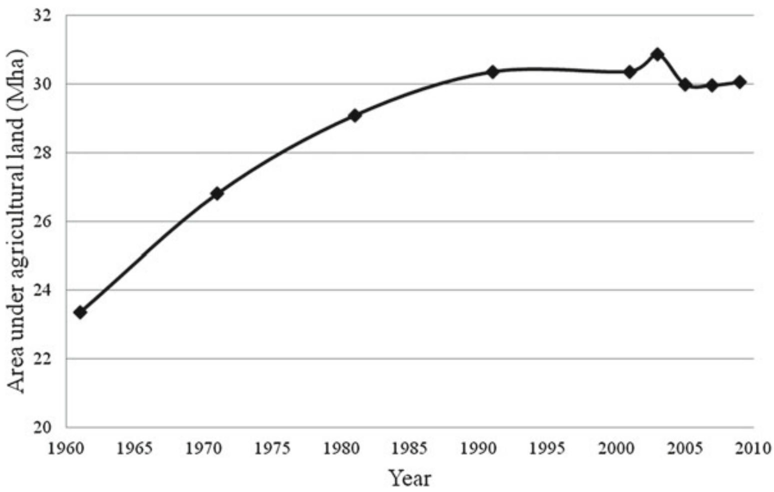


Fig. 5.11 Change in area under agricultural land in Morocco between 1961 and 2009 (FAO 2012c)

between 1965 and 2009 at an average annual rate of 3.5 % and 2.0 %, respectively. The drastic increase in the urban population between 1965 and 1995 was because of migration to cities. Since 1995, with improvement in transportation daily commute to cities, the rate of migration decreased with the attendant decline of the rate of growth of urban population (Courbage 1994).

5.10.2 Agricultural Land Use

Agricultural land comprises a large portion of the total land area, which has also increased since 1960s (Fig. 5.11). For example, it was 23.4 Mha (or 52.4 %) in 1961, and 30.1 Mha (or 67.4 % of the country's total land area) in 2009 (FAO 2012c). It increased between 1961 and 1991, and has stabilized since 1991. Prior to 1991, a large proportion of population was agrarian, which required a relatively large agricultural land area. Since 1991, however, internal and external migration decreased rural population (Courbage 1994). Consequently, the demand for agricultural land decreased, stabilizing its area. Morocco is still an agrarian country. Thus, in 2009, agricultural land area comprised of >67 % of the total land area. But, agricultural labor comprised of 41 % of the total labor force in Morocco between 2006 and 2008, and agriculture contributed only 13.1 % towards the gross domestic product (GDP) (AOAD 2009). The country experienced severe droughts between 1980 and 1985, and 1990 and 1995. Thus, crop yields decreased drastically and the Moroccan imports of wheat doubled in 1999 (ICARDA 2007).

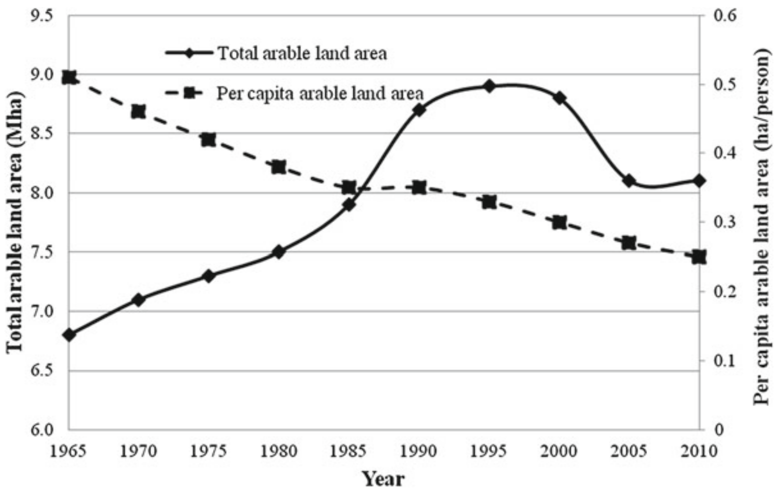


Fig. 5.12 Total and per capita arable land area in Morocco between 1965 and 2010 (FAO 2012c)

5.10.3 Arable Land and Climate Change

Arable land area comprises 27 % of the agricultural land area, and increased from 6.8 Mha (or 15.2 %) in 1965 to 8.9 Mha (or 20 % of the total area) in 1995. The arable land area decreased from 8.9 Mha in 1995 to 8.1 Mha in 2009 (Fig. 5.12). Despite an overall increase in total arable land area since 1960s, the per capita arable land area has decreased as a result of the increase in total population at an annual rate of 2.6 % compared with that of 0.4 % for the arable land area. Predominant soils are Entisols, Inceptisols and Aridisols, and comprise ~70 % of the total area. Alfisols and Mollisols comprise ~27 %, and Vertisols comprise the remaining 3 % (NRCS 2012). Because of climate-related soil degradation, there may be a substantial decrease in the area under Alfisols and Mollisols. The projected increase in temperature and decrease in precipitation may lead to oxidation of SOM at a faster rate. Consequently, the surface horizon characteristics may change from Mollic to an Ochric horizon. Furthermore, Mollisols may change to either Alfisols or Inceptisols according to the degree of development of the B horizon. These degradation trends may reduce soil fertility and decrease crop yields.

The traditional plough-based tillage is widely practiced, which has its pros (e.g., good seedbed), and cons (i.e., low SOM, and high susceptibility to soil erosion) (Mrabet et al. 1993). Adverse effects of tillage were offset in the past with application of manure. Since 1980, however, livestock farming has declined. Thus, manure and animal wastes are not available in adequate quantity as amendment to restore soil fertility. Thus, research on mulch farming and conservation tillage was initiated in Morocco during early 1980s (Mrabet et al. 2001).

Table 5.5 Rotation effects on soil properties in Settat, Morocco (Mrabet et al. 2001)

	Pools (0–20 cm) ($Mg\ ha^{-1}$)[a]		Aggregation (0.25 cm)	
Rotation	SOC	TN	%	MWD (mm)[b]
Wheat – wheat	36.4A	3.6A	72A	3.0B
Wheat – fallow	34.8B	3.4B	48C	3.6A
Wheat – corn	33.7C	3.3B	58B	3.4A
Fallow – wheat – forage	36.7A	3.3B	57B	3.7A
Fallow – wheat – lentils	36.4A	3.3B	60B	3.7A

[a]In each column, values followed by same letter are not significantly different at $p = 0.05$ using LSD test

[b]*MWD* mean weighted diameter

Conversion from conventional to conservation tillage on a Calcixeroll increased SOM and N concentrations in the A horizon, decreased pH, increased amount and stability of soil aggregates, improved soil tilth, sequestered more C, and increased wheat yields (Bouzza 1990; Kacemi 1992; Mrabet 1997; Mrabet et al. 2001). Concentration of SOM and total N (Table 5.5), soil structure and wheat yield can be improved even more when complex rotations are also used along with conservation tillage (Mrabet 2002; Mrabet et al. 2001). The latter maintains crop residues on the soil surface, protects the soil against the erosion hazard, moderates soil temperature, and reduces evaporation (Campbell and Janzen 1995).

5.10.4 Forest Land

Diverse geography and climate create diverse vegetation. The middle Atlas and Rif mountains have coniferous and mixed forests with a wide range of trees (e.g., endemic Atlas cedar (*Cedrus atlantica*), evergreen holm oak (*Quercus ilex* subsp. *ballota*), deciduous oak species (*Quercus faginea, Q. canariensis*), pine forests (*Pinus nigra* subsp. *Mauretanica)*, and fir species, *Abies pinsapo*) (Schoenenberger 1995). The Moroccan forests have undergone drastic change since the Roman era. The historic forest area was twice as much as the contemporary area, i.e., Morocco lost 5.0 Mha of its forest since the Roman era (Thirghood 1981). Similarly, a quarter of the Moroccan forest was lost between 1940 and 1982 (Brandt and Thornes 1996). Data in Table 5.3 show that forest area increased slightly between 1990 and 2009 from 5.05 Mha to 5.12 Mha. The latter is ~11.5 % of the Morocco's total land area. The land area under cedar (*Cedrus Atlantica*) and deciduous forests decreased by 8.1 % and 86.7 %, respectively, in the Middle Atlas Mountains between 1999 and 2003 (Haboudane and Bahri 2007). The expected increase in temperature and drought may exacerbate vulnerability and mortality of Atlas cedar in Morocco and Algeria (El Abidine 2003).

Fig. 5.13 Change in area under permanent pastures and meadows in Morocco (FAO 2012c)

5.10.5 Permanent Pastures, Meadows Land and Grazing

Livestock grazing is a major source of income for the Moroccan farmers (Tiedeman et al. 1998). Therefore, permanent pastures and meadows are important land uses in Morocco. In the past, rangelands were well managed, and the pasture land was sufficient. Since 1990s, however, the rangeland area has become insufficient because of soil degradation caused by overgrazing and the conversion to other land uses (Bounejmate et al. 2012). Land area under permanent pastures and meadows increased from 16.4 Mha (or 36.7 %) in 1961 to 21 Mha (or 47 % of the Morocco's total land area) in 2009, and increased by ~30 % between 1961 and 1995. Since 1995, however, the area has been almost constant (Fig. 5.13). Pasture legumes (e.g., alfalfa (*Medicago sativa*), clover (*Trifolium*), vetch (*vicia*), and medics (*Medicago* spp)) are widely grown throughout Morocco, and their characteristics are compatible with the prevailing dry conditions.

5.10.6 Permanent Crops

Land area under permanent crops comprised of ~1.0 Mha (or ~2.3 % of the Moroccan's land area) in 2009, olive trees comprised of ~45 % of the area under permanent crops, and the remaining 55 % is occupied by fruit trees (e.g., citrus, vineyards, fig, dates, apples, and bananas) (AOAD 2009). The area under permanent crops has been almost constant between 1965 and 1975 of ~430,000 ha (Fig. 5.14). Since 1975, the area has

Fig. 5.14 Change in area of permanent crops in Morocco (FAO 2012c)

doubled to ~1.0 Mha in 2009 (FAO 2012c; AOAD 2009). With the projected change in climate, the areal distribution of permanent crops may change (i.e., the area may increase under dates and olives, and decrease under apples and vineyards).

5.10.7 Temporary Crops

Temporary crops (e.g., cereals, roots and tubers, legumes, oil seeds, and vegetables) are the backbone of the Moroccan agriculture, and are the principal food source for humans and animals. The total area under temporary crops is more than four times that under permanent crops. However, the area declined from 6.7 Mha in 2001 to 4.3 Mha in 2008 (Fig. 5.15) (AOAD 2009). Of the total area, the relative area is the largest under cereals composing of 72 % of the total area under temporary crops (AOAD 2009). However, the area under cereals may decrease under the projected climate change and emerging soil-related constraints.

5.10.8 Drought in the WANA Region

Being predominantly located within the arid and semi-arid regions, and characterized by high MAT and low MAP, these countries have experienced severe drought

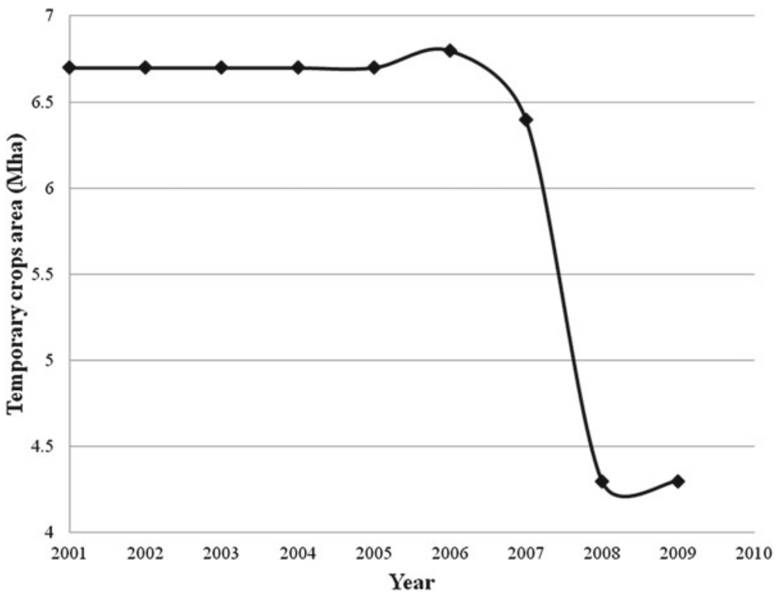


Fig. 5.15 Change in area of temporary crops in Morocco (FAO 2012c; AOAD 2009)

since 1980s. In fact, drought is a very old phenomenon, but it has become prominent since the middle of the twentieth century. Researchers in different fields have been interested in investigating drought, its causes, and its management. Thus, a variety of definitions of drought are used (there are three principal kinds of drought, i.e., meteorological, agricultural, and hydrological). For example, drought can be defined as a natural phenomenon that occurs when precipitation has been substantially below the normal recorded levels, causing severe hydrological imbalances, which adversely affect land resources and the production systems (UNCCD 2012). Many of the WANA countries have experienced severe drought (e.g., Morocco between 1980 and 1985, and from 1990 to 1995; Tunisia and Cyprus between 1982 and 1983, and from 1995 to 2000; and Syria in 1999).

The vulnerability to drought may increase during the coming decades because of changing climate. Rainfall is expected to be more than 20 % across a large area of the WANA region, in the next few decades. Thus, there may be alterations in the land use. For example, moisture will be insufficient for crop production; growing season will be shortened; pasture, permanent crops, and grazing land areas will decrease (Erian 2010). Similarly, alterations will be in farming systems (e.g., more forest land area may convert to temporary and/or permanent crops), possible decline in animal and plant productions, degradation of natural resources, and concerns about agroeconomic issues (ICARDA 2007).

Further, most countries in the WANA region are already faced with water scarcity (the per capita is <1,000 m^3 $year^{-1}$), which will be worsened by 2050 (FAO 2012b).

Fig. 5.16 Flood irrigation system (Courtesy Dr. Swelam)

Consequently, the policy makers in these countries (e.g., the Arab countries) are aware of the risks of drought. Yet, long term plans to manage drought (including the agronomic drought) are not in place. Priorities have been identified through regional and international symposia (such as the one organized by WMO and others in Kuwait in November 2011) to develop strategies for the long term of drought management. Some of the activities include: a drought-information network launched by FAO-ICARDA-EC Expert Consultation and Workshop on Drought Mitigation in the Near East and the Mediterranean (2001); early warning system established by CIHEAM and the European Commission (SMAS) for Morocco, Algeria and Tunisia; and the Network on Drought Management for the Near East, Mediterranean and Central Asia (NEMEDCA Drought Network) coordinated by ICARDA, FAO-RNE, IAM (CIHEAM) Zaragoza.

Several initiatives to manage drought by introducing technologies which improve WUE and water conservation have been initiated by ICARDA (i.e., conservation tillage, crop improvement, erosion control). However, these practices are not well distributed among the WANA countries and might last decades to be widely implemented. Programs are also under way to introduce new species which are drought tolerant.

There are diverse causes for drought such as: (1) global cooling in the northern hemisphere as a cause for the prolonged drought of the Sahelian region (Brooks 2004), (2) increasing greenhouse gases causes global warming, which renders some regions to be wetter and others to be drier (IPCC 2001), (3) decreasing the vegetative cover weakens the rain-producing atmospheric processes, and eventually causes drought (FAO 2002). Thus, managements of drought can be done as follows: (1) governments should give a high priority to manage the drought events when they occur, i.e., governments should not only predict the drought time but also simulate the negative impacts on people, animals, forests, and crops; (2) water management should take more attention regionally and nationally through seeking new sources of water, increasing the communications among countries that share surface or ground water basins, and spreading the awareness among farmers about water scarcity; (3) changing the old irrigation systems such as flood irrigation (Fig. 5.16) to new systems such as drip,

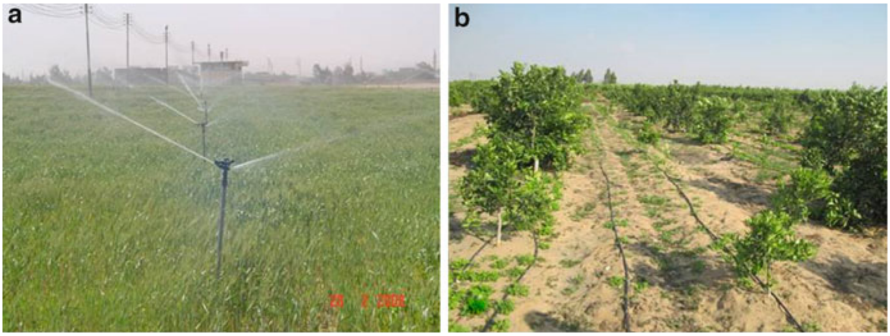


Fig. 5.17 Sprinkler (**a**) and drip (**b**) irrigation systems (Courtesy Dr. Swelam)

Fig. 5.18 Conventional (**a**) and conservation (**b**) tillage systems (Courtesy Dr. Manu)

and sprinkler irrigation (Fig. 5.17); (4) improving soil management practices such as shifting from conventional or traditional tillage to conservation tillage (Fig. 5.18); (5) using controlled grazing to correspond with available pastures and meadows; and (6) reducing deforestation, increasing reforestation, afforestation and agroforestry.

5.11 Conclusions

Most of the WANA region is located within arid and semi-arid climates characterized by high temperature and low precipitation. Thus, deserts comprise a large part of the region. Population has substantially increased since 1960s. Areas under agricultural land, permanent pastures and meadows, and permanent and temporary crops have increased since 1960s. The arable land area has increased since 1960s. However, the per capita arable land area declined as a consequence of the rapid increase in population. Area under forest has decreased since 1960s. With specific reference to Morocco, total population has tripled since 1960s. Arable land area has increased slightly since 1960s, but the per capita arable land has decreased because of the rapid increase of population. Areas under agricultural land, permanent pastures and meadows, and permanent crops have increased since 1960s. In contrast, areas under forest and temporary crops have decreased since 1960s. Drought is a serious problem in the WANA region, e.g., many countries have experienced severe droughts since 1980s, and the vulnerability to drought and aridization may increase even in the near future. Thus, policy interventions such as practicing conservation agriculture, using modern methods of irrigation, afforestation, reforestation, and even increasing the use of the solar power are needed for implementing strategies which adapt to the changing climate.

References

Amin AA (2004) The extent of desertification on Saudi Arabia. Environ Geol 46:22–31

Arab Organization for Agricultural Development (AOAD) (2009) The annual book of Arabic agricultural statistics, vol 29. Cairo. http://www.aoad.org/Statistical_Yearly_Book_Vol_29.pdf. Accessed 30 Sept 2012

Bounejmate M, Mahyou H, Bechchari A (2012) Rangeland degradation in Morocco: a concern for all. http://www.icarda.org/publications/caravan/caravan15/rangeland/rangeland.html. Accessed 9 Apr 2012

Bouzza A (1990) Water conservation in wheat rotations under several management and tillage systems in semiarid areas. PhD dissertation, University of Nebraska, Lincoln, 200 pp

Brandt CJ, Thornes JB (1996) Mediterranean desertification and land use. Wiley, Chichester

Brooks N (2004) Drought in the African Sahel: long term perspectives and future prospects. Saharan Studies Program and Tyndall Center for Climate Change Research, University of Anglia, Norwich, Paper No. 61

Campbell CA, Janzen HH (1995) Effect of tillage on soil organic matter. In: Farming for a better environment. Soil and Water Conservation Society (SWCS), Ankeny, pp 9–11

Casas J, Solh M, Hafez H (1999) The National Agricultural Research Systems in the West Asia and North Africa region. ICARDA, Aleppo

Cervigni R, Dobardzic S (2012) Adaptation to climate change in the Middle East and North Africa region. http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/MENAEXT/0,,contentMDK:21596766~pagePK:146736~piPK:146830~theSitePK:256299,00.html. Accessed 9 Apr 2012

Christensen JH, Hewitson B, Busuioc A et al (2007) Regional climate projections. Climate change 2007: the physical science basis. In: Solomon S, Qin D, Manning M et al (eds) In the fourth assessment report of the Intergovernmental Panel on climate change. Cambridge University Press, Cambridge, pp 847–940

Courbage Y (1994) Demographic change in the Arab world: the impact of migration, education, and taxes in Egypt and Morocco. Middle East Rep 24(190):19–22

Dasgupta S, Laplante B, Meisner C, Wheeler D, Yan J (2007) The impact of sea level rise on developing countries: a comparative analysis. World Bank Policy Research Working Paper 4136. World Bank, Washington, DC

El Abidine AZ (2003) Forest decline in Morocco: causes and control strategy. Science et changements planetaires, Sécheresse 14:209–218

Elnagheeb AH, Bromley DW (1994) Extensification of agriculture and deforestation: empirical evidence from Sudan. Agr Econ 10:193–200

Erian WF (2010) Desertification and drought in Arab countries. Expert meeting of the ASPA countries for developing scientific and technological cooperation on climate change, organized by LAS, ACSAD, MoE, Damascus, 4–6 May

Food and Agriculture Organization (FAO) Staff (2002) Long term plans for drought mitigation and management in the near east region. In: Twenty-sixth FAO regional conference for the near east, Tehran

Food and Agriculture Organization (FAO) Staff (2012a) Statistics division. http://faostat.fao.org/site/550/default.aspx#ancor. Accessed 9 Apr 2012

Food and Agriculture Organization (FAO) Staff (2012b) Aquastat database query. http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en. Accessed 9 Apr 2012

Food and Agricultural Organization (FAO) Staff (2012c) Statistics division. http://faostat.fao.org/site/377/default.aspx#ancor. Accessed 9 Apr 2011

Grove A (1973) Desertification in African environment. In: Dalby D, Church RH (eds) Drought in Africa. School of Oriental and African Studies, London, pp 35–45

Haboudane D, Bahri EM (2007) Deforestation detection and monitoring in cedar forests of the Moroccan Middle-Atlas Mountains, Barcelona. IEE international geoscience and remote sensing symposium – IGRASS. Barcelona, Spain, pp 4327–4330

Hagedorn H, Giessner K, Weise O, Busche D, Grunert G (1977) Dune stabilization: A survey of literature on dune formation and dune stabilization. German Agency for Technical Coop., Dundee

Hamadallah G (2001) Drought preparedness and mitigation plans in the Near East: an overview. Expert consultation and workshop on drought mitigation for the Near East and the Mediterranean. ICARDA, Aleppo, pp 27–31

Havlin JL, Kissel DE, Maddux LD, Claassen MM, Long JH (1990) Crop rotation and tillage effects on soil organic carbon and nitrogen. Soil Sci Soc Am J 53:1515–1519

Intergovernmental Panel on Climate Change (IPCC) (2001) The scientific basis: summary for policy makers and technical summary of the working group I report. Cambridge University Press, Cambridge

IPCC (2007) Climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds). Cambridge University Press, Cambridge, UK

International Center for Agricultural Research in the Dry Areas (ICARDA) Staff (2007) Drought in the Arab world. In: A regional conference on land degradation issues in the Arab region, Cairo

Kacemi M (1992) Water conservation, crop rotations, and tillage systems in semiarid Morocco. PhD dissertation, Colorado State University, Fort Collins, 200 pp

Lal R (2002) Carbon sequestration in dry land ecosystems of West Asia and North Africa. Land Degrade Dev 13:45–59

Lal M, Harasawa H, Murdiyarso D et al (2001) Asia climate change 2001: impacts, adaptation, and vulnerability. In: McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (eds) The third assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp 533–590

Lamb HF, Eicher U, Switsur VR (1989) An 18,000-year record of vegetation, lake-level and climatic change from Tigalmamine, Middle Atlas, Morocco. J Biogeogr 16:65–74

Masri Z, Ryan J (2006) Soil organic matter and related physical properties in a Mediterranean wheat-based rotation trial. Soil Till Res 87:146–154

Mrabet R (1997) Crop residue management and tillage systems for water conservation in a semiarid area of Morocco. PhD dissertation, Colorado State University, Fort Collins, 220 pp

Mrabet R (2000) Differential response of wheat to tillage management systems in a semiarid area of Morocco Field. Crop Res 66:165–174

Mrabet R (2002) Wheat yield and water use efficiency under contrasting residue and tillage management systems in a semiarid area of Morocco. Exp Agric 38:237–248

Mrabet R, Bouzza A, Peterson GA (1993) Potential reduction of soil erosion in Morocco using no-till systems [Abstract]. American Society of Agronomy, Madison, p 323

Mrabet R, Saber N, El-Brahli A, Lahlou S, Bessam F (2001) Total particulate organic matter and structural stability of a Calcixeroll soil under different wheat rotations and tillage systems in a semiarid area of Morocco. Soil Till Res 57:225–235

Nakićenović N, Alcamo J, Davis G et al (2000) Emissions scenarios: a special report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, p 509

Nash MS, Challoud DJ, Kepner WG, Sarri S (2007) Regional assessment of landscape and land use change in the Mediterranean region. Morocco: a case study. In: Liotta PH, Mouat DA, Kepner WG, Lancaster JM (eds) Environmental change and human security: recognizing and acting on hazard impacts. NATO security through science series. Springer, The Netherlands, pp 143–165

Parry ML, Canziani OF, Palutikof JP, Van der Linden PJ, Hanson CE (2007) Cross-chapter case study. Climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the Intergovernmental Panel On Climate Change, Cambridge University Press, Cambridge, pp 843–868

Republique Algerienne Democratique et Populaire (RADP) (1966) Ministere de l' Agriculture et de la Reforme Agraire (MARA). La Statistique Agricole. No 1. Algiers

Rihawi S (2012) Stubble – a burning issue. Pasture, forage and livestock program, ICARDA. http://www.icarda.org/publications/caravan/caravan5/Car58.Html. Accessed 9 Apr 2012

Ruosteenoja K, Carter TR, Jylhä K, Tuomenvirt H (2003) Future climate in world regions: an intercomparison of model-based projections for the new IPCC emissions scenarios, 644th edn. Finnish Environment Institute, Helsink, p 83

Sari D (1978) La Depossession des Fellahs, 1830–1962. SNED, Algiers

Schoenenberger A (1995) Groupements végétaux des séries de végétation. La végétation forestière. Essai de synthèse sur la vègètation et la phyto-écologie tunisiennes, II&III. Programme folore et végétation tunisiennes, vols 5 and 6

Sharif M (1960) Mastung sand dunes: their formation and control. Proc. Symp. Soil erosion and its control in arid and semi-arid zones. Karachi, pp 285–307

Sombrero A, Benito A (2010) Carbon accumulation in soil. Ten-year study of conservation tillage and crop rotation in a semi-arid area of Castile-Leon, Spain. Soil Till Res 107:64–70

Natural Resources Conservation Service (NRCS) Staff (2012) Global soil regions map. United State Department of Agriculture (USDA). http://soils.usda.gov/use/worldsoils/mapindex/order.html. Accessed 10 Apr 2012

Thirghood JV (1981) Man and the African forest. Academic, London

Tiedeman J, Boulanouar B, Christiansen S, Derkaoui M (1998) Sheep production on medic and weedy pasture in semi-arid Morocco. J Range Manag 51:288–292

United Nations Conventions to Combat Desertification (UNCCD) Staff (2012) The convention: UNCCD in countries experiencing serious drought and/or desertification, particularly in Africa. Article 1. http://www.unccd.int/convention/text/convention.php?annexNo=−1. Accessed 10 Apr 2012

Wood CW, Westfall DG, Peterson GA (1990) Soil carbon and nitrogen changes on initiation of no-till cropping systems. Soil Sci Soc Am J 55:470–476

World Meteorological Organization (WMO) (2012) World weather information service. http://worldweather.wmo.int/. Accessed 9 Apr 2012

Zaimeche S (1994) The consequence of rapid deforestation: a North African example. Ambio 23:136–140

Chapter 6
Responses of Insect Pests to Climate Change: Effects and Interactions of Temperature, CO_2, and Soil Quality

Vanessa L. Muilenburg and Daniel A. Herms

Abstract Anthropogenic activities continue to dramatically increase atmospheric concentrations of CO_2, resulting in changes in the climate including elevation in global mean temperatures and altered precipitation patterns. Given that insect development is temperature-dependent, the impact these changes will have on insect pests of crops and forests will likely be substantial. Direct impacts of climate warming on insects include changes in insect physiology, distribution of species, phenology, and voltinism patterns. Insect herbivores will also be indirectly impacted by climate change via changes in host plant quality as plants respond to alterations in resource availability (e.g. changes in atmospheric CO_2 concentrations and precipitation patterns). Environmental heterogeneity, variation among species in their potential for acclimation and/or adaptation, and the current, as well as simultaneous interacting effects on other factors that modulate development and regulate populations suggest that responses of insects to climate change will be idiosyncratic and complex, and thus difficult to predict. Economic impact of some pests is likely to increase, while the impact of others may decrease or become more variable. However, it is clear that anthropogenic changes to the atmosphere and climate will have pervasive effects on the physiology, phenology, voltinism patterns, and species distributions of insects, with emergent effects on trophic interactions, population dynamics, and community composition that ultimately impact evolutionary trajectories.

Keywords Insect life history • Insect distributions • Insect phenology • Insect growth and reproduction

---

V.L. Muilenburg (✉) • D.A. Herms
Department of Entomology, The Ohio State University, Ohio Agricultural Research and Development Center, Wooster, OH 44691, USA
e-mail: vmuilenburg1@gmail.com

M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_6,

6.1 Introduction

The future impact of climate change on agricultural productivity and food security is one of the most pressing questions emerging from a future of climatic uncertainty (McKeown et al. 2006). Effects of climate change on the population dynamics of insect pests is considered a key threat to food security (Whittaker 2001; Tubiello et al. 2007). From its preindustrial level of 280 ppm, atmospheric concentration of CO_2 is now rising 2–3 ppm per year and now exceeds 390 ppm (Canadell et al. 2007; Lacis et al. 2010), which is the highest concentration in the last 26 million years (Pearson and Palmer 2000). The recent, dramatic increase in CO_2 is due to human activities, largely the combustion of fossil fuels (Le Quéré et al. 2009). If the current trajectory of CO_2 accumulation in the atmosphere is maintained, concentrations will reach 550 ppm by 2050 (IPCC 2007). Atmospheric accumulation of CO_2 and other greenhouse gases results in radiative forcing, which changes the amount of energy entering and leaving Earth's atmosphere resulting in elevated global mean temperatures (Lacis et al. 2010). Since 1975, global temperatures have increased at a rate of 0.2 °C per decade, rising on average by 0.6 °C during that period (Hansen et al. 2006) and are projected to increase by 2–6 °C during the twenty-first century (IPCC 2007; Royer et al. 2007).

Given that insect development is temperature-dependent, the impact these changes will have on insect pests of crops and forests will likely be substantial. Because of the direct and indirect effects of CO_2 and temperature on a myriad of biological, physiological, and ecological processes, the potential impact of climate change on insects has been extensively studied. Several published reviews have linked anthropogenic climate change to biological responses including effects on insect pest dynamics (e.g. Whittaker 2001; Bale et al. 2002; Walther et al. 2002; Parmesan 2006; Cleland et al. 2007; Lindroth 2010). This review focuses on the direct and indirect impacts of anthropogenic climate change on insects. Changes in insect distribution, phenology, and voltinism, which are temperature-dependent, may be modified and lead to changes in population dynamics and community composition (Fig. 6.1). Insect herbivores will also be affected indirectly by climate change via altered host plant quality because of changes in the availability of plant resources, including concentrations of atmospheric CO_2, soil fertility, and soil moisture (Fig. 6.1). Moreover, because multiple environmental factors are changing simultaneously (e.g. global temperature, CO_2 concentrations, precipitation patterns), and given the heterogeneity of the environment and the individualistic attributes of insect species, the responses of insect pests to climate change will likely be complex, idiosyncratic, and thus difficult to predict (Robinet and Roques 2010).

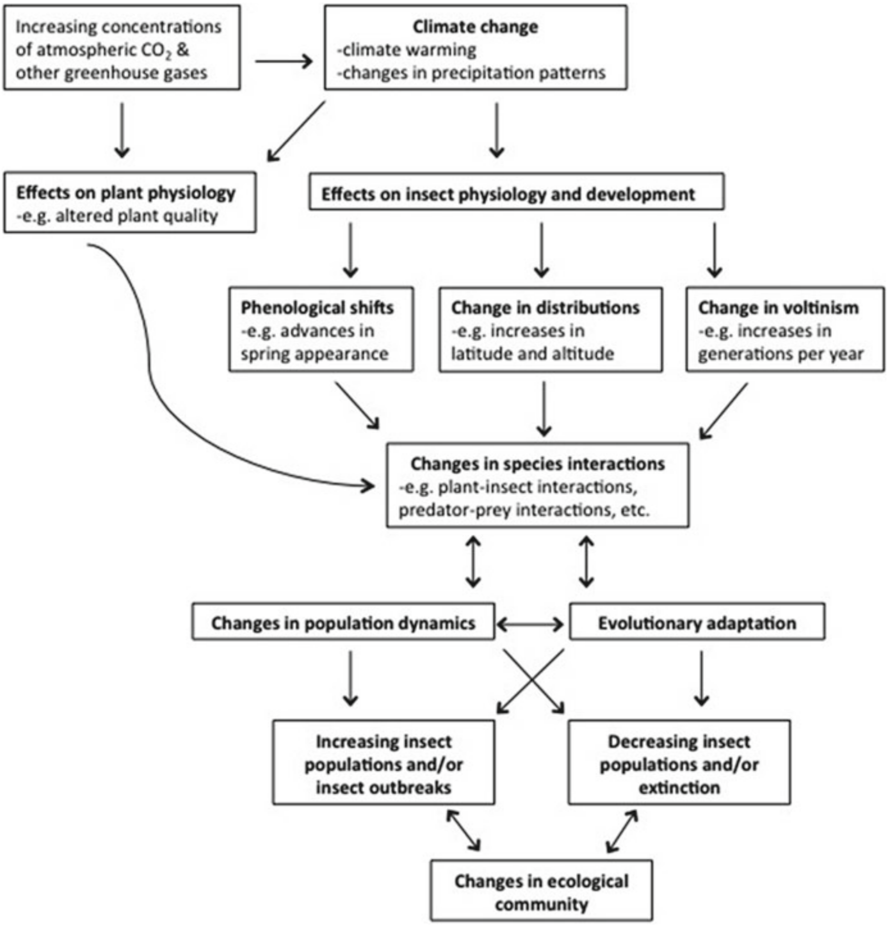


Fig. 6.1 *Postulated direct and indirect impacts of anthropogenic climate change on insects.* Climate warming will directly affect insect development and physiology, altering distributions, voltinism patterns, and phenology of insects. Predicting the effects of elevated CO_2 and temperature on herbivorous insects via altered host plant quality will be complicated by interactions with other environmental factors. Both direct and indirect effects of climate change on insects will impact ecological interactions with other species, altering population dynamics, community composition and function, and ultimately evolutionary trajectories

6.2 Insect Life History: Temperature Dependent Processes

6.2.1 Direct Effect on Insect Physiology

The specific effect that climate warming will have on an insect species depends on its physiological sensitivity to increasing temperature (Deutsch et al. 2008). Physiological sensitivity is largely determined by two factors: tolerance to temperature variation and the difference between an insect's thermal optimum and the temperature of the habitat in which it exists. Generally, tolerance of insects to thermal variation is proportional to the temperature variation they experience in their habitats. Therefore, insects in tropical environments experience much less temperature variation and have lower thermal tolerance than insects in mid-latitude environments, which are characterized by more climatic variability. Moreover, tropical insects also exist near their thermal optimum so that small increases in temperature will reduce their performance. In contrast, insect species indigenous to higher latitudes exist well below their optimal temperature so that warmer temperatures may be advantageous, increasing fitness (Deutsch et al. 2008). In fact, increased fitness of some mid- to high-latitude insect species due to warming and other factors may already be occurring, resulting in insect outbreaks and widespread plant mortality (Breshears et al. 2005; Raffa et al. 2008; Kausrud et al. 2012). However, if temperatures continue to increase in the forthcoming centuries, mid- and high-latitude insects may also exhibit decreased performance if their thermal optima are exceeded (Deutsch et al. 2008). However, these potentially negative impacts of climate warming may be mitigated by insect dispersal, physiological acclimation, and evolutionary adaptation.

6.2.2 Insect Distributions

Because insects must exist between their upper and lower physiological thresholds of temperature, their geographic distributions are heavily influenced by climatic regimes (Walther et al. 2002). As global temperatures rise, many species may migrate to higher latitudes and altitudes as they track the shifting climate to find a thermal environment that matches their physiological limits, given each species' ability to disperse and find resources. With this in mind, there is already ample evidence that distributions of many animals are responding to climate warming as distributions are shifting to higher elevations and latitudes (Chen et al. 2011a). Meta-analysis of 764 species, including arthropods, fish, birds, mammals and other marine organisms, estimates that distributions have shifted at a median rate of 11 m in elevation and 16.9 km in latitude per decade (Chen et al. 2011a). Distributions of insect species, specifically, are also shifting due to temperature-mediated changes in winter survival, developmental rate, and dispersal (Robinet and Roques 2010).

Due to the charismatic nature of butterflies and moths, there are detailed historical records of distributions of many species, particularly in Europe. This long-term monitoring has yielded strong evidence of shifts in distributions. For example, of 35 non-migratory European butterflies, 63 % have shifted northward by 35–240 km while only 3 % shifted southward (Parmesan et al. 1999). Similar northward range shifts by butterflies have also been observed in Great Britain (Pollard and Eversham 1995; Warren 1992), Finland, and Spain (Jordano et al. 1991). In North America, the range of sachem skipper, *Atalopedes campestris*, has also shifted northward in response to winter warming. Warmer winters reduced the range-limiting effect of temperature on overwintering larvae (Crozier 2003; Crozier 2004).

Outbreaks and range expansions of pine processionary moth, *Thaumetopoea pityocampa*, have also been linked to climate warming (Battisti et al. 2005). Range shifts of 87 km northwards in France and 110–230 m upwards in altitude in northern Italy have occurred between 1972 and 2004 (Battisti et al. 2005; Battisti et al. 2006). Range expansion is attributed to a rise in winter temperatures, which has facilitated increased winter-feeding and survival by larvae, as well as to warmer summer night temperatures, which has increased dispersal by females (Battisti et al. 2005; Battisti et al. 2006). Pine processionary moth is oligophagous, typically limited to feeding on pine species. Host plant availability does not currently limit the distribution of pine processionary moth and will not constrain future northward and upward expansions. Moreover, recent outbreaks of pine processariony moth on *P. mugo* in northern Italy and *Psuedotsuga menziesii* in France suggest that this insect can adopt novel hosts (Battisti et al. 2005).

Climate change also has the potential to impact the distribution of infectious disease by impacting their arthropod hosts. For example, population dynamics of *Anopheles gambiae,* a vector of malaria parasites (*Plasmodium falciparum* and *Plasmodium vivax*), are tightly linked to temperature and rainfall. In the East African highlands, the increased incidence of malaria since the 1970s has been linked to rising temperatures as malarial species, *P. falciparum* and *P. vivax*, cannot develop below 18 °C and 15 °C, respectively (Pascual et al. 2006; Patz and Olson 2006). Increasing altitudinal temperatures have led to increasing abundances of mosquitoes and the malaria they carry at higher altitudes (Pascual et al. 2006). This example also highlights the potential impact of biological amplification of temperature effects: an increase of only 0.5 °C could translate into an increase in mosquito abundance by 30–100 % (Patz and Olson 2006).

Warming temperatures have already had a marked negative effect on coffee farmers and consumers due to range expansion of coffee's most important pest, coffee berry borer (*Hypothenemus hampei*) (Jaramillo et al. 2011). Coffee is the world's most valuable export crop, estimated in value of 90 billion in US dollars annually. Until 10 years ago, distribution of coffee berry borer was below the altitude of which Arabica coffee plantations (*Coffea arabica*) are grown. However, due to recent warming in mountainous regions of East Africa, insects now colonize these plantations (Jaramillo et al. 2009). Models suggest that damage by coffee berry borer will continue to increase as temperatures rise, by increasing the number of generations per year, dispersal, population growth, and range (Jaramillo et al. 2011).

6.2.3 Insect Phenology and Voltinism

Interactions between temperature and photoperiod (the length of time that an organism is exposed to light) are primary determinants of insect phenology. The seasonality of life history is adaptive because the suitability of many environments for processes such as growth or reproduction is frequently limited to particular periods in the year. Tracking changes in plant and insect phenology has provided strong evidence of biological responses to climate warming. Global meta-analysis of 172 species of plants and animals indicates an advancement of spring events by 2.3 days per decade (Parmesan and Yohe 2003), which was attributed to climate warming.

By far the most extensive phenological records involve plants, many of which date back hundreds of years (Parmesan 2006). One of the most comprehensive analyses of phenological trends includes over 125,000 observations of 542 plant species in 21 European countries (Menzel et al. 2006). Analysis of data from 1970 to 2000 showed that more than 75 % of plant species studied had accelerated phenology, as leaf unfolding and flowering had advanced 2.5 days per decade and fruit ripening had advanced 2.4 days per decade (Menzel et al. 2006). Another compelling example involves comparison of current timing of phenological events of 43 plant species in Concord, Massachusetts, USA to records kept by the naturalist Henry David Thoreau. From 1852 to 2006 Concord warmed by 2.38 °C. Accordingly, plants bloomed an average of 7 days earlier than in Thoreau's time (Miller-Rushing and Primack 2008).

Climate warming is also affecting insect phenology. Long-term monitoring of European butterflies demonstrates that 26 out of 35 species of butterflies exhibit earlier spring appearances and, for multivoltine species, extended flight periods (Roy and Sparks 2000). For example, from 1976 to 1998, the date of first apperance of the red admiral butterfly, *Vanessa atalanta,* has advanced by 36.3 days and the flight period duration has been extended by 39.8 days (Roy and Sparks 2000). These shifts were strongly related to increasing temperatures (Roy and Sparks 2000). Similarly, in California, USA, 16 of 23 (70 %) butterfly species show an earlier date of spring flight, and this shift was associated with higher winter maximum temperature and drier winter conditions (Forister and Shapiro 2003).

Because insect phenology and development are largely driven by temperature, increases in the number of generations per year (voltinism) of some species are predicted as global temperatures rise (e.g. Mitton and Ferrenberg 2012). However, other factors can also affect insect development. For instance, many multivoltine insects use photoperiodic cues, which are static year-to-year, to initiate diapause (a state of physiological dormancy used by many insects for the purpose of overwintering). Temperature and diapause interact in a non-linear fashion that makes precise predictions of voltinism complex (Tobin et al. 2008; Chen et al. 2011b). For example, voltinism in the grape berry moth, *Paralobesia viteana*, a pest of grapes (*Vitis* spp.) in North America, does not respond linearly to accumulation of heat units. Voltinism in this insect increases only when the heat units accumulate at the right time. After the moth has entered diapause, heat accumulation does not affect development; however, warmer winter or spring temperatures can induce early spring emergence, resulting in enough time for additional generations to successfully develop, which would positively affect population densities (Tobin et al. 2008).

6.2.4 Phenological Asynchrony

The phenologies of interacting organisms, such as herbivores and their host plants, may not shift in synchrony to climate change, leading to phenological mismatches between them. Several studies suggest that a few trophic interactions are already shifting due to differential phenological responses of the interacting species to rising temperatures (Thackeray et al. 2010). Decoupling these tropic relationships could have considerable impacts on food webs and could lead to loss of biodiversity (Visser and Both 2005; Parmesan 2006).

In regard to plant-insect interactions, the 'phenological window hypothesis' postulates the existence of a narrow temporal window when host plant traits are most suitable for insect herbivores and predicts that insect growth and survival will decline as host-insect synchronicity is altered (Feeny 1976; Mattson et al. 1982). Substantial evidence supports this hypothesis, especially for leaf-feeding and gall-making insects. A long-term study in Ohio, USA involving more than 50 species of phytophagous insects and 70 species of plants indicates that the phenological sequence is quite robust to variation in weather, suggesting that the phenology of many interacting plant and insects may respond in tandem to a warming climate and asynchronies may not occur (Herms 2004).

One example of phenological asynchrony between an insect and plant involves winter moth, *Operophtera bruamata* and oak trees in the Netherlands (Visser and Holleman 2001). Timing of egg hatch of winter moths must correspond with bud burst to maximize fitness. If egg hatch occurs before budburst, larvae can starve and die. If egg hatch occurs too long after budburst, larvae consume less digestible leaves due to higher concentrations of defensive chemicals in the leaves (Feeny 1970). This can lead to lower pupal weight or slowed larval development, making them more vulnerable to natural enemies. Increasing spring temperatures in the Netherlands, largely due to changes in the North Atlantic Oscillation, have advanced egg hatching more than oak budburst (Visser and Both 2005). Because there is no available food for hatching larvae, they die, and this mortality can have strong impacts on population dynamics of winter moth (Visser and Holleman 2001).

There is also potential for climate change to disrupt mutualistic interactions between insect pollinators and plants (Memmott et al. 2007; Hegland et al. 2009), impacting pollinator-dependent crops. Memmot et al. (2007) simulated the consequences of temperature warming expected from the doubling of CO_2 concentrations on pollinators and flowering plants. Their model was comprised of 1,420 pollinators and 429 plant species, and depending on model parameters, changes in floral resources due to altered phenology was predicted to impact 17–50 % of pollinator species. Specialist species were found to be the most likely impacted as food resources were not available, but generalist species could also be impacted by diet reductions due to phenological shifts (Memmott et al. 2007). However, phenological responses of many flowering plants and pollinators may advance in tandem to temperature increases (Hegland et al. 2009; Bartomeus et al. 2011).

6.3 Host Quality: Insect Growth and Reproduction

6.3.1 Atmospheric CO_2

Insects will also be indirectly affected by anthropogenic changes to the atmosphere and climate. For example, increases in atmospheric CO_2 will affect insect herbivores by altering plant quality. Carbon dioxide is the substrate for photosynthesis, and thus an increase in CO_2 alters plant growth, allocation, physiology, and biochemistry. Under enriched CO_2 environments, plants typically have increased rates of photosynthesis and growth (Saxe et al. 1998), and as stomatal conductance declines, reduced water loss via transpiration (Long et al. 2004). Plants also generally exhibit a higher carbon-to-nitrogen ratio (McGuire et al. 1995) and a reduction in leaf nitrogen concentration, on average 16 % lower than leaves grown in ambient levels of CO_2 (Curtis and Wang 1998). The reduction in nitrogen is largely due to decreases in RuBisCO concentrations, an enzyme involved in carbon fixation (Bowes 1991; Tissue et al. 1993). Although nitrogen concentrations decrease, plants generally have improved nitrogen-use efficiency. This, coupled with increased rates of photosynthesis and higher water-use efficiency, accelerates plant growth and is known as the "fertilizer effect" of CO_2 (Beedlow et al. 2004). However, this effect may diminish over time in natural and cropping systems as nitrogen and other factors limit plant productivity (Long et al. 2006; Norby et al. 2010).

Increasing atmospheric CO_2 concentrations are also predicted to change host plant quality and insect herbivore performance by increasing concentrations of phenolics (secondary plant metabolites that can act as defenses against insects) and carbohydrates (Peñuelas and Estiarte 1998; Lindroth 2010), but there are exceptions. Plant defense theory predicts that plants under a carbon-enriched environment will exhibit an increase in carbon-based chemical defenses (e.g. simple phenolics, tannins, and terpenes) when net photosynthesis also increases. Increased photosynthetic rates can increase the carbon availability above that which is shunted to growth and storage processes, availing more carbon to be allocated to secondary metabolism (Herms and Mattson 1992; Mattson et al. 2005). However, changes in concentrations of secondary metabolites appear to be specific to groups of carbon-based defenses with elevated CO_2 more strongly impacting the shikimic pathway, which produces phenolics, than the mevalonic acid and methylerythritol phosphate pathway, which produce terpenes (Koricheva et al. 1998; Peñuelas and Estiarte 1998; Lindroth 2010). Elevated CO_2 usually increases tannins and simple phenolics (Koricheva et al. 1998; Stiling and Cornelissen 2007; Lindroth 2010) but often does not affect concentrations of terpenes (Koricheva et al. 1998; Stiling and Cornelissen 2007).

Changes in plant quality due to exposure to elevated CO_2 can modify insect herbivore preference, performance, and survival (Peñuelas and Estiarte 1998). Because CO_2-enriched foliage has reduced nitrogen concentrations, insects commonly respond by increasing food consumption. However, the ability of insects to fully compensate for reduced nitrogen may be limited in some cases by increased concentrations of carbon-based secondary metabolites (Lindroth 2010) and may therefore exhibit decreased performance. Insect performance can be negatively impacted by protracted developmental rates and reduced adult size and fecundity (Peñuelas and Estiarte 1998; Awmack et al. 2004). However, these responses to CO_2 are not universal and are limited by context, the species involved, and other environmental factors (Hunter 2001; Whittaker 2001).

There are numerous examples of insect herbivores exhibiting reduced performance when feeding on leaves exposed to elevated CO_2: reduced growth and increased mortality of the buckeye butterfly (*Junonia coenia*) on *Plantago* leaves (Fajer 1989; Fajer et al. 1991); decreased feeding efficiency and growth rates of gypsy moth (*Lymatria dispar*) on poplar leaves (McDonald et al. 1999); and reduced preference, reduced growth rate, and increased mortality of polyphemus moth (*Antheraea polyphemus*) on oak leaves (*Quercus* spp.) (Knepp et al. 2007). However, not all interactions follow this pattern. For instance, in an analysis of the effects of elevated CO_2 on various insect-feeding guilds representing 61 plant-insect interactions, impact on insect feeding guild was variable (Bezemer and Jones 1998). On average, leaf chewers increased food consumption to compensate for reduced plant nitrogen concentrations but not enough to prevent a decrease in pupal mass. Leaf-miners also increased food consumption but also had reduced pupal weights. Phloem-feeders, on the other hand, were positively affected by CO_2, as development time decreased and population size increased (Bezemer and Jones 1998). Ultimately, changes in insect preference and performance in a CO_2 enriched environment could alter host selection and population dynamics of herbivores (Peñuelas and Estiarte 1998; Lindroth 2010).

Another example of how changes in atmospheric composition can affect interactions between crops and pests involves soybeans and Japanese beetles (*Popillia japonica*) (DeLucia et al. 2008). Unlike the previous examples, soybeans are nitrogen-fixing plants and utilize nitrogen-based defenses. Soybean crops exposed to elevated CO_2 at the Soybean Free Air CO_2 Enrichment (FACE) facility in Illinois, USA had twice the foliar damage due to feeding by Japanese beetles (*Popillia japonica*) than soybeans exposed to ambient levels of CO_2 (DeLucia et al. 2008). Soybeans growing under elevated CO_2 had a compromised ability to produce proteinase inhibitors, which are defensive proteins (Zavala et al. 2008). Japanese beetles feeding on these less defended leaves had increased fecundity. If agricultural pests respond to changes in plant quality by feeding more, resulting in more plant damage, then the increased productivity that is projected for agricultural crops under a CO_2-enriched environment may not materialize (Zavala et al. 2008).

6.3.2 Ecological Complexity: Interactions of CO_2 and Climate Warming with Other Abiotic Factors

Many other environmental factors may interact with climate warming and/or increases in atmospheric concentrations of CO_2, impacting insects in ways that are not predicted by studying one factor in isolation. In fact, elevated temperature and CO_2 may have interacting effects on host quality and insect performance (Zvereva and Kozlov 2006). In a metanalysis of 31 plant species and seven herbivore species, Zvereva and Kozlov (2006) found that elevated CO_2 indirectly decreased insect performance by decreasing plant nitrogen concentrations and increasing concentrations of non-structural carbohydrates and phenolics. Elevated temperature, on the other hand, had a direct, positive effect on insect performance. Temperature affected plants by decreasing concentrations of carbohydrates and phenolics, increasing

Fig. 6.2 *One of twelve experimental plots at the Aspen Free Air* CO_2 *Enrichment (FACE) facility in northern Wisconsin, United States*. Trees were exposed to combinations of ambient and elevated carbon dioxide and ozone in order to study their effects on various physiological and ecological processes, including their interactions with key herbivores

concentrations of terpenes, but nitrogen concentrations were unchanged. However, when simultaneously elevated, climate warming mitigated the negative effects of elevated CO_2 on insect herbivores, decreased plant nitrogen concentrations, as well as had non-additive effects on some plant compounds (Zvereva and Kozlov 2006).

In many regions, concentrations of tropospheric ozone (a plant stressor) are increasing simultaneously with increases in concentrations of CO_2. The interactive effects of CO_2 and ozone on plant-insect interactions are exemplified by interactions between paper birch (*Betula papyrifera*) and bronze birch borer (*Agrilus anxius*) (Muilenburg, Herms, and Mattson, unpublished), which is a wood-boring beetle native to North America that is prone to expansive outbreaks. The effects of elevated CO_2 and ozone on this interaction were studied at the Aspen FACE facility in northern WI, USA. The Aspen FACE site consisted of 12 thirty-meter diameter rings containing aspen, paper birch and maple trees (Fig. 6.2). The rings were arranged in a 2 × 2 factorial randomized block design with two levels of CO_2 (ambient and 560 ppm) and two levels of O_3 (ambient and 1.5× ambient) (Dickson et al. 2000). Trees were planted in July of 1997 and were exposed to elevated concentrations of CO_2 and/or O_3 for their entire life history when this study was conducted from 2005 to 2008.

Throughout the 4-year study, bronze birch borer colonization was highest in trees exposed to elevated ozone in combination with ambient CO_2. This was consistent with our prediction as ozone generally increases plant stress by disrupting photosynthesis, thereby decreasing plant resistance to herbivores. However, elevated CO_2 ameliorated the negative effects of elevated ozone, as bronze birch borer colonization was much lower in trees exposed to this treatment combination. This was also consistent with our prediction as elevated CO_2 increases rates of photosynthesis, which can increase plant resistance. Over time, levels of bronze birch borer colonization increased in trees exposed to elevated CO_2 in combination with ambient ozone, but there was high variation in levels of colonization among rings. These results suggest that on-going changes in atmospheric composition could compromise resistance of paper birch to bronze birch borer, possibly facilitating outbreaks, which could result in altered distribution and abundance of paper birch of North American boreal forests (Muilenburg, Herms, and Mattson, unpublished).

The indirect effects of elevated concentrations of CO_2 on insect herbivore performance via changes in host plant quality will also be modulated by soil fertility. Insect growth is nitrogen-limited and insect herbivore performance often increases as plant nitrogen concentrations increase (Mattson 1980). Because CO_2 generally reduces the carbon-to-nitrogen ratio, decreasing plant proteins while increasing chemical defenses, herbivores have reduced growth and/or increased feeding to compensate for reduced nitrogen concentrations. Soil fertility also impacts host quality for insect herbivores (Bryant et al. 1983; Herms and Mattson 1992; Herms 2002). Plants growing in high fertility soils have higher nitrogen concentrations (Koricheva et al. 1998) and frequently have lower concentrations of carbon-based defenses (Mattson 1980; Kytö et al. 1996; Koricheva et al. 1998; Herms 2002) than those growing under lower fertility, resulting in increased herbivore performance (Kytö et al. 1996; Herms 2002). Therefore, the predicted detrimental impact of elevated CO_2 concentrations on host plant quality and insect performance may be ameliorated or negated in high fertility environments.

More specific predictions about the effects of CO_2 and fertility on plant physiology and the potential impact on insect herbivores can be made using the conceptual framework of the growth/differentiation balance hypothesis (GDBH) (Herms and Mattson 1992). The GDBH predicts a parabolic response of secondary metabolism to variation in fertility (Herms 2002) and atmospheric CO_2 concentrations (Mattson et al. 2005) due to a physiological tradeoff between growth and secondary metabolism. For instance, GDBH predicts that fertilization of moderately nutrient deficient plants will decrease secondary metabolism if growth increases but photosynthesis is unchanged. Fertilization of very nutrient-deficient plants is predicted to increase secondary metabolism if photosynthesis also increases (Herms 2002). Similarly, elevated CO_2 will increase partitioning of carbon to secondary metabolism, if photosynthesis increases, creating a pool of carbon above that which is allocated to growth and storage (Mattson et al. 2005). The GDBH framework can also be used to predict the effects of CO_2 and fertility simultaneously if one considers the relationship between growth, storage, and photosynthesis. If resources, in this case CO_2 and fertility, stimulate growth and storage but not photosynthesis, then allocation to secondary metabolism will decrease. However, if resources stimulate growth, storage, and photosynthesis, then allocation to secondary metabolism will increase to the amount that is not consumed by growth and storage processes. Although the GDBH is a phytocentric model (Mattson et al. 2005), it may be useful in future environmental conditions for predicting plant resistance to insects when pools of carbon-based secondary metabolites underlie resistance (Herms 2002).

A predicted consequence of climate warming is change in precipitation patterns, resulting in droughts in some areas while prolonged periods and increased intensity of high precipitation are predicted in other regions (Allan and Soden 2008; Knapp et al. 2008; O'Gorman and Schneider 2009). In areas experiencing drought, high temperatures can exacerbate water deficiency in plants by increasing soil evaporation and plant evapotranspiration. Plants respond to water deficiency by decreases in cell volume and turgor, stomatal closure, inhibition of photosynthesis, and altered allocation of assimilates.

The physiological changes in plants in response to drought also result in altered plant quality for insects, which can be negative or positive, depending on the system and guild of insects being considered (Huberty and Denno 2004). In forest systems, trees that have been stressed by droughts generally positively affect tree-killing bark beetles and wood-boring insects. In the southwest region of the United States from 2002 to 2003, subcontinental drought and warmer temperatures increased susceptibility of piñon pine (*Pinus edulis*) to colonization by bark beetles (*Ips confuses*), resulting in region-wide mortality of the dominant tree (Breshears et al. 2005). Fifteen months of reduced soil water content stressed pines, stopping transpiration and photosynthesis. Widespread mortality ensued, encompassing a broad range of size and age classes, including over 90 % mortality of dominant, overstory trees in high elevation sites (Breshears et al. 2005). Similarly, outbreaks of mountain pine beetle (*Dendroctonus ponderosae*) have impacted over 13 million ha of forest in western Canada, including sites higher in elevation and latitude than previously recorded (Raffa et al. 2008). Raffa and colleagues (2008) enumerated several controls, of which climate was a major factor, governing bark beetle population dynamics in the recent, unprecedented outbreaks. Warmer temperatures have increased the range, larval survival, and developmental rates of the beetle as well as interacted with drought to increase tree susceptibility to beetle colonization, facilitating outbreak population densities.

6.4 Conclusions

The emergence of a general model that accurately predicts the effects of climate change on the population dynamics of insect pests is unlikely. Each species has unique physiology, behavioral plasticity, dispersal ability, life-history strategy, and potential for genetic adaptation and evolution. Therefore, responses of insect species to climate change will be complex and idiosyncratic as one species may be more impacted by changes, for example, in host phenology while another may be more impacted by the inability to physiologically acclimate to warmer temperatures. Moreover, much of the research conducted thus far analyzes the effects of one or two factor(s) of climate change on insects, but given that many factors are changing simultaneously (e.g. temperature, CO_2, ozone, precipitation patterns, agricultural practices, etc.) and environmental heterogeneity, many outcomes may be more complex than that predicted by analysis of one or two factor(s). However, it is clear that anthropogenic changes to the atmosphere and climate will have pervasive effects on the physiology, phenology, species distributions, population dynamics, trophic interactions, and community composition, and ultimately evolutionary trajectories of insects. No doubt, in some cases, economic losses to key insect pests will increase in a warmer, CO_2 enriched world, but this pattern will be species-specific.

References

Allan RP, Soden BJ (2008) Atmospheric warming and the amplification of precipitation extremes. Science 321:1481–1484

Awmack CS, Harrington R, Lindroth RL (2004) Aphid individual performance may not predict population responses to elevated CO_2 or O_3. Global Change Biol 10:1414–1423

Bale JS, Masters GJ, Hodkinson ID et al (2002) Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. Global Change Biol 8:1–16

Bartomeus I, Ascher JS, Wagner D et al (2011) Climate-associated phenological advances in bee pollinators and bee-pollinated plants. Proc Natl Acad Sci U S A 108:20645–20649

Battisti A, Stastny M, Netherer S et al (2005) Expansion of geographic range in the pine processionary moth caused by increased winter temperatures. Ecol Appl 15:2084–2096

Battisti A, Stastny M, Buffo E et al (2006) A rapid altitudinal range expansion in the pine processionary moth produced by the 2003 climatic anomaly. Global Change Biol 12:662–671

Beedlow PA, Tingey DT, Phillips DL et al (2004) Rising atmospheric CO_2 and carbon sequestration in forests. Front Ecol Environ 2:315–322

Bezemer TM, Jones TH (1998) Plant-insect herbivore interactions in elevated atmospheric CO_2: quantitative analyses and guild effects. Oikos 82:212–222

Bowes G (1991) Growth at elevated CO_2: photosynthetic responses mediated through rubisco. Plant Cell Environ 14:795–806

Breshears DD, Cobb NS, Rich PM et al (2005) Regional vegetation die-off in response to global-change-type drought. Proc Natl Acad Sci U S A 102:15144–15148

Bryant JP, Chapin FS, Klein DR (1983) Carbon nutrient balance of boreal plants in relation to vertebrate herbivory. Oikos 40:357–368

Canadell JG, Le Quéré C, Raupach MR et al (2007) Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks. Proc Natl Acad Sci U S A 104:18866–18870

Chen I-C, Hill JK, Ohlemüller R et al (2011a) Rapid range shifts of species associated with high levels of climate warming. Science 333:1024–1026

Chen S, Fleischer SJ, Tobin PC et al (2011b) Projecting insect voltinism under high and low greenhouse gas emission conditions. Environ Entomol 40:505–515

Cleland EE, Chuine I, Menzel A et al (2007) Shifting plant phenology in response to global change. Trends Ecol Evol 22:357–365

Crozier L (2003) Winter warming facilitates range expansion: cold tolerance of the butterfly *Atalopedes campestris*. Oecologia 135:648–656

Crozier L (2004) Warmer winters drive butterfly range expansion by increasing survivorship. Ecology 85:231–241
Curtis PS, Wang XZ (1998) A meta-analysis of elevated CO_2 effects on woody plant mass, form, and physiology. Oecologia 113:299–313
DeLucia EH, Casteel CL, Nabity PD et al (2008) Insects take a bigger bite out of plants in a warmer, higher carbon dioxide world. Proc Natl Acad Sci U S A 105:1781–1782
Deutsch CA, Tewksbury JJ, Huey RB et al (2008) Impacts of climate warming on terrestrial ectotherms across latitude. Proc Natl Acad Sci U S A 105:6668–6672
Dickson RE, Lewin KF, Isebrands JG et al (2000) Forest atmosphere carbon transfer and storage (FACTS-II) – The Aspen Free-air CO_2 and O_3 Enrichment (FACE) Project: an overview. General Technical Report. NC-214. USDA Forest Service, North Central, St. Paul
Fajer ED (1989) The effects of enriched CO_2 atmospheres on plant-insect herbivore interactions: growth responses of larvae of the specialist butterfly, *Junonia coenia* (Lepidoptera: Nymphalidae). Oecologia 81:514–520
Fajer ED, Bowers MD, Bazzaz FA (1991) The effects of enriched CO_2 atmospheres on the buckeye butterfly, *Junonia coenia*. Ecology 72:751–754
Feeny P (1970) Seasonal changes in oak leaf tannins and nutrients as a cause of spring feeding by winter moth caterpillars. Ecology 15:565–581
Feeny PP (1976) Plant apparency and chemical defense. Recent Adv Phytochem 10:1–40
Forister ML, Shapiro AM (2003) Climatic trends and advancing spring flight of butterflies in lowland California. Global Change Biol 9:1130–1135
Hansen J, Sato M, Reudy R et al (2006) Global temperature change. Proc Natl Acad Sci U S A 103:14288–14293
Hegland SJ, Nielsen A, Lázaro A et al (2009) How does climate warming affect plant-pollinator interactions? Ecol Lett 12:184–195
Herms DA (2002) Effects of fertilization on insect resistance of woody ornamental plants: reassessing an entrenched paradigm. Environ Entomol 31:923–933
Herms DA (2004) Using degree-days and plant phenology to predict pest activity. In: Krischik V, Davidson J (eds) IPM (Integrated Pest Management) of midwest landscapes. Minnesota Agricultural Experiment Station Publication SB-07645, St. Paul, MN, pp 49–59 (316 pp)
Herms DA, Mattson WJ (1992) The dilemma of plants: to grow or defend. Q Rev Biol 67:283–335
Huberty AF, Denno RF (2004) Plant water stress and its consequences for herbivorous insects: a new synthesis. Ecology 85:1383–1398
Hunter MD (2001) Effects of elevated atmospheric carbon dioxide on insect-plant interactions. Agric For Entomol 3:153–159
IPCC (2007) Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds). Cambridge University Press, Cambridge, UK/New York
Jaramillo J, Chabi-Olaye A, Kamonjo C et al (2009) Thermal tolerance of the coffee berry borer *Hypothenemus hampei*: predictions of climate change impact on a tropical insect pest. PLoS One 4:e6487
Jaramillo J, Muchugu E, Vega FE et al (2011) Some like it hot: the influence and implications of climate change on coffee berry borer (*Hypothenemus hampei*) and coffee production in East Africa. PLoS One 6:e24528
Jordano D, Retamosa EC, Fernandez H (1991) Factors facilitating the continued presence of *Colotis evagore* (Klug 1829) in southern Spain. J Biogeogr 18:637–646
Kausrud K, Økland B, Skarpaas O et al (2012) Population dynamics in changing environments: the case of an eruptive forest pest species. Biol Rev 87:34–51
Knapp AK, Beier C, Briske DD et al (2008) Consequences of more extreme precipitation regimes for terrestrial ecosystems. Bioscience 58:811–821
Knepp RG, Hamilton JG, Zangerl AR et al (2007) Foliage of oaks grown under elevated CO_2 reduces performance of *Antheraea polyphemus* (Lepidoptera: Saturniidae). Environ Entomol 36:609–617

Koricheva J, Larsson S, Haukioja E et al (1998) Regulation of woody plant secondary metabolism by resource availability: hypothesis testing by means of meta-analysis. Oikos 83:212–226

Kytö M, Niemela P, Larsson S (1996) Insects on trees: population and individual response to fertilization. Oikos 75:148–159

Lacis AA, Schmidt GA, Rind D et al (2010) Atmospheric CO_2: principal control knob governing Earth's temperature. Science 330:356–359

Le Quéré C, Raupach MR, Canadell JG, Marland G (2009) Trends in the sources and sinks of carbon dioxide. Nat Geosci 2:831–836

Lindroth RL (2010) Impacts of elevated atmospheric CO_2 and O_3 on forests: phytochemistry, trophic interactions, and ecosystem dynamics. J Chem Ecol 36:2–21

Long SP, Ainsworth EA, Rogers A et al (2004) Rising atmospheric carbon dioxide: plants face the future. Annu Rev Plant Biol 55:591–628

Long SP, Ainsworth EA, Leakey ADB et al (2006) Food for thought: lower-than-expected crop yield stimulation with rising CO_2 concentrations. Science 312:1918–1921

Mattson WJ (1980) Herbivory in relation to plant nitrogen content. Annu Rev Ecol Syst 11:119–161

Mattson WJ, Lorimer N, Leary RA (1982) Role of plant variability (trait vector dynamics and diversity) in plant/herbivore interactions. In: Heybroek HM, Stephan BR, Wiessenberg KV (eds) Resistance to diseases and pests in forest trees. Pudoc, Wageningen, pp 295–303

Mattson WJ, Julkunen-Tiitto R, Herms DA (2005) CO_2 enrichment and carbon partitioning to phenolics: do plant responses accord better with the protein competition or the growth differentiation balance models? Oikos 111:337–347

McDonald EP, Agrell J, Lindroth RL (1999) CO_2 and light effects on deciduous trees: growth, foliar chemistry, and insect performance. Oecologia 119:389–399

McGuire AD, Melillo JM, Joyce LA (1995) The role of nitrogen in the response of forest net primary production to elevated atmospheric carbon dioxide. Annu Rev Ecol Syst 26:473–503

McKeown AW, Warland J, McDonald MR (2006) Long-term climate and weather patterns in relation to crop yield: a minireview. Can J Bot 84:1031–1036

Memmott J, Craze PG, Waser NM et al (2007) Global warming and the disruption of plant–pollinator interactions. Ecol Lett 10:710–717

Menzel A, Sparks TH, Estrella N et al (2006) European phenological response to climate change matches the warming pattern. Global Change Biol 12:1969–1976

Miller-Rushing AJ, Primack RB (2008) Global warming and flowering times in Thoreau's concord: a community perspective. Ecology 89:332–341

Mitton JB, Ferrenberg SM (2012) Mountain pine beetle develops an unprecedented summer generation in response to climate warming. Am Nat 179:E163–E171

Norby RJ, Warren JM, Iversen CM et al (2010) CO_2 enhancement of forest productivity constrained by limited nitrogen availability. Proc Natl Acad Sci U S A 107:19368–19373

O'Gorman PA, Schneider T (2009) The physical basis for increases in precipitation extremes in simulations of 21st-century climate change. Proc Natl Acad Sci U S A 106:14773–14777

Parmesan C (2006) Ecological and evolutionary responses to recent climate change. Annu Rev Ecol Evol Syst 37:637–669

Parmesan C, Yohe G (2003) A globally coherent fingerprint of climate change impacts across natural systems. Nature 421:37–42

Parmesan C, Ryrholm N, Stefanescu C et al (1999) Poleward shifts in geographical ranges of butterfly species associated with regional warming. Nature 399:579–583

Pascual M, Ahumada JA, Chaves LF et al (2006) Malaria resurgence in the East African highlands: temperature trends revisited. Proc Natl Acad Sci U S A 103:5829–5834

Patz JA, Olson SH (2006) Malaria risk and temperature: influences from global climate change and local land use practices. Proc Natl Acad Sci U S A 103:5635–5636

Pearson PN, Palmer MR (2000) Atmospheric carbon dioxide concentrations over the past 60 million years. Nature 406:695–699

Peñuelas J, Estiarte M (1998) Can elevated CO_2 affect secondary metabolism and ecosystem function? Trends Ecol Evol 13:20–24

Pollard E, Eversham BC (1995) Butterfly monitoring 2: interpreting the changes. In: Pullin AS (ed) Ecology and conservation of butterflies. Chapman & Hall, London, pp 23–36
Raffa KF, Aukema BH, Bentz BJ et al (2008) Cross-scale drivers of natural disturbances prone to anthropogenic amplification: the dynamics of bark beetle eruptions. Bioscience 58:501–517
Robinet C, Roques A (2010) Direct impacts of recent climate warming on insect populations. Integr Zool 5:132–142
Roy DB, Sparks TH (2000) Phenology of British butterflies and climate change. Global Change Biol 6:407–416
Royer DL, Berner RA, Park J (2007) Climate sensitivity constrained by CO_2 concentrations over the past 420 million years. Nature 446:530–532
Saxe H, Ellsworth DS, Heath J (1998) Tree and forest functioning in an enriched CO_2 atmosphere. New Phytol 139:395–436
Stiling P, Cornelissen T (2007) How does elevated carbon dioxide (CO_2) affect plant-herbivore interactions? A field experiment and meta-analysis of CO_2-mediated changes on plant chemistry and herbivore performance. Global Change Biol 13:1823–1842
Thackeray SJ, Sparks TH, Frederiksen M et al (2010) Trophic level asynchrony in rates of phenological change for marine, freshwater and terrestrial environments. Global Change Biol 16:3304–3313
Tissue DT, Thomas RB, Strain BR (1993) Long-term effects of elevated CO_2 and nutrients on photosynthesis and rubisco in loblolly pine seedlings. Plant Cell Environ 16:859–865
Tobin PC, Nagarkatti S, Loeb G et al (2008) Historical and projected interactions between climate change and insect voltinism in a multivoltine species. Global Change Biol 14:951–957
Tubiello FN, Soussana JF, Howden SM (2007) Crop and pasture response to climate change. Proc Nat Acad Sci USA 104:19686–19690
Visser ME, Both C (2005) Shifts in phenology due to global climate change: the need for a yardstick. Proc R Soc Lond B Biol Sci 272:2561–2569
Visser ME, Holleman LJM (2001) Warmer springs disrupt the synchrony of oak and winter moth phenology. Proc Biol Sci 268:289–294
Walther G-R, Post E, Convey P et al (2002) Ecological responses to recent climate change. Nature 416:389–395
Warren MS (1992) The conservation of British butterflies. In: Dennis RLH (ed) The ecology of butterflies in Britain. Oxford University Press, Oxford, UK, pp 246–274
Whittaker JB (2001) Presidential address: insects and plants in a changing atmosphere. J Ecol 89:507–518
Zavala JA, Casteel CL, DeLucia EH et al (2008) Anthropogenic increase in carbon dioxide compromises plant defense against invasive insects. Proc Nat Acad Sci USA 105:5129–5133
Zvereva EL, Kozlov MV (2006) Consequences of simultaneous elevation of carbon dioxide and temperature for plant–herbivore interactions: a metaanalysis. Global Change Biol 12:27–41

Chapter 7
Climate Change and Locusts in the WANA Region

Keith Cressman

Abstract The Desert Locust is probably the oldest and most feared migratory pest in the world, plaguing farmers in Africa and Asia since Phaoronic times. Under optimal conditions, locusts increase rapidly and form swarms. A single swarm, larger than Paris or Cairo, can contain billions of insects, migrate across continents, and eat enough food for 2,500 people in 1 day. During plagues, vulnerable households can find themselves in debt, limited national resources are rapidly depleted and food security can be at risk in affected countries. It can take several years and hundreds of millions of dollars to bring a plague to an end. Changes in the climate during the remainder of this century will affect Desert Locust habitats, breeding, migration and plague dynamics in West Asia and North Africa (WANA). Although it is widely acknowledged that WANA will become warmer, there are differing views about changes in precipitation under the various climate change scenarios. General trends may contain hidden variations within the regions and countries. Certain areas will become more prone to extreme events such as flooding and droughts. Regular assessment of climate change impacts is a component of the locust early warning system operated by the Food and Agriculture Organization (FAO) of the United Nations to monitor the global situation and alert locust-affected countries and international donors. The latest scientific evidence is reviewed to postulate potential effects on the Desert Locust. It is probably reasonable to assume that this ancient pest, which is particularly well suited for survival under difficult conditions in arid areas and has successfully endured previous changes in the climate, will adapt to climate variability in the foreseeable future.

Keywords Temperature effects • Locust migration • Locust breeding • Wind effects

K. Cressman (✉)
Food and Agriculture Organization of the United Nations (FAO),
viale delle Terme di Caracalla, Rome, Italy
e-mail: keith.cressman@fao.org

M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_7,

7.1 Introduction

The Desert Locust (*Schistocerca gregaria*, Forskål) is a pest well known to farmers, nomads and locals in West Asia and North Africa (WANA). It is probably the oldest and most feared of all migratory pests in the world. Its presence in Egypt has been documented during Phaoronic times, some 5,000 years ago, and is mentioned in the Bible and the Koran. Under normal conditions, low numbers of individual solitary adults are present within a vast desert area of some 16 million km^2, extending from West Africa to India. When good rains fall, females lay eggs in sandy soil that normally hatch after about 2 weeks into wingless larvae or nymphs called hoppers. Hoppers undergo a process of moulting in which they shed their skin five or six times, each time growing in size. The final moult from the wingless hopper to the winged adult is called fledging. The new adult, known as a fledgling, has soft wings that must dry and harden after a few days before it can fly. Adults are initially immature but eventually become sexually mature and, after about 1 month, they are ready to lay eggs. The entire lifecycle takes about 2–6 months, depending on temperature and habitat conditions. Favourable maturation conditions are usually associated with rain and warm temperatures. Locust eggs, hoppers and adults will mature faster under warmer temperatures. Immature adults can survive for 6 months or more under cool dry conditions but adults cannot survive for long under hot dry conditions with little to eat.

Desert Locusts have the ability to change their behaviour, physiology, colour and shape in response to a change in locust numbers. At low numbers, they behave as individuals (solitary phase) and at high numbers they behave as a single mass (gregarious phase). This process is referred to as *gregarization* and the intermediate phase between solitary and gregarious is called *transiens*. Three processes are involved in phase transformation: concentration, multiplication and gregarization. Scattered locusts will concentrate in green vegetation in response to habitat conditions and as a result of convergent winds and, as locust numbers increase, they form small groups. Grouping can be considered as an intermediate step in the change from solitary hoppers and adults to gregarious hopper bands and adult swarms. If sufficient numbers of locusts are present or if good rains fall and there is another generation of breeding, then locust numbers can increase rapidly and hopper bands and swarms can form.

Locust adults migrate with the wind as passive fliers flying downwind at roughly the wind speed up to about 1,800 m above the ground. Solitary adults fly at night while swarms migrate during the day. Downwind displacement of up to about 200 km per day tends to bring locusts into seasonal rainfall areas. Locust movements often take place during periods of particular winds rather than coinciding with the prevailing wind flow. Furthermore, rare and even unprecedented movements can occur, for example, migration across the Atlantic Ocean from West Africa to the Caribbean in October 1988.

Desert Locusts are normally present at low densities in semi-arid or arid areas away from major cropping areas. They do not pose a significant threat to agriculture and hopper bands and swarms are rare or completely absent. This calm period is called a recession. The transition from a recession to a plague is characterized by outbreaks and upsurges. An outbreak occurs when there is an increase in locust numbers over several months in a relatively small area. It is localized and restricted to certain habitats in an individual country. Small groups of hoppers and adults, hopper bands and adult swarms may form as the outbreak continues. If an outbreak is not controlled and if good rains fall, locusts will continue to multiply, concentrate and gregarize so that with each additional generation the proportion of the total population in bands and swarms increases. This is referred to as an upsurge. An upsurge may affect several countries within a given region. If an upsurge is not controlled and further rains fall, then a plague can develop on a regional or continental scale.

During upsurges and plagues, Desert Locust hopper bands and swarms can damage subsistence crops, pastures, irrigated agricultural areas and export cash crops, threatening the food security of affected countries and regions. One tonne of locusts, a very small part of average swarm, can consume as much food in 1 day as 2,500 people (Steedman 1990). In most of the recession area, farming systems are already naturally vulnerable and fragile, and cannot sustain additional stress or disruption posed by Desert Locust infestations. This fragility could be exacerbated if temperatures become warmer and rainfall decreases in the recession area.

The Food and Agriculture Organization (FAO) of the United Nations (UN) operates an early warning system that monitors weather and ecological conditions, and locust infestations in the recession area on a daily basis. The Desert Locust Information Service (DLIS) at FAO Headquarters acts as a focal point and clearing-house for all survey and control data transmitted by national locust field teams. The data are analyzed within a geographic information system to assess the current locust situation and forecast the scale, timing and location of breeding and migration. Alerts and warnings are issued to the international community during periods of increased locust activity as part of the early warning system and the global strategy to prevent plagues.

This paper provides an initial attempt to postulate how potential changes in temperature, rainfall and wind associated with climate change and variability might affect Desert Locusts by the end of this century.

7.2 Temperature Effects

Several general circulation models using data collected by the Intergovernmental Panel on Climate Change (IPCC) Data Distribution Center (DDC) indicate that Africa will face future warming, ranging from 0.2 °C per decade (B1 low scenario[1])

[1]The B1 scenario is one of an integrated world that is more ecological friendly, characterized by rapid economic growth, rising population to 2050 then declining, reductions in material intensity and the introduction of efficient technologies, and an emphasis on global solutions to economic, social and environmental stability.

to more than 0.5 °C per decade (A2 high scenario[2]) (Christensen et al. 2007). The warming is expected to be greatest over the interior of the semi-arid margins of the Sahara. Hence, by 2100, temperatures could be as much as 4 °C higher than today.

7.2.1 Locust Breeding

The effect of warmer temperatures could cause Desert Locust maturation to occur more rapidly, leading to an overall shorter lifecycle of the insect. Warmer temperatures could also potentially allow breeding to commence earlier and last longer in each seasonal breeding area if there is rainfall, or end earlier if there is no rainfall. A prolonged season of favourable breeding conditions could allow for a possibility of at least one extra generation. This, in turn, would cause Desert Locust numbers to increase much more rapidly than at present under current temperature conditions. On the other hand, increased temperatures without a corresponding increase in precipitation would cause ecological conditions for breeding and survival, that is moist soil and green vegetation, to deteriorate faster than under current conditions. This would reduce the length of possible breeding within a given season and the likelihood of extra generations. Consequently, locust numbers would not increase very much. Nevertheless, rapid drying of ecological conditions would encourage gregarization as locusts crowd into those few areas that remain green; however, the scale of this gregarization would be limited due to lower than normal numbers of locust.

A model was used to estimate the potential effect of future warming on the maturation rate of locust eggs and hoppers. The model, known as the *Desert Locust Egg and Hopper Simulation Programme*, estimates the egg and hopper development periods of the Desert Locust using long-term monthly mean temperatures from weather stations in the Desert Locust recession area (Reus and Symmons 1992). It calculates the daily mean temperature and the daily-related amount of development. Egg and hopper development rates are assumed to be zero when the daily mean temperature is below 10 °C. When the mean temperature is below 20 °C, model results are interpreted with caution as there may be an overestimate of the actual egg and hopper development periods.

For this study, the model was used to estimate egg and hopper development rates under normal (current) conditions and under future extreme warming conditions. In order to use the model for the latter situation, it was modified by increasing the long-term monthly mean temperatures of the weather stations by 4 °C. Three breeding seasons were examined: (a) summer (May to December) in the Sahel from

[2]The A2 scenario is of a more divided world characterized by independent operating, self-reliant nations, continuously increasing population, regionally oriented economic development, and slower technological changes and improvement to per capita income.

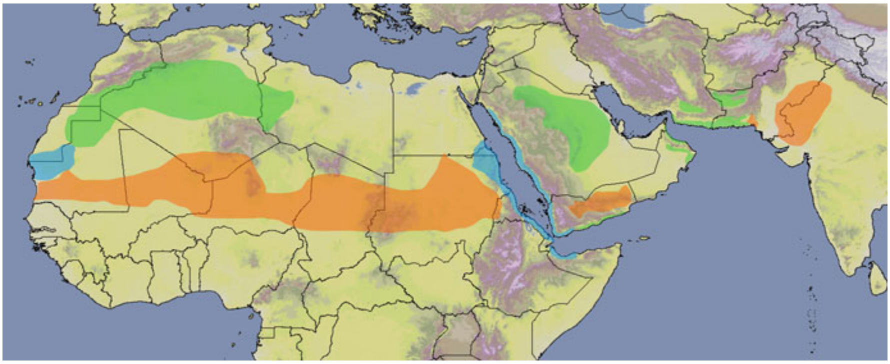


Fig. 7.1 Seasonal breeding areas of the Desert Locust – orange (summer, May/Jul to Oct/Dec), blue (winter, Oct/Nov to Mar/May), green (spring, Jan/Mar to May/June)

West Africa to Sudan and along both sides of the Indo-Pakistan border, (b) winter (October to May) along both sides of the Red Sea, the northern coast of the Horn of Africa and in northern Mauritania, and (c) spring (January to June) in northwest Africa south of the Atlas Mountains, in the interior of Saudi Arabia and in Baluchistan of western Pakistan and southeastern Iran (Fig. 7.1). Each season consisted of different temperature regimes. The summer period corresponded to declining temperatures as the season progressed; the winter to an initial decline, then increasing temperatures; and the spring to increasing temperatures throughout the season. Seven to eight representative weather stations were used in each season. The time period for each breeding season was extended by one or more months before and after the current breeding period to allow for any effects of increased warming. The model was run on the 15th day of each month within the breeding season period forward in time from egg laying to hopper fledging. The outputs of the model consisted of the estimated dates of egg hatching and hopper fledging. The minimum, maximum and mean number of days for hatching and fledging under normal and future extreme warming conditions were compared and contrasted with each other for each of the three breeding seasons.

The results suggest a number of trends for each season (Figs. 7.2–7.4):

- *Extended spring period* (January to June). Under warmer conditions, hatching was on average up to 2 weeks shorter and fledging was 1–3 weeks shorter than normal conditions. The greatest differences occurred at the beginning of the season when temperatures were still low while as the season progressed and temperatures increased, the differences became less. In January, hatching was up to 27 days faster and fledging was 35 days faster under warmer conditions. In both normal and warmer temperatures, the theoretical maximum number of generations during the extended spring from 1 January to 30 June remained as two although this occurred about 1 month faster under warmer conditions.
- *Extended summer period* (May to December). There was no significant effect of warmer conditions on the time required for hatching except at the end of the

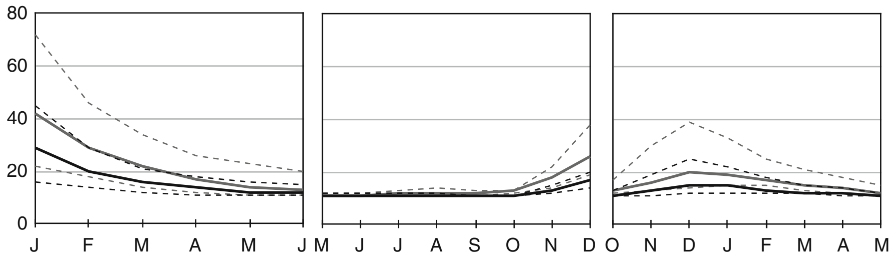


Fig. 7.2 The average number of days required for egg development under normal (*gray line*) and warmer (+4 °C) (*dark line*) conditions in the spring (January to June), summer (May to December) and winter (October to May) breeding areas. *Dashed lines* represent minimum and maximum values

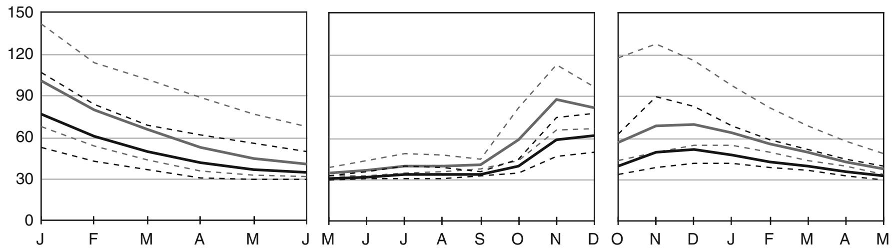


Fig. 7.3 The average number of days required for hopper development under normal (*gray line*) and warmer (+4 °C) (*dark line*) conditions in the spring (January to June), summer (May to December) and winter (October to May) breeding areas. *Dashed lines* represent minimum and maximum values

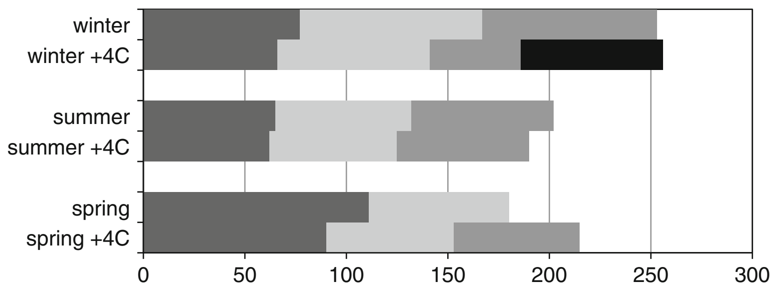


Fig. 7.4 The theoretical potential number of Desert Locust generations and their length (days) during the extended summer, winter and spring breeding periods under normal and warmer (+4 °C) conditions

season (December) when on average it was about 9 days shorter than under normal current temperature conditions. On the other hand, the length of time required for fledging decreased by about 1 week throughout the season under warmer conditions, and up to 2–4 weeks by the end of the extended season when temperatures are declining from October onwards. In both normal and warmer temperatures, the theoretical maximum number of generations during the extended summer from 1 May to 31 December remained as three. Under warmer conditions, summer breeding finished about 2 weeks earlier than under normal temperatures, assuming no temperature effects on adult maturation.

- *Extended winter period* (October to May). Under warmer conditions, hatching was generally only a few days shorter while fledging was 1–2 weeks shorter than normal conditions. As temperatures were initially declining, hatching was on average about 5 days faster in December and fledging was up 2 weeks faster from October to February under warmer conditions. There is a possibility that four generations of breeding could occur under warmer conditions compared to three under normal temperatures.

The reliability of the model results may be affected by differences in the relationship between air temperature and the temperature experienced by locust eggs and hoppers (Reus and Symmons 1992).

7.2.2 Locust Migration

During recession periods when the majority of Desert Locust populations are solitarious in low numbers, adults migrate at night, normally taking off about 20 min after sunset and flying for up to 10 h, or an average of 2 h per night (Symmons and Cressman 2001). Swarms, on the other hand, fly during the day, taking off about 2–3 h after sunrise in warm weather and 4–6 h after sunrise in cooler weather. Swarms will take off in temperatures of 15–17 °C under sunny conditions and 23–26 °C under cloudy conditions, and fly for 9–20 h. Swarms normally settle on the ground for the night about 2 h before sunset to a half hour after sunset. Adults and swarms are passive fliers, moving downwind at or near the wind speed. Swarms can easily move up to 200 km in a day while adults may move anywhere from 1 to 400 km in a night. The limiting temperature for both day and night flights is about 20–22 °C.

Warmer temperatures could potentially affect locust migration by allowing adults to fly longer during nights, especially during the autumn and spring when nighttime temperatures are usually cooler. Consequently, adults may arrive at destinations sooner or reach new areas further away. Warmer temperatures could allow swarms to take off earlier in the morning, allowing for a longer period of flight and a greater displacement distance. Under future warming, swarms could perhaps reach areas quicker than in the past.

Locusts normally fly up to about 1,800 m above ground. Assuming that the height limits are temperature dependent, then warmer temperatures could allow adults to theoretically fly higher. If this is the case, then some of the natural barriers to migration such as the Atlas Mountains in northwest Africa, the Hoggar Mountains in the Algerian Sahara, the mountain ranges along both sides of the Red Sea,

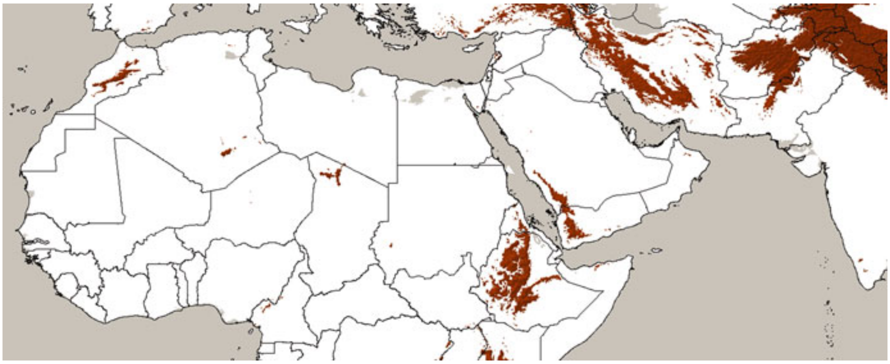


Fig. 7.5 Natural barriers to Desert Locust migration in the recession area

the Jebel Akdar in northern Oman and the mountains in the interior of Iran may no longer be effective (Fig. 7.5). This could permit new migration routes, allowing swarms to reach southern Europe and central Asia, assuming that the winds are favourable.

7.3 Rainfall Effects

Warming generally increases the spatial variability of precipitation, leading to a decrease of rainfall in the subtropics and an increase in higher latitudes and in parts of the tropics (Christensen et al. 2007). Increased rainfall may arise from enhanced moisture convergence associated with monsoonal circulations. Although increasingly reliable regional climate change projections are becoming available with improved resolution, predictions of how climate change will affect rainfall in the Sahara Desert remain varied and lack consensus.

The fourth assessment synthesis IPCC Report (2007) indicates that annual rainfall is likely to decrease in the northern Sahara by up to 18 % with a greater likelihood of declining rainfall (up to 30 %) as the Mediterranean coast is approached (Fig. 7.6). This area includes Mauritania, Western Sahara, Morocco, Tunisia, and the northern portions of Algeria, Libya and Egypt. It is unclear how rainfall in the Sahel (Mali, Niger, Chad and Sudan) and the southern Sahara in Algeria, Libya and Egypt will evolve as the various models are in disagreement. Prior to this report, it had been suggested that rainfall might increase in the Sahel as a result of increasing carbon dioxide levels leading to an increase in vegetation growth and moisture levels (Claussen et al. 2003). Other researchers hypothesize that increasing land-ocean temperatures and decreasing surface pressures over the Sahara may contribute to increased rainfall in the Sahel (Biasutti et al. 2009; Haarsma et al. 2005) or may not (Schepanski and Knippertz 2011).

In Northeast Africa, annual rainfall is likely to increase during December–February in Ethiopia and Somalia. One study suggested that mean precipitation

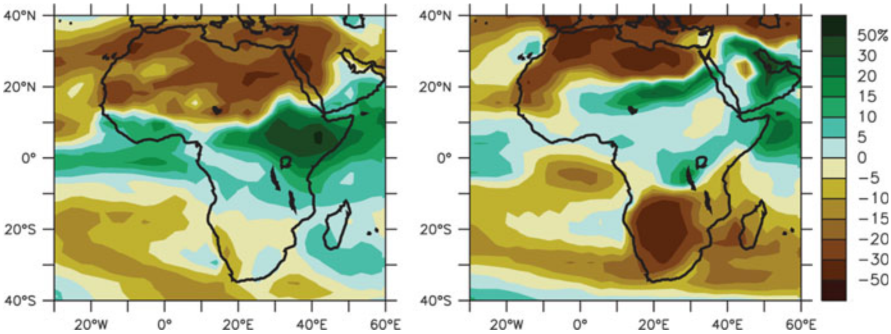


Fig. 7.6 Precipitation changes from the MMD-A1 simulations between 1980–1999 and 2080–2099 over Africa and the Near East during the winter (December–February) and summer (June–August) averaged over 21 models (Christensen et al. 2007)

would decrease in Sudan and the Ethiopian Highlands in June and July, and increase in September and October (de Boer 2007).

Desert Locusts normally breed during the winter along both sides of the Red Sea and occasionally in northern Mauritania. During the spring, breeding usually occurs in Baluchistan in western Pakistan and southeast Iran, and occasionally in the interior of the Arabian Peninsula, and along the southern side of the Atlas Mountains in Morocco and Algeria. Spring breeding is most pronounced during periods of increased locust activity and during upsurges and plagues. During the summer, locust breeding takes place in the northern Sahel between Mauritania and western Eritrea, and along both sides of the Indo-Pakistan border. Relative changes in precipitation for 2090–2099 compared to 1980–1999 under the A1B climate change scenario[3] indicate up to 20–30 % decrease in rainfall in northern Mauritania and along the Red Sea coast in Egypt, Sudan and Saudi Arabia (Fig. 7.6). For the same period, a 5–20 % increase in rainfall is projected for the Red Sea coast in Eritrea and Yemen and the Gulf of Aden coast in southern Yemen and northern Somalia. In the summer breeding areas, a 10–20 % decline in rainfall is projected for Mauritania while a 5–20 % increase is estimated over the northern Sahel in Mali, Niger, Chad and Sudan as well as in the interior of Yemen (Christensen et al. 2007). There is not a clear indication of rainfall effects along the Indo-Pakistan border or in the spring breeding areas.

It is worthwhile to note that none of the model-simulated current or future rainfall in the Desert Locust recession area is similar to that observed in recent decades. Perhaps some of this can be explained by the absence of land cover and atmospheric (dust and biomass aerosols) processes in the models (Hulme et al. 2001).

[3]The main characteristics of the A1B scenario include low population growth, very high GDP growth, very high energy use, low-medium land use changes, medium resource (mainly oil and gas) availability, and rapid pace and direction of technological change favoring balanced development.

Limited research on extreme rainfall events suggests that there may be a general increase in the intensity of high-rainfall events in Africa (Christensen et al. 2007). The importance of extreme rainfall events and their link to Desert Locust plagues should not be underestimated. For example, a cyclone in Oman in 1968 led to a plague and widespread unusually heavy rain from Dakar, Senegal to Morocco in October 2003 caused a regional plague in North Africa in 2004–2005.

7.4 Wind Effects

Since Desert Locust are passive fliers and fly with the wind, then shifts in wind direction and speed due to climate change and variability could affect locust migration routes and daily displacement speed. If wind patterns or the geographic distribution of wind change, then adults could be carried to new areas; however, if ecological and weather conditions in the new areas differ significantly from those in the semi-arid and arid habitats, then locusts are not likely to survive and become established. For example, the species did not become established in the Caribbean after Desert Locust swarms migrated from West Africa in October 1988 because of ecological and weather conditions (Ritchie and Pedgley 1989).

Climate change may affect the geographic distribution and the annual variability of winds but only very limited research has been conducted in this field. There is some evidence that, by the end of the twenty-first century, there will be small magnitude changes in winds with potential increases of extreme winds over northern Europe and a general decline in average wind speeds in northern latitudes, depending on the time of year (Pryor and Barthelmie 2010; Ren 2010). There is also a possibility that coastal winds might increase while interior winds could decrease by up to 12 % (Harley et al. 2006). If climate change alters the jet stream and completely rearranges global air circulation and ocean currents, then local wind patterns, those that affect the Desert Locust, will certainly change. However, the potential impact of global climate variability and change on wind remains unclear, especially in the Desert Locust recession area.

7.5 Conclusions

The bulk of this study concentrated on temperature effects because, of the three parameters important to Desert Locust, there is the greatest agreement on potential impacts of climate change and variability. In contrast, there is much less certainty about the impact on rainfall in certain areas and on winds in general.

Under warmer conditions associated with climate change and variability, Desert Locust eggs and hoppers could potentially develop faster during the coldest time of each seasonal breeding period. The greatest impact was seen during the extended spring breeding period when the time required for fledging decreased by 35 days and that for hatching by 27 days in January, the coldest month at the beginning of the season. A similar trend was noted during the summer (fledging shortened by 26 days and hatching by 10 days at the end of the season in December) and the winter (fledging shortened by 14 days and hatching by 5 days in December, the coldest month). Changes in the development rate of eggs and hoppers during warmer periods of each season (i.e. the beginning of summer, and the end of winter and spring) did not vary so much; eggs still required at least 10 days to hatch and hoppers at least 24 days to fledge. However, there is a possibility for an extra generation of breeding during the winter under warmer temperature conditions.

During the winter, a 20–30 % decrease in rainfall in the locust breeding areas in northwest Mauritania and along both sides of the central and northern Red Sea would be expected to reduce the scale of breeding. Reduced breeding would affect the number of locusts present at the end of the breeding season that would then move to the summer breeding areas in the northern Sahel of West Africa and Sudan, and the interior of Yemen. In this case, fewer locusts would be present to take advantage of summer rainfall for breeding. A further 10–20 % decline in expected summer rainfall in Mauritania would exacerbate this situation, potentially causing a significant and dramatic decline in locust activity within the country. The only exception to this could be along the Red Sea coast of Yemen and southern Eritrea and along both sides of the Gulf of Aden. Here, a 5–20 % increase is projected that could cause an increase in locust numbers that could eventually move into the summer breeding areas in the interior of Sudan and Yemen.

During the summer, rainfall is projected to increase in the northern Sahel from Mali to Sudan and in the Yemen interior by 5–20 %. This could allow the initially low populations in Mali, Niger and Chad to increase to normal levels, and the potentially higher than normal populations in Sudan and Yemen to increase further. If increased rainfall was to continue beyond August in these areas, then another generation of breeding could occur, potentially causing a substantial increase in locust numbers. These populations could act as a source for winter breeding.

Nevertheless, the combined effects of both temperature and rainfall must be evaluated together since successful breeding requires both components. In this case, locust activity could potentially increase during the summer in the interior of Sudan and Yemen and during the winter along the coastal plains of the southern Red Sea in Eritrea and Yemen and along both sides of the Gulf of Aden in southern Yemen and northern Somalia. Increased locust activity in both the summer and winter breeding areas within the region could lead to a progressive buildup of locust populations in Sudan, Eritrea, Yemen and northern Somalia. In the northern Sahel of Mali, Niger and Chad, locust activity is likely to remain at normal levels; that is, neither increasing or decreasing significantly because populations produced during the summer in increased rainfall areas would be kept in check by poorer than normal rains and subsequent breeding in northwest Mauritania during the winter. Potential locust activity in Mauritania could decline dramatically given the anticipated decreases in rainfall during the summer and winter under warmer conditions.

The effects of temperature and rainfall in the summer breeding areas along the Indo-Pakistan border and in the spring breeding areas of Arabia, Baluchistan and

Northwest Africa could not be assessed due to inconclusive estimates of rainfall changes under warmer conditions. The effects of wind are less certain but any changes in wind speed, direction and circulation flows are likely to affect Desert Locust migration and could allow adults and swarms to reach new areas. Whether they will be able to become established, survive and breed in these new areas will depend on ecological and habitat conditions.

Further research is required to better understand the impacts of climate change and variability on the Desert Locust. For example, Desert Locust outbreaks and upsurges should be cataloged and correlated with drought indices and rainfall anomalies to gain further insight into the relationship of droughts and extreme rainfall events with increases in Desert Locust activity. Potential areas at risk by Desert Locust under warming conditions should be investigated to identify any new threats to national and regional food security. Lastly, the data required to operate global and regional climate change models need to be improved, more accessible and shared amongst the various stakeholders. Integrated models should be developed to test different climate change scenarios. Policy makers should be made aware of the uncertainty of the potential impacts of climate change and variability on agricultural production and food security, and the need to expand contingency planning to include different climate change scenarios and include these in national locust programmes.

References

Biasutti M, Sobel AH, Camargo SJ (2009) The role of the Sahara low in summertime Sahel rainfall variability and change in the CMIP3 model. J Climate 22:5755–5771. doi:10.1175/2009JCLI29969.1

Christensen JH, Hewitson B, Busuioc A, Chen A, Gao X, Held I, Jones R, Kolli RK, Kwon WT, Laprise R, Magaña Rueda V, Mearns L, Menéndez CG, Räisänen J, Rinke A, Sarr A, Whetton P (2007) Regional climate projections. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK

Claussen M, Brovkin V, Ganopolski A, Kubatzki C, Petoukhov V (2003) Climate change in Northern Africa: the past is not the future. Clim Change 57:99–118

de Boer B (2007) The impact of climate change on rainfall extremes over Northeast Africa. Royal Netherlands Meteorological Institute (KNMI). De Bilt (The Netherlands), 46 pp

Haarsma RJ, Selten F, Weber S, Kliphuis M (2005) Sahel rainfall variability and response to greenhouse warming. Geophys Res Lett 32:L17702. doi:10.1029/2005GL023232

Harley CDG, Randall Hughes A, Hultgren KM, Miner BG, Sorte CJB, Thornber CS, Rodriguez LF, Tomanek L, Williams SL (2006) The impacts of climate change in coastal marine systems. Ecol Lett 9:228–241. doi:10.1111/j.1461-0248.2005.00871.x

Hulme M, Doherty R, Ngara T, New M, Lister D (2001) African climate change: 1900–2100. Clim Res 17:145–168

Pryor SC, Barthelmie RJ (2010) Climate change impacts on wind energy: a review. Renew Sust Energy Rev 14:430–437

Ren D (2010) Effects of global warming on wind energy availability. Renew Sust Energy Rev 2:052301. doi:10.1063/1.3486072

Reus JAWA, Symmons P (1992) A model to predict the incubation and nymphal development periods of the desert locust, *Schistocerca gregaria* (Orthoptera: Acrididae). Bull Entomol Res 82:517–520

Ritchie M, Pedgley D (1989) Desert Locust across the Atlantic. Antenna 13:10–12

Schepanski K, Knippertz P (2011) Soudano-Saharan depressions and their importance for precipitation and dust: a new perspective on a classical synoptic concept. Q J Roy Meteor Soc 137:1431–1445. doi:10.1002/qj.850

Steedman A (ed) (1990) Locust handbook. Natural Resources Institute, Chatham, p 204

Symmons P, Cressman K (2001) Desert locust guidelines I. Biology and behaviour. FAO, Rome, p 43

Part III
Climate Change and Food Security: Perspectives from WANA Sub-Regions

Chapter 8
Climate Change Impact on WANA: Key Researchable Issues and Proposed Measures

Ibrahim Hamdan and Susanna Smets

Abstract AARINENA mission is to contribute to the enhancement of agricultural and rural development in the West Asia & North Africa (WANA) region by fostering agricultural research and technology development and by strengthening collaboration within and outside the region, AARINENA aims to achieve greater degree of self-sufficiency while sustaining and further improving the productive capacity of the natural resources base. The WANA region has fragile ecosystems of semi-arid and arid areas facing the challenging issues of absolute water scarcity, drought, land degradation and desertification. In addition to these, the region also has to deal with other issues including a significant increase in population, poverty, a geo-politically fragile environment, gender imbalance, weak investment in agricultural research for development and constraints in human resources and institutional capacities. As a result of all these factors, WANA region is one of the largest food deficit regions in the world.

AARINENA stakeholders during their meeting in Alexandria in November 2009 have identified climate change as number one of the key researchable issues in this region and have highlighted a number of key researchable issues for climate change. AARINENA stakeholders in this meeting also proposed some measures to compact climate change. These are described in detail.

Keywords AARINENA • Sustainable development • GCARD • Regional e-consultation • Solutions and innovative partnerships

I. Hamdan (✉) • S. Smets
Association of Agricultural Research Institutions in the Near East and North Africa (AARINENA), c/o ICARDA, P.O. Box 851758, 11185 Amman, Jordan
e-mail: ihamdan@link.net; ihamdan@yahoo.com

M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_8,

8.1 WANA Region Background

8.1.1 Introduction

AARINENA was established in 1985 as an autonomous body and a platform for agricultural research and innovation in the West Asia and North Africa (WANA) region. AARINENA mission is to contribute to the enhancement of agricultural and rural development in the West Asia and North Africa (WANA) region by fostering agricultural research and technology development and by strengthening collaboration within and outside the region, AARINENA aims to achieve greater degree of self-sufficiency while sustaining and further improving the productive capacity of the natural resources base.

AARINENA includes five sub-regions:

- Arabian Peninsula (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and UAE)
- North Africa -Maghreb (Algeria, Libya, Malta, Mauritania, Morocco, and Tunisia)
- Mashreq (Cyprus, Iraq, Jordan, Lebanon, Palestinian Authority, and Syria)
- Nile Valley and Red Sea (Djibouti, Egypt, Sudan, Somalia, and Yemen)
- West Asia (Afghanistan, Iran, Pakistan, and Turkey)

Since its creation, AARINENA has organized a series of global conferences in collaboration with its cosponsors, stakeholders and representatives from civil society, the private sector and donor agencies.

The Global Conference on Agricultural Research for Development (GCARD) held in Montpellier aims to ensure that:

- Research is focusing on the right approaches and questions to meet the needs of resource-poor farmers, as well as the needs of poor consumers for sufficient, affordable, healthy food
- Research is embedded into development processes, with outputs easily accessible and relevant to the poor
- Scientific knowledge and advances impact development thinking and practices
- Research and development funding systems are aligned with each other to ensure effective investment in new forms of institutions and partnerships required for the delivery of development impacts at scale
- The international research system is effectively integrated with national partners (public, private and civil) and responds to national and sub-regional (or transnational) demands to ensure development impact.

8.1.2 Characteristics of WANA Region

The economic situation and poverty incidence in the region is very diverse, ranging from the wealthy Gulf States to extremely poor countries as Yemen, with more than 45 % of the population living on less than 2 USD/day. In addition, around

5–15 % of the population lives just above the poverty threshold and hence is vulnerable to environmental and economic shocks (World Bank et al. 2009).

In the WANA region, 70 % of the poverty can be found in rural areas even though only around 40 % of the total population lives in rural areas. Despite the dependence of the rural population on agriculture, many national plans show a declining emphasis on agriculture and rural development. In addition the region is facing a number of converging trends that threaten the future livelihoods of the poorest communities in society, such as high population growth rates, water scarcity, land degradation, and global climate change (FAO 2008).

The region is characterized by the second highest population growth rates in the world, with some countries in the region growing at 3.5 % per year. The WANA region features an arid and semi-arid climate and is already one of the most water scarce in the world. The situation of water scarcity is predicted to worsen significantly over the next 25 years. As a consequence of climate change, the region is projected to become warmer and drier with reduced crop productivity. The region is already a large net importer of grains and in the future it will become increasingly dependent on food imports, worsening the regional food security situation (FAO 2003).

Being at a junction between three continents, encompassing various marine ecosystems, and comprising large variations in altitude, the region has a high terrestrial and marine biodiversity, including hotspots of endemic species. Managing its natural resources in an efficient and sustainable manner is now one of the most critical issues for food production in the region. As much as 45 % of the total land area dedicated to agriculture and rangeland is experiencing some form of land degradation, thus reducing the already low productive potential of the land.

Most countries have invested heavily in irrigation over the past half century. Wherever land and water are available, large and medium irrigation schemes have been established requiring large public investments. However, recent assessments show that water productivity and irrigation efficiency are low. Traditional surface irrigation methods prevail, often complemented with unsustainable groundwater irrigation, with the exception of large-scale application of modern irrigation methods in the Gulf countries, Cyprus and Jordan. The common practice of over-irrigation has led to large-scale soil and water quality degradation and decreasing profits for farmers. The issue of sustainable water management to achieve higher water productivity and stop further environmental degradation is crucial for the region's agricultural and economic development (Zehni 2011).

8.2 Methodology

The regional review was implemented through the following three steps (El-Hababab 2009):

(a) Situation analysis WANA agricultural research and research networks through a literature review and a survey in the WANA region
(b) Regional E-consultation process for WANA region

(c) Regional Face-to-Face consultation workshop to agree on prioritization of research themes and discuss innovative research mechanisms and partnerships

A Regional Task Force was erected to manage and lead the preparation process for GCARD 2010. The Task Force provided valuable guidance and feedback to the regional consultants.

The regional review aimed at producing a high-level regional development targets and refreshed, high-level set of regional agricultural research priorities, identification of areas of specific need in agricultural research for the poorest in AARINENA countries, and developing an action plan for implementing the identified regional priorities.

The regional review included: overview of the existing priorities, developmental goals and challenges in the region, researchable themes with priorities, mechanisms and partnerships, changes needed in agricultural research system and extension, and constraints that prevents impacts to farmers, and conduct a comparative analysis between the priorities of conducted in 2002 and ongoing research up to 2009 (AARINENA 2009a, b).

8.3 Results and Discussions

8.3.1 Situation Analysis WANA Region

8.3.1.1 WANA Needs

WANA region is the cradle of agriculture and the origin of domestication of several crop and livestock species. It is the origin of many vital food crops such as barley and lentils for the World. In ancient times, the region was the bread basket of various empires. Today it is food deficient. The region has several development problems, among them, poverty, lack of gainful livelihoods, shortage of water, droughts and desertification and conflicts and implications of climate change on regional food security and beyond. The region has not emphasized, taking an overview, agricultural development and developing capacities in agricultural research. WANA needs for strategic regional agricultural development plans, increased and improved investment in AR4D and better regional cooperation and cooperation beyond the region, was never as urgent as it is now (AARINENA 2010). Moreover, WANA region is characterized by:

- Low investment in AR4D at national levels
- Geo-political tensions and conflicts
- Gender imbalance
- Constraints in human resources
- Weak institutional capabilities
- Weak governance.

Constraints to Sustainable Agricultural Development in WANA include:

- Typical fragile ecosystems of dry areas
- Hot spot for climate change impact
- Water scarcity & drought is becoming a common phenomenon
- Land degradation and desertification
- Population boom and poverty
- Weak investment in agricultural research for development
- Inadequate policies
- Geo-politically fragile environment
- Gender imbalance
- Constraints in human resources and institutional capacities (IPCC 2007)

8.3.1.2 Results of Desk Review and Survey

The literature review focused on extracting lessons learnt from previous research strategies and assessments, such as the study "Setting Agricultural Research Priorities for the Central and West Asia and North Africa Region", conducted in 2002 (Belaid et al. 2003), as well as the "International Assessment of Agricultural Knowledge Science and Technology for Development" conducted in 2009 (Thomas et al. 2003). Additional national and/or institutional agricultural strategies and reports were used in this desk review. A better understanding was obtained on the evolution of agricultural research in the region, and the complementary roles of different research partners, such as the National Agricultural Research and Extension Systems (NARS), Agricultural Research Institutes (ARIs) and the CG-centers operating in the region (Shideed et al. 2008).

A survey was designed to better understand ongoing research programs and current collaborative practices of knowledge sharing in the agricultural and social sectors. Questionnaires were sent out all major research institutes, agricultural centers and universities and in total over 1,400 research projects were reviewed.[1] The regional review was led by a senior regional consultant, support by coordinators for the four sub-regions.

Based on the survey and desk review, actual research priorities emerged and were evaluated based on the following criteria: productivity, poverty alleviation, resource conservation, food security, and contribution to development. Moreover, the evaluation considered different agro-ecological systems, such as arid zones, irrigated lands, rangelands and forests. This analysis resulted in the formulation of seven themes with *key researchable issues*, which would require further public consultation to determine if their focus is right and if they are relevant to the reality of resource-poor farmers (Table 8.1).

[1] It should be mentioned that the data collection faced major constraints in terms of timing (summer period) and in terms of the weak response from participants. The only two countries with more or less complete information were Egypt and Sudan, where the focal points themselves collected the information personally from the concerned institutions.

Table 8.1 Themes and issues identified by the regional review (August 2009)

1	**Food security**
1.1	Need for research on the comparative and competitive advantage of regional products
1.2	Need for effective financing of agriculture to support small-scale farmers in the region
1.3	Enhance the sustainable productivity of agriculture in irrigated and rainfed areas, which "lagging behind" in terms of productivity, while protecting the natural resource-base
1.4	Need to explore the full potential of the livestock sector in the region
1.5	Need to emphasize research on fisheries and aquatic production systems
1.6	Need to pay attention to trans boundary animal and plant diseases and pests
2	**Improvement of the livelihoods of farmers (poverty reduction)**
2.1	Analyze the declining living standards in rural areas and develop opportunities for household income generation
2.2	Organize and promoting the role of rural women in agriculture, and agricultural research for development
3	**Protection of the environment**
3.1	Enhancing efforts on protecting land and water resources
3.2	Protecting forests and rangeland from degradation
3.3	Enhance efforts on protecting the natural biodiversity in the region
4	**Meeting the special challenges of climate change**
4.1	Align agriculture research and development to meet the challenges of global warming
4.2	Need to address the issue of desertification
5	**Technology, information, knowledge and innovations**
5.1	Enhance investment in and strengthen agricultural research, innovation, extension and education systems, related institutions and research processes
5.2	Revitalize, strengthen and reorient agricultural extension system
5.3	Improve quality of agricultural education and employability of agricultural graduates and increase availability of appropriately trained human resources at different levels
6	**Market and marketing**
6.1	Effectively link small and marginal farmers with markets, including the fast emerging large (multi-national) retailers and super markets
6.2	Benefit small farmers and protect consumer from food price rise and fluctuation
7	**Energy**
7.1	Develop bio-fuels as a complement to fossil fuel, but not at the cost of food security
7.2	Enhance energy security compatible with economics and ecology

Source: AARINENA (2009b)

8.3.2 Climate Change Impact on WANA

Climate change is already a reality that we are facing, it will add constraints for the already fragile ecosystems of dry areas and limited natural resources in WANA. Crop productivity is projected to decrease over the WANA region due to reduced precipitation and increased frequency and intensity of droughts. Climate change directly affects the quality and quantity of the forage that can be produced in a given ecoregion and an overall productivity decline in livestock nomadic system is expected due to erratic rainfall and decline in the moisture regime. Climate change is projected to have adverse impacts on ecosystem functions and services due to disruptions in life-support processes (FAO 2008). There is an urgency to strengthen further research and technology transfer on adaptation,

Table 8.2 Priority setting for key issues on climate change- identified key-researchable issues

Climate change	No. of votes	Group rank[a]
1. Adaptation: salinity and drought tolerant crops, conservation agriculture	28	–
2. Data management capabilities, analysis and climate modeling	25	–
3. Impact assessments of climate change	17	–
4. Climate forecasts, early warning, land use planning and hazard zoning	15	–
5. Advocacy on importance of CC to policy makers and politicians	12	–
6. Use of local community-based knowledge in adaptation	10	–
7. Develop climate change policies and sector action plans	10	–
8. Energy efficiency in agricultural production and use of renewable energy	6	–
9. Risk management and developing options for increased resilience	4	–
10. Promote carbon sequestration	4	–
11. Feasibility and opportunities for non-food bio-fuels	2	–
12. Collective action of farmers to achieve scale to access carbon credits	1	–

Source: AARINENA (2009b), FAO (2009)

[a]No ranking exercise done in the group

mitigation and production system resilience. Table 8.2 identifies key researchable issues on climate change.

There is evidence on the global decline in food production; and although developing countries have contributed the least to climate change, they will be hit the hardest, particularly in WANA. The climate change impacts are closely related to the hydrological cycle, such as water shortages, sea level rise, ecosystem stress, the increase of extreme events as droughts, floods, hurricanes and the risk of irreversible damage, such as bleaching of coral reefs due to higher levels of ocean acidity (Wilhite 2002). Striking examples of potential impacts, such as the Nile delta with six million people will be affected by 1 m of sea-level rise.

The plenary emphasized the following issues:

- The role of extension did not came through very strongly in the prioritized list, while this is actually the weakest point in the chain towards scaling-up
- It was mentioned that the extension system has not well understood the issues around using opinion leaders to facilitate quick adoption of new technologies and the role of ICT to support the scaling-up of innovations; the role of the private sector and of farmer organizations in scaling-up needs to be more appreciated
- Recognizing that organizing farmers is crucial, more research is required into legislation and framework conditions which are required
- Research is needed to understand the incentive systems for farmers to adopt new technologies
- Adoption of new practices and technologies will only work if extension and research communities are able to communicate in a language that farmers understand and triggers behavior change; field days and simple farmer-to-farmer meetings were suggested

8.3.3 The WANA Regional E-Consultation

The regional e-consultation was held in September 2009. The consultation aimed at soliciting opinions from all those involved in agricultural research for development on the following issues:

- To what extent do the priorities identified from the regional review capture the key regional needs for delivering greatest development impacts?
- In relation to "researchable themes", what mechanisms and partnerships are required in innovation pathways turning research into development impacts at scale?
- What are the key blockages, barriers and bottlenecks that prevent research from benefiting the poor? How best should these be resolved and what enabling investments, policies and capacities are most needed?

The consultation referred to the issues raised by a commissioned regional review that has been done to provide a synthesis of existing national and regional studies, policies and reports on how agricultural research priorities currently match to development aims and needs. The key researchable themes from the previous step were used as an input to start the discussion in the e-consultation. Around 180 persons participated in the e-consultation from Bahrain, Cyprus, Egypt, Iran, Iraq, Jordan, Kuwait, Lebanon, Morocco, Oman, Pakistan, Palestine, Sudan, Syria, Tunisia, Turkey, United Arab of Emirates and Yemen in addition to some guests of WANA region. About 150 messages have been received from about 85 participants.

The participants representing major agricultural research and development disciplines including livestock; plant protection; field crops; agronomy; vegetable and ornamental plants; microbiology; agricultural economics and extension; soil, irrigation, water management and environment; land use management; geo-informatics; computer science; information and communication technologies. The participated institutions working on agricultural research for development in WANA region were mainly ICARDA, FAO Regional Office, ACSAD and AOAD. Moreover, universities, Ministries, Research Centers, NGOs and private sectors from different countries participated in this event.

In the first week, the participants introduced themselves and shared their experiences and views. In the second week they reflected on the issues raised in the preceding week and put their experiences in perspective of the regional review findings. Conclusions towards the face-to-face meetings were drawn in the third week of e-consultation.

The participants of e-consultation suggested and discussed valuable ideas, experiences, information and innovations which will be of help to have greater impact on major development needs of the region. Key areas deeply discussed in the e-consultation included: Food security, and water scarcity; Linkage between research, extension and farmers; Polices and strategies; Innovation; Importance of regional cooperation, networking and knowledge sharing; Livestock and trans-boundary animal and plant; Salinization; Climatic change; Standard of living of farmers; Plant genetic resources; Land degradation and combating desertification.

The e-consultation confirmed the key researchable issues. However, new issues were identified such as:

- Poor linkages between research, extension and farming communities
- Improving and adopting innovative ways of knowledge sharing
- Implications of water scarcity and its impact on regional food security
- Adopting a strategic approach towards agricultural research
- Better integrating policy and institutional issues in research programs (AARINENA 2009a)

8.3.4 Face-2-Face Regional Consultation Workshop

A regional Face-2-Face workshop was held in Alexandria, Egypt from 10 to 12 November 2009, which objectives were to identify:

- Prioritized agricultural researchable issues to achieve development impact at scale
- Improved research processes and mechanisms and partnerships that will ensure greater development impact and poverty reduction

The workshop was attended by 54 participants, representing 18 countries in WANA region, including 29 participants from NARES, ten participants from NGOs, farmer organizations and the private sector, 15 participants from regional and international organizations and three observers from GFAR. The Face-2-Face meeting included sample space for group work, organized as follows (AARINENA 2009b)

– *Thematic working groups*

  - Food security and productivity
  - Natural resources management
  - Livestock, rangelands and fisheries
  - Markets and value chain development

– *Cross-cutting working groups*

  - Poverty and socio-economic policy
  - Research management and capacity development
  - Dissemination and scaling-up
  - Climate change

The working groups were asked to carry out the following three tasks:

(a) Review and modify the list of key-researchable issues
(b) Prioritization based on their potential to achieve development impact at scale
(c) Identify constraints in research systems, solutions and (new) partnerships

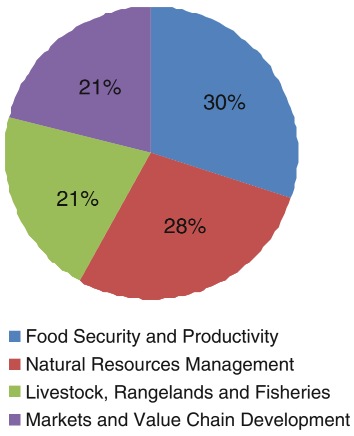


Fig. 8.1 Distribution of votes over thematic issues (Source: AARINENA 2009b)

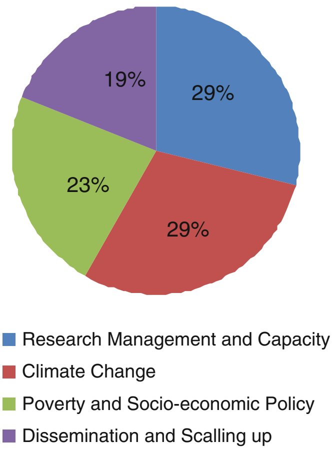


Fig. 8.2 Distribution of votes over cross-cutting issues (Source: AARINENA 2009b)

In order to allow *all* participants to give their opinion, a voting exercise was carried out for the thematic issues and the cross cutting issues. For the thematic issues the distribution of votes over the four thematic groups is indicated in Fig. 8.1. Food security and productivity, followed by natural resources management were deemed to be the most important thematic areas. However, it was felt that fishery and aquatic ecosystem issues were not very well addressed due to lack of participants with such a specialization. Obviously, there are overlapping issues and clear linkages between the various thematic groups due to the complexity ad holistic nature of farming systems.

For the cross-cutting the distribution of votes over the four cross-cutting groups is indicated in Fig. 8.2. Climate change and research management and capacity building were seen to be the most critical cross-cutting themes. Although the group on *Research management and capacity development* was focusing mainly on scientific interests and goals, it should be noted that the demands and relevance of research to achieve development impact would be center stage.

8.4 Conclusions and Recommendation

8.4.1 Constraints and Solutions to Improve AR4D in WANA

8.4.1.1 Current Constraints

In terms of existing constraints in the research systems, the groups identified similar barriers and hindering factors to achieve development impact:

- Mistrust between farmers and extension workers and researchers
- Different "languages" and worldviews of stakeholders
- Communication is poor, not enough attention is paid to communication issues
- Institutional weaknesses of many organizations
- Coordination capacity is weak (national, regional, global)
- Funding and human resources are not at all sufficient, especially on national level
- Lack of infrastructure and logistical capacity on national level
- Low public awareness about importance of AR4D
- Incentive systems are not geared towards collaboration and development impact
- Too much focus on scientific publications, rather than development impact
- Policy makers and politicians are not on board
- Individualism and illiteracy of farmers

8.4.1.2 Solutions and Innovative Partnerships

Although it was found "easy" to diagnose the obstacles, it appeared to be much harder to think out of the box and come-up with innovative mechanisms and partnerships to reform the way agricultural research is carried out to ensure development impact at scale. The following measures were proposed:

- Public awareness campaigns are required on all fronts
- Make an evidence-based case to politicians and policy makers
- Invest in communicating results and impacts and crossing barriers between farmers, researchers, policy makers and others
- Redefine extension and find new models including use of new technologies
- Attract private sector funds and use Corporate Social Responsibility agenda
- Participatory approach to be applied in all AR4D

- Capacity development on all levels, tailored to needs of different groups
- Building national alliances to convince policy makers
- Use (social) networking for scaling-up
- Organize farmers, CBOs, WUAs, producer groups, etc. involve them in all aspects of AR4D

In terms of (new) partnerships and mechanisms the working groups came up with the following (innovative) ideas:

- *Really* work more with farmers and grass-root organizations
- Identify opinion leaders, tribal leaders to facilitate scaling-up and adoption of results
- Work more with women and their (in)formal networks
- Work together with policy makers, go beyond the Ministry of Agriculture
- Tap experience from new-media firms, Public Relations advisors, ICT firms
- Explore public-private partnerships and corporations interested in CSR
- Use and mobilize public figures and celebrities as champions
- Revitalize relationships with existing research and extension partners
- Strengthen AARINENA as a regional platform

8.4.2 Key-Messages to GCARD 2010

On finance

- WANA region should be given adequate funding for research and development; scaling up funding for applied research is urgently required, especially at national level

On priorities and focus

- Climate change is crucial for WANA region; WANA needs an above average share of the global MP on climate change and agriculture
- Emphasis on the resource-poor people in *both* urban and rural communities, with special attention to smallholders and resource-poor farmers
- Priority research on water, natural resources management and food security
- Facilitate technology transfer in adaptation to climate change impacts

On capacity building and regional cooperation

- More cooperation is necessary between developed countries and WANA region for capacity development in participatory research and extension
- Support and strengthen AARINENA and intensify links with GFAR process
- Implementation of Mega Programs needs ICARDA as a strong focal point for CGIAR in the WANA region

On policy and scaling up impact

- Emphasize agricultural sector in national development and poverty reduction strategies and policies
- Work with new partners for scaling-up impact
- Explore new technologies for scaling-up.

References

AARINENA (2009a) Proceedings of E-consultation of WANA region, Amman, 2–24 Sept 2009

AARINENA (2009b) Proceedings of face-to-face workshop regional consultations, WANA region, Alexandria, 10–12 Nov 2009

AARINENA (2010) Proceedings of AARINENA retreat for the WANA region, Aleppo, 22–24 Nov 2010

Belaid A, Solh M, Mazid A (2003) Setting agricultural research priorities for the Central and West Asia and North Africa Region (CWANA). Toward a new NARS/NARS and CGIAR/NARS collaboration spirit. ICARDA, Aleppo

El-Hababab M (2009) Regional reviews, towards the global conference on agricultural research for development in WANA region. Alexandria, Egypt

FAO (2003) Agricultural development policies in the Near East: situation, issues, institutional requirements and approaches. In: Proceedings of the joint FAO/NAPC regional workshop on institution building for agricultural policies in the Near East, Damascus, 6–7 Dec 2003

FAO (2008) Climate change: implications for agriculture in the Near East, NERC/08/INF/5. Regional conference, Cairo, 1–5 Mar 2008

FAO (2009) World summit on food security. FAO, Rome

IPCC (2007) Climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds). Cambridge University Press, Cambridge, UK

Shideed K, Mahmoud S, Ibrahim H (2008) Revisiting CWANA research priorities and needs assessment. In: 11th general conference of AARINENA, Damascus, 12–14 Oct 2008

Thomas R, Aw-Hassan A, Bari Salkini A et al (2003) Minutes of consultation for the CWANA region on the proposed international assessment of the role of agricultural science and technology in reducing hunger. Improving rural livelihoods, and stimulating environmentally sustainable growth. The natural resource management program of ICARDA. ICARDA, the World Bank and the Department of Agriculture and Land Reclamation, Egypt

Wilhite D (2002) Building institutional capacity to cope with drought: moving from crisis to risk management. In: FAO regional workshop on capacity building on drought mitigation in the Near East, Rabat, 1–5 Nov 2002

World Bank, FAO and IFAD (2009) Improving food prices in the Arab countries. The World Bank, Washington, DC

Zehni M (2011) Towards a regional strategy for the conservation of plant genetic resources in West Asia and North Africa (WANA). Presented on behalf of AARINENA at the international conference on adaptation to climate change and food security in WANA region, Kuwait, 13–16 Nov 2011

Chapter 9
Climate Variability and Change in North African Countries

F. Driouech, S. Ben Rached, and T. El Hairech

Abstract This study gives a short overview on climate evolution and change in North Africa. It focusses on observed evolutions and climate projections in Tunisia and Morocco. Current climate shows a trend towards drier conditions in the north-western part (Morocco) with a decrease in annual mean precipitation due to winter and spring negative trends. The length of the dry period became longer with time during these two seasons. The number of high precipitation events shows some significant negative trends in winter and spring. Tunisian precipitation does not exhibit any significant trends although some negative high values were seen in the east. As opposed to the trends in rainfall, temperature has the same sense of evolution in the two countries where it increases by 0.2–0.4 °C per decade. In terms of future changes, North African precipitation is projected to decrease by about 10–30 % in winter. Temperature rise should vary between 1.2 °C and 1.8 °C. Drought and high precipitation changes are projected to be more spatially heterogeneous.

Keywords North Africa • Climate change • Trends • Drought • Extremes

9.1 Introduction

Africa is one of the most vulnerable continents to climate change (IPCC 2007) and its Mediterranean countries seem to be not excluded (Douglas et al. 2008; Sullivan and Huntingford 2009; Yohe et al. 2006). Many parts of this already water stressed

F. Driouech (✉) • T. El Hairech
Direction de la Météororlogie, Casablanca, Morocco
e-mail: driouechfatima@yahoo.fr

S. Ben Rached
Institut National de la Météorologie, Tunis, Tunisia

M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_9,

region – with only less than 1,000 m^3 per capita of renewable water resources (FAO AQUASTAT compiled in World Bank (2007)) – should register in the future a reduction of its total rainfall amounts and a warming of about 2–4 °C or even more (Christensen et al. 2007; Giorgi and Bi 2005; Paeth et al. 2009; Patricola and Cook 2010). In terms of current climate, North Africa has already experienced climate extreme events which have had negative impacts on social and economic sectors (drought in Morocco during 1982–1983, high precipitation events leading to floods with loss of human lives in Redayef, Tunisia in 2009 and in Ourika valley in Morocco in 1995).

The purpose of this paper is to give a brief overview on the evolution of observed climate in North Africa and the expected future changes focusing mainly on Morocco and Tunisia where the access to information and data was relatively easier.

9.2 Observed Trends of Precipitation and Temperature

According to the Köppen-Geiger climate classification (Peel et al. 2007), North Africa can be classified into two main climate types; the temperate climate in the north and the arid climate in the south dominating most of the area. Temperate climate includes Mediterranean climate zones in the western northern coast of African continent (Morocco, Algeria, and part of Libya). Precipitation of North Africa is characterized by relatively wet winters and dry summers. The region receives annually moderate to low rainfall amounts (less than 100 mm in the south to about 600–800 mm in the north and high mountains). Mean temperature varies generally between 10 °C and 20 °C in winter and between 25 °C and 35 °C in summer. Although there are important similarities in the characteristics of climate in the North African countries, the temporal variability is more homogeneous for temperatures than precipitation. For example, Hertig and Jacobeit (2008, 2011) divided the coastal area around the Mediterranean Sea from Morocco to Tunisia into five homogeneous regions of similar precipitation variability in January instead of three for temperature (Hertig and Jacobeit 2011).

Different studies on observed climate showed trends toward drier and warmer conditions in different regions of North Africa. Hoerling et al. (2006) showed a reduction of February-March-April precipitation during 1950–1999. It is estimated as a loss of about 10–30 mm in the north of Algeria and Tunisia and from 20 to 50 mm in northern Morocco. Using daily temperature and precipitation data from the GCOS Surface Network (GSN) data set for North Africa, Alexander et al. (2006) have calculated a set of climate indices coordinated by the WMO Commission for Climatology (CCl) Expert Team on Climate Change Detection and Indices (ETCCDI) (http://cccma.seos.uvic.ca/ETCCDI/). They found for the period 1951–2003 positive trends in the number of warm days and nights combined with negative trends in the number of cold days and nights in the northern part of Mediterranean African countries of Algeria, Egypt, Libya, Morocco and Tunisia. They show also positive, but not significant, trends in extreme events of precipitation (drought and high precipitation events) in some parts in northern Algeria and Tunisia. Using data

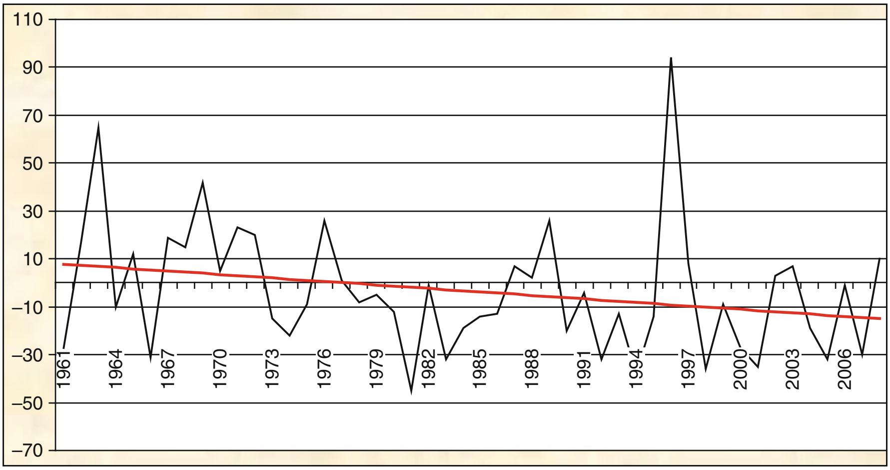


Fig. 9.1 Relative anomalies of Moroccan annual precipitation during 1961–2008

(Sheffield et al. 2006) based on the CRU TS2.0 dataset, Sheffield and Wood (2007) found positive and significant trends in annual mean temperature over Morocco and Tunisia (0.01–0.03 °C $year^{-1}$) and significant negative trends in annual precipitation in northern Morocco. They found also an augmentation in the frequency of mean drought severity and duration in the north of the region during 1950–2000. The city of Sfax (Tunisia) exhibited comparable results with the period 1950–2007 registering a trend of 0.38 °C per decade for minimum temperature and 0.27 °C per decade for the maximum temperature (Dahech and Beltrando 2012).

9.2.1 Morocco

The results concerning the Moroccan precipitation and temperature trends are based on the work done by Driouech (2010) who concluded that the temporal distribution of Moroccan rainfall had undergone an undeniable change.

Figure 9.1 represents the relative anomaly of Moroccan precipitation calculated using 14 stations covering all the climate regions except the south (the Sahara). It exhibits a high temporal variability of precipitation; the coefficient of variation in Morocco ranges between 30 % and over 70 % (Driouech et al. 2009). During a dry year, the deficit of rainfall can exceed at national level 40 % of the climatological value (1981, 1994, 1998, 2001). National rainfall amount registered between 1961 and 2008 shows a negative trend of −5 % per decade. At seasonal scale (not shown), mean precipitation decreases in most of regions during winter and spring show positive, but not significant, trends in autumn. Winter and spring positive trends are generally more important in the northern stations but according to the non parametric trend test of Mann–Kendall (Mann 1945; Kendall 1975; Hirsch and Slack 1984), only few of them are significant. Driouech (2010) has also estimated trends of a set

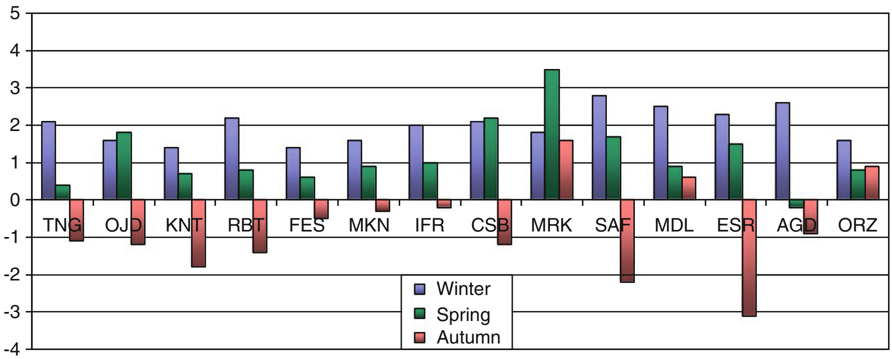


Fig. 9.2 Trends (day/decade) of the number of maximum consecutive dray days in Moroccan meteorological stations (see the text for names of stations) for winter, spring and autumn. Period of calculation is 1961–2008 (Based on Driouech (2010))

of climate indices defined by the STARDEX European project (Goodess 2003). Figure 9.2 shows the trends calculated over 1961–2008 for the number of maximum consecutive dry days (pxcdd) in 14 Moroccan meteorological stations: Tangier (TNG), Oujda (OJD), Kenitra (KNT), Rabat (RBT), Fes (FES), Meknes (MKN), Ifrane (IFR), Casablanca (CSB), Marrakech (MRK), Safi (SAF), Midelt (MDL), Essaouira (ESR), Agadir (AGD) and Ouarzazate (ORZ). A dry day is a day with precipitation amount less than 0.5 mm.

The middle (winter) and the end of the rainy season (spring), an important period for the agriculture, show positive trends in all regions excluding Agadir in spring. On the contrary, autumn shows a trend towards less persistent drought. None of these trends is significant excepting for Safi and Midelt in winter. The number of high precipitation events (not shown) defined relatively to the 90th percentile, registered negative trends in the northern stations during winter and spring. Many stations show positive trends in autumn season. Most of the trends are, however, not significant.

Mean temperature in Morocco registered significant increase nearly in the whole territory represented by the 14 meteorological stations (not shown). The trends of annual mean temperature varies from 0.1 °C/decade at Essaouira (the unique station with non significant trend) and 0.4 °C/decade at Oujda (the eastern station), Ifrane and Midelt (two Atlas Mountains stations). The trends in the remaining stations vary between 0.2 °C decade^{-1} and 0.3 °C decade^{-1}.

9.2.2 Tunisia

The work done by Driouech (2010) for Morocco in terms of observed trends is extended here to Tunisia using daily data for five meteorological stations (Fig. 9.3): Jendouba (JND) in the North-west continental zone with a humid and relatively cold winter and dry and hot summer, Mednine (MDN) in the south-east with hot

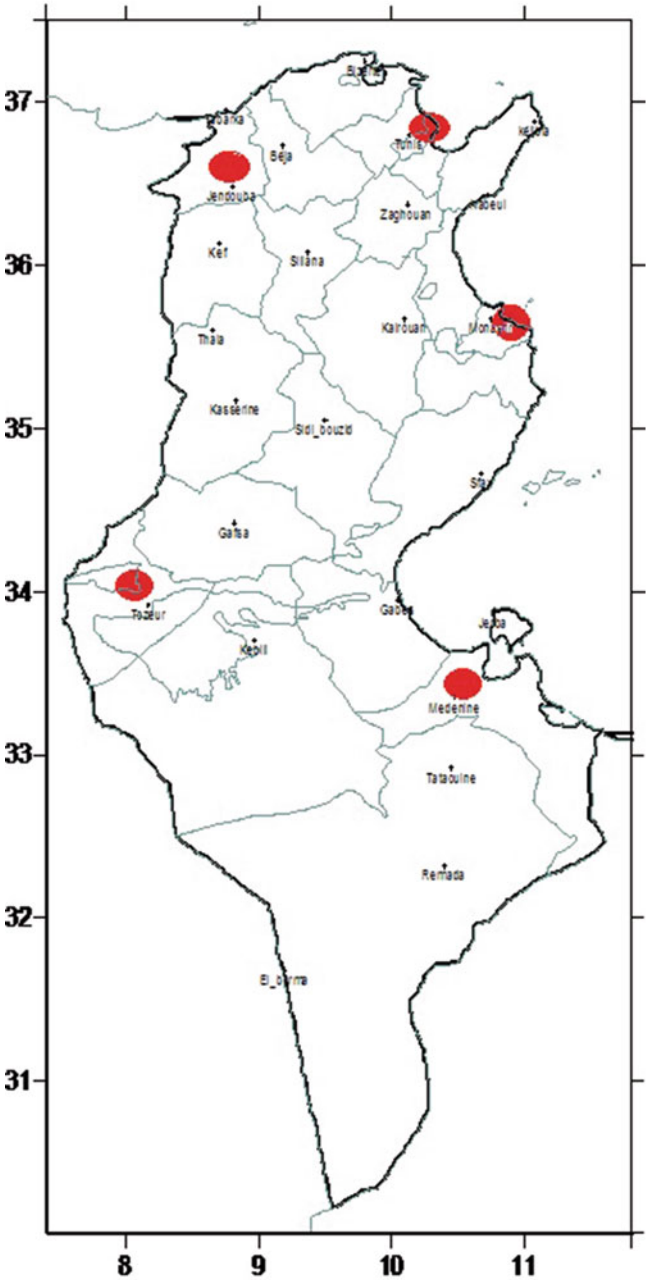


Fig. 9.3 Location of the five Tunisian meteorological stations

Table 9.1 Trends calculated for the mean precipitation (*pav*), maximum consecutive dry day (*pxcdd*) and the number of high precipitation events (*pnl90*) in five Tunisian meteorological stations. Periods of calculation: 1960–2009 for Jendouba and Tunis and 1969–2009 for Mednine, and Monastir and 1966 for Tozeur

	Jendouba	Mednine	Monastir	Tunis	Tozeur
pav					
Winter	4.5	−2.7	−0.9	5.4	2.7
Spring	1.8	−8.3	−1.8	−0.9	−0.9
Summer	−0.9	0.9	3.7	1.8	0.9
Autumn	4.6	−15.6	−101	5.5	−3.7
Year	11.0	−25.6	−18.3	11.0	0.7
pxcdd					
Winter	0.8	−1.9	0.0	0.7	0.0
Spring	0.1	0.6	0.5	0.1	2.2
Summer	−1.0	0.0	−2.3	−1.3	−5.4
Autumn	−1.1	−0.8	−1.9	−1.4	−0.6
Year	−0.8	−3.3	−4.4	−1.1	−10.4
pnl90					
Winter	0.2	−0.1	0.0	0.2	0.1
Spring	0.2	−0.1	−0.1	−0.1	0.0
Summer	−0.1	0.1	0.2	0.0	0.0
Autumn	0.1	−0.2	−0.2	−0.1	−0.1
Year	0.3	−0.4	0.0	0.2	−0.2

and relatively humid climate, Monastir (MNS) in the central eastern coast with temperate and relatively humid climate, Tunis (TNS) in the north-east with temperate and humid climate and Tozeur (TZR) in the south-west with a Saharan climate (dry and hot). A set of STARDEX climate indices have been calculated at seasonal and annual scales. The periods used for calculating the trends are indicated in Table 9.1. The eastern stations Mednine and Monastir show negative trends in mean precipitation during the whole rainy season (autumn, winter, spring). Due to autumn trends, this results respectively in a decrease in the annual total rainfall by about 14 % of the climatological mean (calculated over 1971–2000) in Mednine (25.6 mm decade^{-1}) and 5 % of the climatological mean in Monastir (18.3 mm decade^{-1}). As the remaining positive and negative trends are still relatively small, none of the mean precipitation trends is significant according to the Mann–Kendall test. Significant, but small, trend is shown by the autumn maximum consecutive dry days in Monastir corresponding to a diminution of about 2 days per decade in the longest dry period of this season. A more important and significant trend is shown in summer in Tozeur (−5.4 days), which, combined with the autumn trend, leads to a significant diminution of about 10 days per decade at the annual scale. In terms of top extremes, the number of high precipitation events does not exhibit any important trend although there is a small summer positive trend in Monastir. No significant trend is found for the amplitude of high precipitation events (not shown).

Figure 9.4 shows the annual anomalies (relative to 1961–1990 climatological mean) of Tunisian mean temperature for 1950–2009. The last three decades show

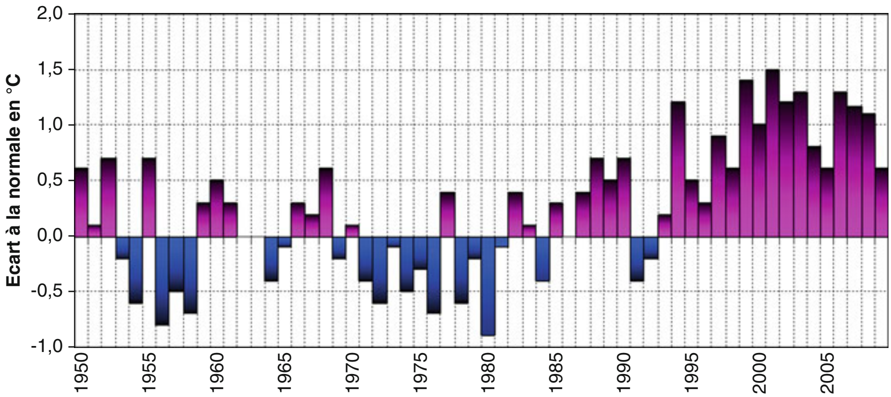


Fig. 9.4 Annual anomalies of Tunisian mean temperature for 1950–2009

a very high dominance of positive anomalies which surpassed 1 °C in 8 years since 1994 and reached 1.5 °C in 2001. At local scales, decadal trends of mean temperature vary between 0.3 in Jendouba and Tozeur and 0.4 °C in Mednine, Monastir and Tunis.

9.3 Future Changes

Driouech et al. (2010) has evaluated the future climate changes over Morocco using the variable resolution configuration of the General Climate Model ARPEGE-Climate (Déqué and Piedelievre 1995; Driouech et al. 2009). In this section we extend this work to the North Africa using the outputs of this model version recognizing that the resolution is not as high over the whole region as it is the case for Morocco. The changes are calculated, under the scenario A1B, by comparing 1971–2000 (present period) to 2021–2050. Annual mean precipitation does not show any pronounced change in Moroccan regions located west of the Atlas Mountains and the northern band starting from Tunisia until Algeria (Fig. 9.5). The remaining zones indicate an increase in the annual mean precipitation of 5–30 %. Considering the low total rainfall amounts received by this mainly Saharan region, the projected increases should not exceed few millimeters.

At seasonal scale, winter mean precipitation in the three North African countries (Algeria, Tunisia and Morocco), is projected to decrease by about 10 % (in the north) to more than 30 % in the Sahara (Fig. 9.5). A decrease is also projected in summer for most of the northern half. Autumn rainfall amounts should not change considerably in north and west of Morocco and northeastern Algeria (not shown). It is projected to increase over Tunisia (5–30 %) and the Moroccan and Algerian deserts. Spring mean precipitation could increase over whole the region. The smallest rise is for northern

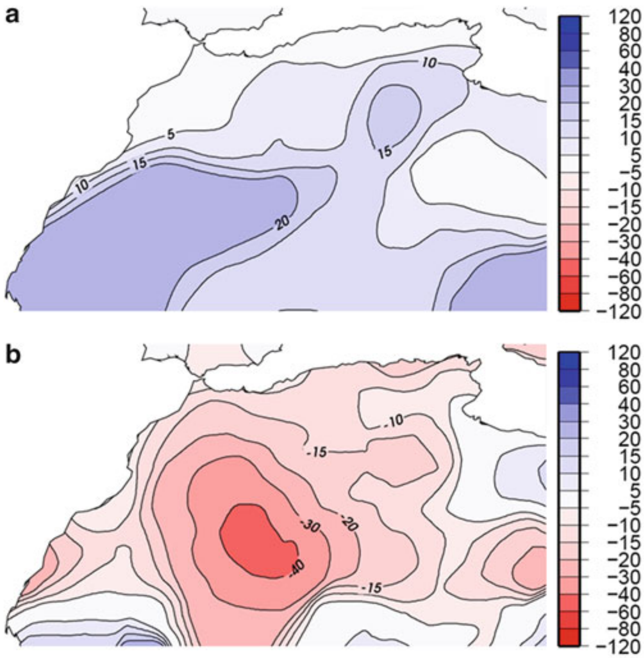


Fig. 9.5 Future changes for annual (**a**) and winter (**b**) mean precipitation

Morocco and eastern Algeria (5–10 %) and changes between 10 % and 40 % are projected for the remaining zones. Using an ensemble of low resolution GCMs, Giorgi and Lionello (2008) project, under A1B scenario, a decrease of winter and summer precipitation over the entire region (2041–2070 compared to 1961–1990). By the end of the current century they project a decrease of precipitation generalized to the entire region during the four seasons. It is important to take into account that at shorter horizons (like 2021–2050) the natural variability of precipitation is still important which adds a degree of uncertainty to climate change evaluation.

The changes in terms of extreme events are evaluated for winter (Fig. 9.6); the season of maximum rainfall. The longest winter dry period (maximum consecutive dry days) increases over the entire region west of the Atlas Mountains (an important agricultural zone) by 2–5 days, over northern Algeria by 2–3 days and over western Tunisia by 1–3 days. The number of high precipitation events is projected to decrease by 10–20 % over Morocco and northern Algeria and by 5–10 % over Tunisia excluding its south-eastern part where no pronounced change is expected. A decrease of 10–30 % is given for the Saharan regions.

They confirm the additional warming projected for the region by previous studies. By 2050, mean temperature is projected to increase by 1.2–1.8 °C. The warming is generally less important in the coasts than in the inland regions. Winter mean temperatures (not shown) are expected to increase by 1–1.6 °C and exhibit a

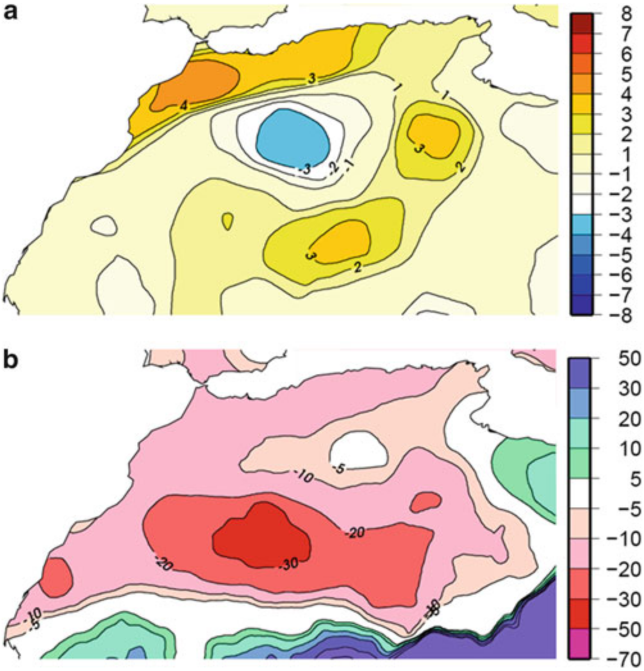


Fig. 9.6 Future changes for the maximum consecutive dry drays (**a**) and the number of high precipitation events in winter. (**b**) Projected future changes of mean annual temperature are shown in Fig. 9.7

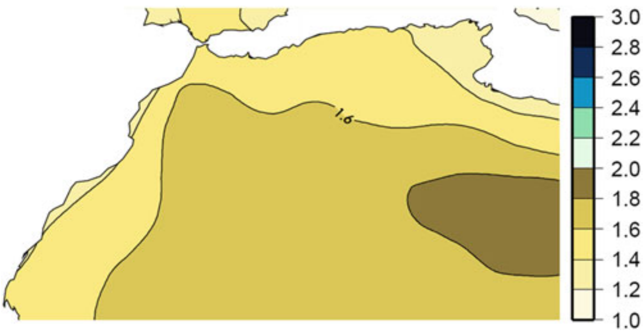


Fig. 9.7 Future changes for annual mean temperature

north–south gradient. A more pronounced gradient is given for summer changes which vary from 1.4 °C (in the costal regions) to 2.2 °C.

9.4 Conclusions

This work is aimed at giving a brief overview of the observed changes in climate and future climate change in North Africa with special focus on Morocco and Tunisia. Observed daily data of precipitation in different Moroccan stations show trends towards drier conditions in winter and spring; two important seasons for the agriculture and water supply. The same sense of evolution is given by extreme events of drought which registered an increase in both the winter and spring in terms of the maximum number of consecutive dry days. During these two seasons high precipitation events do not show significant trends although there is a generally negative sign in nearly all the stations. On the contrary, the autumn season showed positive but small trends. Globally, observed climate in Tunisia did not register significant trends of precipitation. Temperature trends are more comparable for the two countries. They varied between 0.2 °C and 0.4 °C per decade.

Future climate change evaluated using the outputs of the variable resolution of the GCM ARPEGE-Climate gives, for 2021–2050 compared to 1971–2000, a reduction of winter precipitation over the entire region (Algeria, Morocco, Tunisia). The decrease of mean precipitation should be accompanied by more persistent drought and less high precipitation events mainly northern Algeria and north western Morocco; the most important agricultural zone in this country.

The results found here are globally compatible with earlier studies which showed more pronounced trends over Morocco than the other parts of North Africa. Future precipitation changes combined with projected warming should have significant impacts on agriculture especially in Morocco as it is shown by Gommes et al. (2009) using statistically downscaled climate scenarios.

Acknowledgments The authors are indebted to Michel Déqué from Météo-France for having made available the outputs of the GCM ARPEGE-Climate and to Tunisian and Moroccan meteorological services for providing station daily data.

References

Alexander LV et al (2006) Global observed changes in daily climate extremes of temperature and precipitation. J Geophys Res-Atmos 111:D05109. doi:10.1029/2005JD006290

Christensen JH, Hewitson B, Busuioc A, Chen A, Gao X, Held I, Jones R, Kolli RK, Kwon WT, Laprise R, Magaña Rueda V, Mearns L, Menéndez CG, Räisänen J, Rinke A, Sarr A, Whetton P (2007) Regional climate projections. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK/New York

Dahech S, Beltrando G (2012) Observed temperature evolution in the City of Sfax (Middle Eastern Tunisia) for the period 1950–2007. Clim Chang 114:689. doi:10.1007/s10584-012-0420-x

Déqué M, Piedelievre J-P (1995) High resolution climate simulation over Europe. Clim Dyn 11:321–339

Douglas I, Kurshid A, Maghenda M, McDonnell Y, McLean L, Campbell J (2008) Unjust waters: climate change, flooding and the urban poor in Africa. Environ Urban 20:187–205. doi:10.1177/0956247808089156

Driouech F (2010) Distribution des précipitations hivernales sur le Maroc dans le cadre d'un changement climatique: descente d'échelle et incertitudes (Distribution of Moroccan winter precipitation in the context of climate change). Dissertation, University of Toulouse. http://www.ethesis.inp-toulouse.fr/archive/00001300/01/driouech.pdf. Accessed 20 Apr 2012

Driouech F, Déqué M, Mokssit A (2009) Numerical simulation of the probability distribution function of precipitation over Morocco. Clim Dyn 32:1055–1063. doi:10.1007/s00382-008-04310-6

Driouech F, Déqué M, Sánchez-Gómez E (2010) Weather regimes—Moroccan precipitation link in a regional climate change simulation. Glob Planet Change 72:1–10. doi:10.1016/j.gloplacha.2010.03.004

Giorgi F, Bi X (2005) Regional changes in surface climate interannual variability for the 21st century from ensembles of global model simulations. Geophys Res Lett 32:L13701. doi:10.1029/2005gl023002

Giorgi F, Lionello P (2008) Climate change projections for the Mediterranean region. Glob Planet Change 63:90–104

Gommes R, El Hairech T, Rosillon D, Balaghi R (2009) Impact of climate change on agricultural yields in Morocco. World Bank – Morocco study on the impact of climate change on the agricultural sector. Food and Agriculture Organization of the United Nations (FAO), Rome. ftp://extftp.fao.org/SD/Reserved/Agromet/WB_FAO_morocco_CC_yield_impact/report/WB_Morocco_20091013.pdf. Accessed 6 May 2012

Goodess C (2003) STAtistical and Regional dynamical Downscaling of EXtremes for European regions: STARDEX. European Geophysical Union Information Newsletter 6. http://www.the-eggs.org/articles.php?id=37. Accessed 05 Jan 2010

Hertig E, Jacobeit J (2008) Assessments of Mediterranean precipitation changes for the 21st century using statistical downscaling techniques. Int J Climatol 28:1025–1045

Hertig E, Jacobeit J (2011) Predictability of Mediterranean climate variables from oceanic variability. Part II: statistical models for monthly precipitation and temperature in the Mediterranean area. Clim Dyn 36:825–843. doi:10.1007/s00382-010-0821-3

Hirsch RM, Slack JR (1984) A nonparametric trend test for seasonal data with serial dependence. Water Resour Res 20:727–732

Hoerling M, Hurrell J, Eischeid J (2006) Detection and attribution of 20th century northern and southern African rainfall change. J Climate 19:3989–4008

IPCC (2007) Climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds). Cambridge University Press, Cambridge, UK

Kendall MG (1975) Rank correlation methods. Charles Griffin, London, 202 pp

Mann HB (1945) Non-parametric test against trend. Econometrika 13:245–259

Paeth H, Born K, Girmes R, Podzun R, Jacob D (2009) Regional climate change in Tropical and Northern Africa due to greenhouse forcing and land use changes. J Climate 22:114–132. doi:10.1175/2008JCLI2390.1

Patricola C, Cook K (2010) Northern African climate at the end of the twenty-first century: an integrated application of regional and global climate models. Clim Dyn 35:193–212. doi:10.1007/s00382-009-0623-7

Peel MC, Finlayson BL, McMahon TA (2007) Updated world map of the Köppen-Geiger climate classification. Hydrol Earth Syst Sci 11:1633–1644

Sheffield J, Wood EF (2007) Characteristics of global and regional drought, 1950–2000: analysis of soil 24 moisture data from off-line simulation of the terrestrial hydrologic cycle. J Geophys Res-Atmos 112, D17115. doi:10.1029/2006JD008288

Sheffield J, Goteti G, Wood EF (2006) Development of a 50-year high-resolution global dataset of meteorological forcings for land surface modeling. J Climate 19:3088–3111

Sullivan CA, Huntingford C (2009) Water resources, climate change and human vulnerability. Paper presented at the 18th world IMACS/MODSIM congress, Cairns, 13–17 July 2009

World Bank (2007) Making the most about scarcity: accountability for better water management results in the Middle East and North Africa. Middle East and North Africa Development Report, Washington, DC

Yohe G, Malone E, Brenkert A, Schlesinger M, Meij H, Xing X (2006) Global distributions of vulnerability to climate change. Integr Assess Stud 6:35

Chapter 10
Climate Change in Drylands of the Eastern Mediterranean: From Assessment Methods to Adaptation Strategies

E. De Pauw and W. Göbel

Abstract The Fourth Assessment Report of the Intergovernmental Panel on Climate Change projects that the drylands around the Mediterranean are likely to be severely affected by climate change. Most Global Circulation Models (GCMs) predict for the Mediterranean region in the coming decades a continuation of a trend of precipitation decline, derived for the period 1901–2007 from the Full Data Reanalysis Product Version 4 of the Global Precipitation Climatology Centre, of 0–3 mm year^{-1} in the annual precipitation. Thus climate change is likely to hit the Mediterranean zone twice, by higher temperatures, raising the risk of heat stress to the traditional crops of the region, and by lower precipitation and increased risk of drought. Using a case study from the eastern Mediterranean, a GIS-based method is presented for generating high-resolution maps that overcome the restrictions on use for planning imposed by the coarse resolution of the GCM predictions. The downscaled climate change projections for the near future, obtained from these maps, are the starting point for exploring how the time-honored coping mechanisms of the region's diverse agricultural systems could be adjusted in order to deal with the additional stresses to be imposed by climate change. The key to adaptation to climate change will be in reviewing how these agricultural systems have been coping in the past and present, and in revisiting and fine-tuning the recommended management practices established after decades of dryland agricultural research. The main adaptation strategies anticipated under climate change are geographical shifts in the agricultural systems, better climate-proofing of rainfed systems, making irrigated systems more efficient and in expanding the role of intermediate rainfed-irrigated systems.

With the expected increase of aridity in the Mediterranean Zone, shifts are likely in the geographical location of the agricultural systems: those that currently occur within a particular aridity class will tend to occupy the agroecological niche of those

E. De Pauw (✉) • W. Göbel
International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria
e-mail: E.DE-PAUW@cgiar.org

M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_10,

systems currently in a more humid zone, and will themselves be substituted by systems currently in a more arid climate. The expected increase in high-intensity precipitation events calls for improved water conservation leading to higher soil moisture and better control of runoff and evaporation losses. Whereas in the past there was a clear differentiation between rainfed and irrigated systems, it is also likely that climate change will promote the spread of hybrid systems, which make alternative use of rainfall and irrigation water, in order to cope with increasing water shortage while maintaining a high productivity. As climate change is likely to be accompanied by more severe intra-seasonal drought, more salvation may come from incorporating drought tolerance in traditional crops through breeding or genetic manipulation and trading off productivity against security. If markets can be created, there may also be potential for introducing drought-tolerant 'new' crops that have shown high potential under research conditions. In conclusion, location-specific combinations of these key adaptation strategies should allow the agricultural systems of the region to cope with climate change, at least in the near future, although some systems may come under more stress than others.

Keywords Agricultural systems • Climate change downscaling • GCMs • Emission scenarios • Data extraction • Climate proofing

10.1 Introduction

Since the publication of the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC), a broad consensus has developed among the scientific community that climate change is real, has started to show in the current weather, and that it has a discernible human signature (IPCC 2007).

Globally, under the IPCC greenhouse gas emission scenario A1b and the averaged results from 21 Global Circulation Models, the temperature increases expected for the drylands[1] are in the range of 2–4 °C, with a tendency in the tropical drylands towards the lower part of the range, and in the non-tropical drylands towards the higher part of the range. For those parts of the globe that have higher precipitation (non-drylands), the range in expected temperature increases is wider (2–5 °C). The changes in precipitation totals show some extremes, with a clear tendency towards increase in the non-drylands and tropical drylands, and a mixed pattern of increase or decrease in the non-tropical drylands. However, particularly striking is the substantial precipitation decrease expected in the area around the Mediterranean (Fig. 10.1).

Global Circulation Models (GCMs), complex models that emulate the interactions between the atmosphere, land and ocean surfaces, geosphere, biosphere and human

[1]Drylands are those areas with aridity index (AI = ratio of annual precipitation over annual potential evapotranspiration) below 0.75, covering hyper-arid (AI < 0.03), arid (AI 0.03–0.2), semi-arid (AI 0.2–0.5) and sub-humid (0.5–0.75) zones in accordance with the criteria of UNESCO (1979).

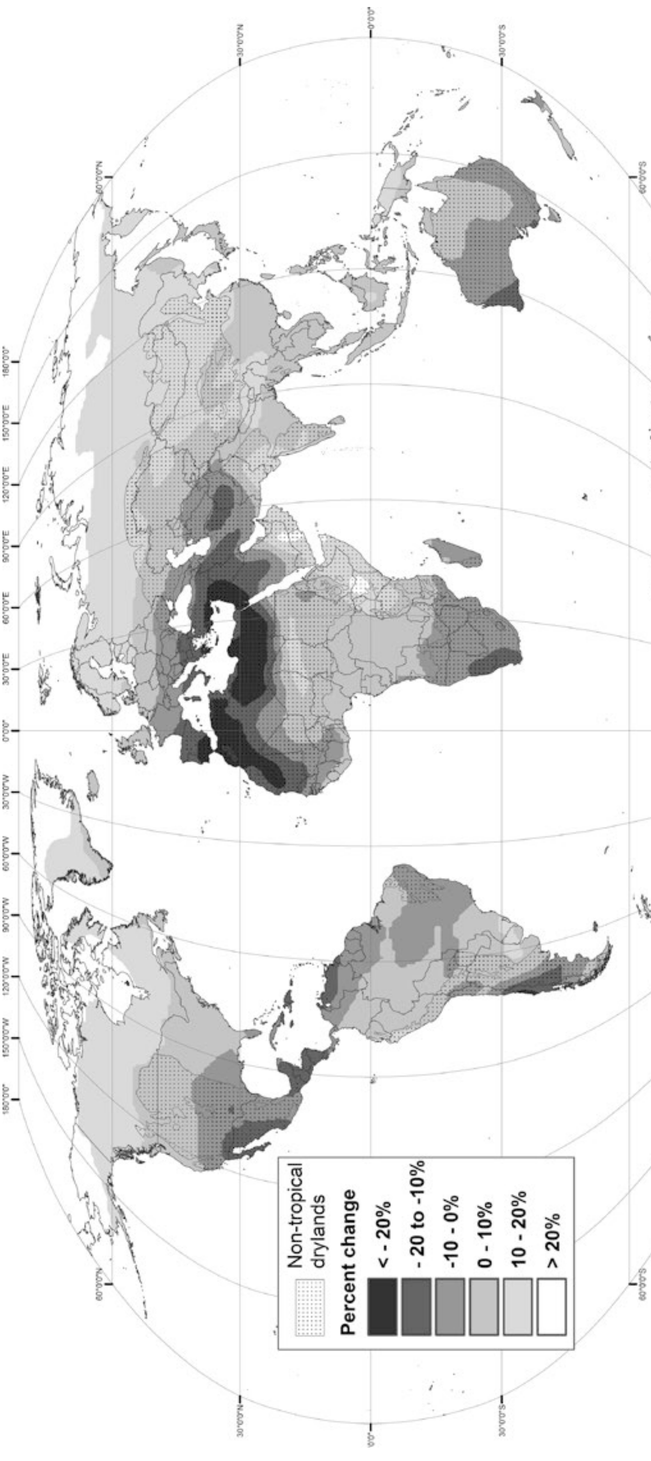


Fig. 10.1 Relative change of mean annual precipitation 1980/1999–2080/2099, scenario A1b, average of 21 GCMs (Compiled by GIS Unit ICARDA, based on partial maps in Christensen et al. (2007))

interventions, have been at the forefront in making these projections. Typical for GCM models is that parameter estimation is at a relatively coarse spatial resolution (typically 2–3°, corresponding to a grid cell of 10,000–36,000 km^2 depending on the model and geographical latitude). This scale is too coarse to include small-scale processes, the ones responsible for local weather patterns, and particularly in hilly to mountainous terrain these can be very important. Apart from these possible distortions, the coarse resolution of GCMs is perhaps the main bottleneck for planning of adaptation to climate change, as it prevents linkage to features with variability at much finer spatial variability, such as arable land, water resources, human settlements, agricultural production systems, poverty hot-spots etc. Downscaling the output of GCMs is therefore an extremely important step for mainstreaming climate change projections into development planning, and will be discussed further in this chapter.

10.2 Climate and Agricultural Systems in the Drylands of the Mediterranean Zone

Figure 10.1 and its enlarged zoom towards the countries around the Mediterranean (Fig. 10.2) indicate that, in terms of precipitation decline, the drylands around the Mediterranean are projected to be one of the most severely affected by climate change.

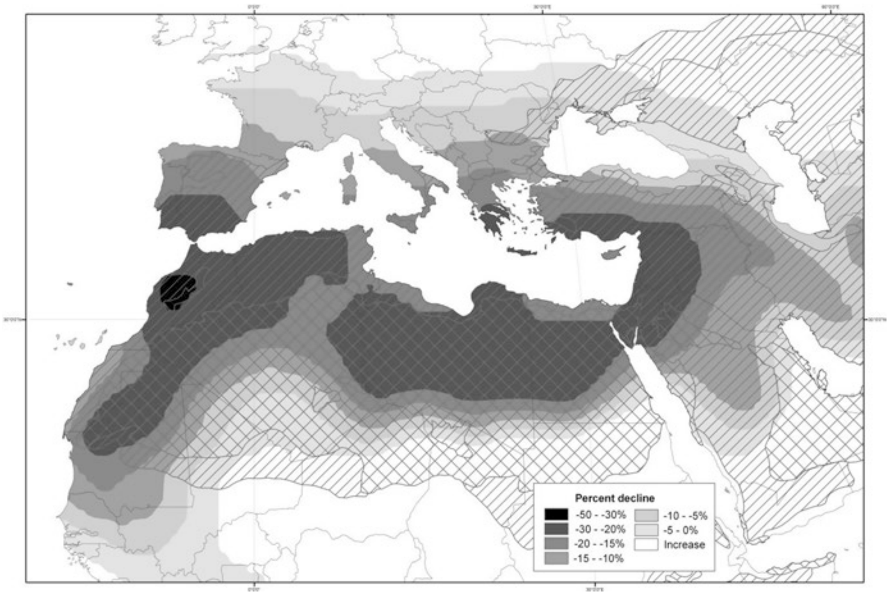


Fig. 10.2 Projected precipitation decline in the area around the Mediterranean between 1980–1999 and the period 2070–2099 (Source: Christensen et al. 2007). *Hatched*: non-tropical drylands; *cross-hatched*: deserts

In fact, according to AR4 and several follow-up studies, the eastern Mediterranean region is likely to be one of the most severely affected by climate change in the world. Predictions from General Climate Models (GCM) are for lower precipitation, increase in precipitation variability leading to more extreme events and more droughts, and of course higher temperatures, resulting in severe stress on already scarce water resources.

Focus on this particular dryland region offers a very relevant case for illustrating how the continuity between current climate and the projections for the near future allow existing as well as new land, water and crop management practices to serve as models for coping with climate change.

Currently the Mediterranean zone is mostly characterized by Mediterranean-type climates, which typically have warm and dry summers and mild and rainy winters. Within this overall Mediterranean distinctiveness and similarity, the climates of the region show great diversity. Particularly moisture and temperature conditions can differ markedly as a result of differences in local topography, nearness to regions with either temperate climates (especially in the north) or arid and even desert climates (especially in the south and east), and exposure to either maritime or continental influence.

In response to the agroecological diversity of the Mediterranean region, land use and agricultural systems are very diversified and a wide variety of crops is being grown under rainfed and irrigated conditions. Rainfed agriculture is the dominant form of crop production, with wheat, barley, and food legumes as the dominant crops. Irrigation is practiced on only a small proportion of the land, usually 10 % or less. Although the area under irrigation is still expanding, supply constraints are likely to increase for a variety of reasons, summarized by Margat and Vallée (2000). Livestock plays a key role in this region; in most cases, it is characteristically interrelated with other land uses, through residue and stubble grazing or use of marginal lands, in particular rocky shrubs or woodlands, and the more arid rangelands, most of which are overgrazed (Ryan et al. 2006).

In accordance with the terminology developed by Dixon et al. (2001), the following 'model' types of agricultural systems occur in the Mediterranean zone (De Pauw 2004):

- *Rainfed mixed*: Highly diversified systems, with a wide range of rainfed crops, including tree crops (olives, fruits and nuts) and field crops (mainly wheat, barley, lentils, chickpeas, potatoes, sugar beet and faba beans). Terracing is common in hilly areas. Seasonal interaction with livestock, mainly sheep and goats, and use of crop residues and other fodder are common features.
- *Dryland mixed*: Less diverse than the rainfed mixed systems, with barley and wheat as main crops grown in alternation with single or double-season fallows or with legumes (lentil, chickpea). Interactions with small livestock systems mainly take the form of barley and stubble-grazing and are stronger than in the previous system.
- *Highland mixed*: Dualistic land-use systems at higher altitude (1,500–3,000 m) with cropping pattern dominated by wheat and barley on arable land, and communal grazing on marginal land; mostly monoculture with occasional fallow, terracing common, sometimes supplemental irrigation.

- *Irrigated*: Traditionally along major river systems downstream from dams, but more recently also based on groundwater extraction. Systems can be either large-scale or small-scale and include a wide variety of crops and cropping patterns depending on temperature regime.
- *Pastoral*: Systems based on the mobility of flocks and herds moving between more humid and drier areas, with the availability of grazing and water. Range resources under a wide precipitation range (typically 100–400 mm) are accessed.
- *Sparse*: Too dry for productive land use which remains limited to opportunistic grazing following rain storms.

An in-depth treatment of the climatic characteristics, land use patterns, agricultural systems and soils of the Mediterranean Zone is given by Ryan et al. (2006).

Already under current climatic conditions the main challenge for the agricultural systems of the region is to cope with moisture deficits and drought. Water availability is the main constraint for agriculture in the Mediterranean zone and agricultural production of major grain crops is strongly affected by precipitation fluctuations (Keatinge et al. 1986), and crop and livestock losses due to drought can have very severe repercussions on both the countries balance of payments and the livelihoods of individual producers. For this reason, irrigation plays a critical role in the widening of agricultural options and has a stabilizing influence on rainfed agriculture and farmer livelihoods which goes far beyond its areal extent.

10.3 Downscaling the Potential Impact of Climate Change in the Eastern Mediterranean Region

Worldwide many development agencies are already preparing strategies for adaptation to climate change. As mentioned earlier, one major bottleneck they face is the coarse resolution of the GCM predictions. In this section we illustrate, through a case study from the eastern Mediterranean region, how GCM information can be downscaled for making projections of possible impact and plan adaptation strategies using a simple GIS-based approach.

10.3.1 General Approaches for Climate Change Downscaling

Generally speaking, three methods are available for downscaling GCM output to higher spatial resolutions:

- Calibration of current climate surfaces with GCM output
- Statistical downscaling with or without weather typing
- Dynamical downscaling with regional climate models (RCM)

Statistical downscaling yields good results, in terms of reproducing current climates from GCMs. They can be applied to output of different GCMs. On the down side, statistical relationships have to be established individually for each station and GCM, requiring quality data. Surfaces have to be created from point data, a problem in data scarce regions, such as the eastern Mediterranean. Moreover, this method is computationally challenging.

The *dynamical downscaling* using a RCM yields the best results, even in areas with complex topography, and directly generates climate surfaces. It is the only technique able to model complex changes of topographical forcing. A disadvantage is that different methods of dynamical downscaling are linked to specific GCMs, thus transferring inherent flaws in particular models from a lower to a higher resolution. They are also methodologically and computationally challenging.

In the absence of any downscaled data obtained from a RCM, in this study we used the *calibration method* of GCM downscaling, which involves essentially the superposition of a low-resolution future climate change field on top of a high-resolution current climate surface. This method leads to fast results, which are directly applicable to individual models or averages of multi-model ensembles and leads directly to climate surfaces. A drawback of this approach is that only linear changes to current topographical forcing are assumed.

10.3.2 Methodology for Downscaling

Four climatic variables were considered: precipitation, minimum, maximum and mean temperatures. Climate change as represented by these variables was assessed for the 2010–2040 time horizon, a 'near' future of interest to planners.

For the transformation of GCM data into high-resolution climate maps the following steps were implemented:

- Selection of GCMs and emission scenarios
- Data extraction procedures
- Change mapping at coarse resolution
- Resampling
- Generating downscaled climate surfaces
- Calculating averages

10.3.2.1 Selection of GCMs and of Emission Scenarios

A first screening was based on data availability. For only 17 GCM models out of the 23 on which the IPCC report is based, the necessary climatic variables were available on-line. A final selection of seven GCMs was based on age of the model, the spatial resolution of the GCM grid cells, and how well they represent a particular modeling approach. The selected models are listed in Table 10.1.

Two GHG emission scenarios were selected: the fairly optimistic A1b and the more pessimistic A2 scenario.

Table 10.1 GCM models used in the study

No	Name	Country	Year	Resolution (degrees) + (levels)	Source
01	BCCR-BCM2.0	Norway	2005	2.8 × 2.8 (31)	http://www.ipcc-data.org/ https://esg.llnl.gov:8443/home/publicHomePage.do
02	CSIRO-MK3.0	Australia	2001	1.9 × 1.9 (18)	http://www.ipcc-data.org/ https://esg.llnl.gov:8443/home/publicHomePage.do
04	MIROC3.2	Japan	2004	2.8 × 2.8 (20)	http://www.ipcc-data.org/
08	CGCM3.1(T63)	Canada	2005	2.8 × 2.8 (31)	http://www.ipcc-data.org/ http://www.cccma.ec.gc.ca/data/cgcm3/cgcm3.shtml
09	CNRM-CM3	France	2005	2.8 × 2.8 (45)	http://www.ipcc-data.org/ https://esg.llnl.gov:8443/home/publicHomePage.do http://www.mad.zmaw.de/projects-at-md/ensembles/experiment-list-for-stream-1/cnrm-cm3/
10	ECHAM5/MPI-OM	Germany	2003	1.9 × 1.9 (31)	http://www.ipcc-data.org/
12	GFDL-CM2.0	USA	2005	2 × 2.5 (24)	http://www.ipcc-data.org/

10.3.2.2 Data Extraction Procedures

Datasets for each GCM were retrieved from the sources mentioned above in a NetCDF format, a self-describing format for weather and climate data files, developed by UCAR,[2] using the program GrADS[3] (for Grid Analysis and Display System), which runs under Linux platforms, and converted into a ArcGIS format.

10.3.2.3 Change Mapping at Coarse Resolution

After computing every monthly average for each climatic variable, GHG scenario and time horizon, the averages were subtracted by the grid of the 1961–1990 time period (also a GCM output) in the case of temperature data. In the case of precipitation data, the ratio was computed.

For mean, minimum and maximum temperature (Celsius):

$$\Delta T = T_{LR,21} - T_{LR,20}$$

For precipitation (dimensionless):

$$r_{prec} = P_{LR,21} / P_{LR,20}$$

Where, LR: low-resolution, 20: twentieth century data, 21: twenty-first century data

10.3.2.4 Resampling

In order to refine the coarse climate change raster maps, a resampling was carried out in ArcGIS down to a resolution of 0.008333 decimal degrees (about 1 km), which corresponds to that of the reference climate maps of the study area. The resampling was done using the cubic convolution method, which computes new pixel values on the basis of a weighted average of the 16 nearest pixels of the original map (four by four window). This method is relatively time-consuming, but it offers a smoother appearance than other available methods (nearest neighbour or bilinear interpolation). Possible edge effects (where the 16 pixel values are not all available) were avoided by selecting an area of interest larger than the study area. In our case the resampling of the climate change maps was carried out in ArcGIS over the rectangle 0–55° N × 3–64° E.

[2] http://www.unidata.ucar.edu/software/netcdf/
[3] http://www.iges.org/grads/

10.3.2.5 Generating Downscaled Climate Surfaces of Precipitation and Temperature

Downscaled high-resolution (1 km) monthly climate surfaces were obtained for each GCM by adding the resampled monthly change maps to monthly high-resolution reference climate surfaces (De Pauw 2008) for temperature variables, and by multiplying for precipitation.

The calculations were performed in ArcGIS using simple raster algebra according to the formulas:

For mean, minimum and maximum temperature (°C):

$$T_{HR,21} = T_{HR,20} + \Delta T_{resampled}$$

For precipitation (mm):

$$P_{HR,21} = P_{HR,20} * r_{resampled}$$

where, HR: high resolution

10.3.2.6 Calculating Averages

Given the vast amount of data generated and the divergence between the results from the selected GCMs, averages were computed from the seven GCMs for the resampled high-resolution change maps of precipitation, mean, maximum and minimum temperature during each month and over the year, as well as the winter, spring, summer and autumn seasons under the two emission scenarios A1b and A2.

10.3.2.7 Derived Climatic Variables

Using the high-resolution monthly precipitation and temperature rasters, the following derived climate grid surfaces were produced for the time frame 2010–2040 under the two GHG scenarios:

- Climatic zones according to the Köppen classification system
- Potential evapotranspiration (mm) on monthly and annual basis
- Aridity index on annual basis
- Growing period

The Köppen climate classification system (Köppen and Geiger 1930–1939) is based on the annual and monthly averages of precipitation and temperature and is, despite its venerable age, still the most widely used to date.

The potential evapotranspiration is the rate of evapotranspiration from an extensive surface of a 8–15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water (Doorenbos and Pruitt 1984).

The aridity index is the ratio of the annual precipitation over the annual potential evapotranspiration (UNESCO 1979).

The climatic growing period is a concept developed by the Food and Agriculture Organization of the United Nations (FAO 1978) to estimate the duration of the period during the year in which neither moisture nor temperature are limiting to plants.

A detailed account of the methods used in deriving these climatic variables from the primary climatic variables is provided by Göbel and De Pauw (2010).

10.4 Climate Change Projections for the Near Future

10.4.1 Precipitation

Except for the extremely arid desert areas of Egypt, where the decrease of precipitation is very high in relative terms, but the absolute loss is very small and therefore of little consequence, annual precipitation during the period 2010–2040 will decline in the region studied by around 10 % in comparison to the recent past (Fig. 10.3a). This decrease is more pronounced under scenario A1B than under A2, but overall the difference between the two scenarios is small (typically <10 %). This is to be expected as the modeled greenhouse-gas emissions diverge significantly only from 2030 onwards. The precipitation decrease is least pronounced in Iraq (5–10 % for both scenarios), while elsewhere it typically varies between 5 % and 10 % for scenario A2 and between 10 % and 20 % for scenario A1B. Most of the decline takes place during winter and spring, when decreases of up to 20 % are expected to happen everywhere, while during summer and autumn, the picture is less uniform and areas with slight precipitation increases, particularly in Iraq and eastern parts of Jordan and Syria, but also in Cyprus, occur alongside areas of decreasing precipitation. The loss of precipitation in winter and spring during the growth cycle of most of the major field crops has potentially serious consequences for agriculture.

10.4.2 Temperature

Temperatures are going to rise everywhere and all around the year with very small differences between the two scenarios. The mean annual temperature is expected to increase by 0.5–1.5 ° (Fig. 10.3b), with most of the change happening in summer and least in winter. In winter, the expected increase will be in the range of 0.5–1.0 ° everywhere except in the Egyptian desert, where it can reach up to 1.5 °. In summer, the increase will range between approximately 1.0 ° and 2.0 °, with the largest increases occurring in Iraq, Syria, and parts of Jordan. In spring and autumn, increases will be between those expected for winter and summer.

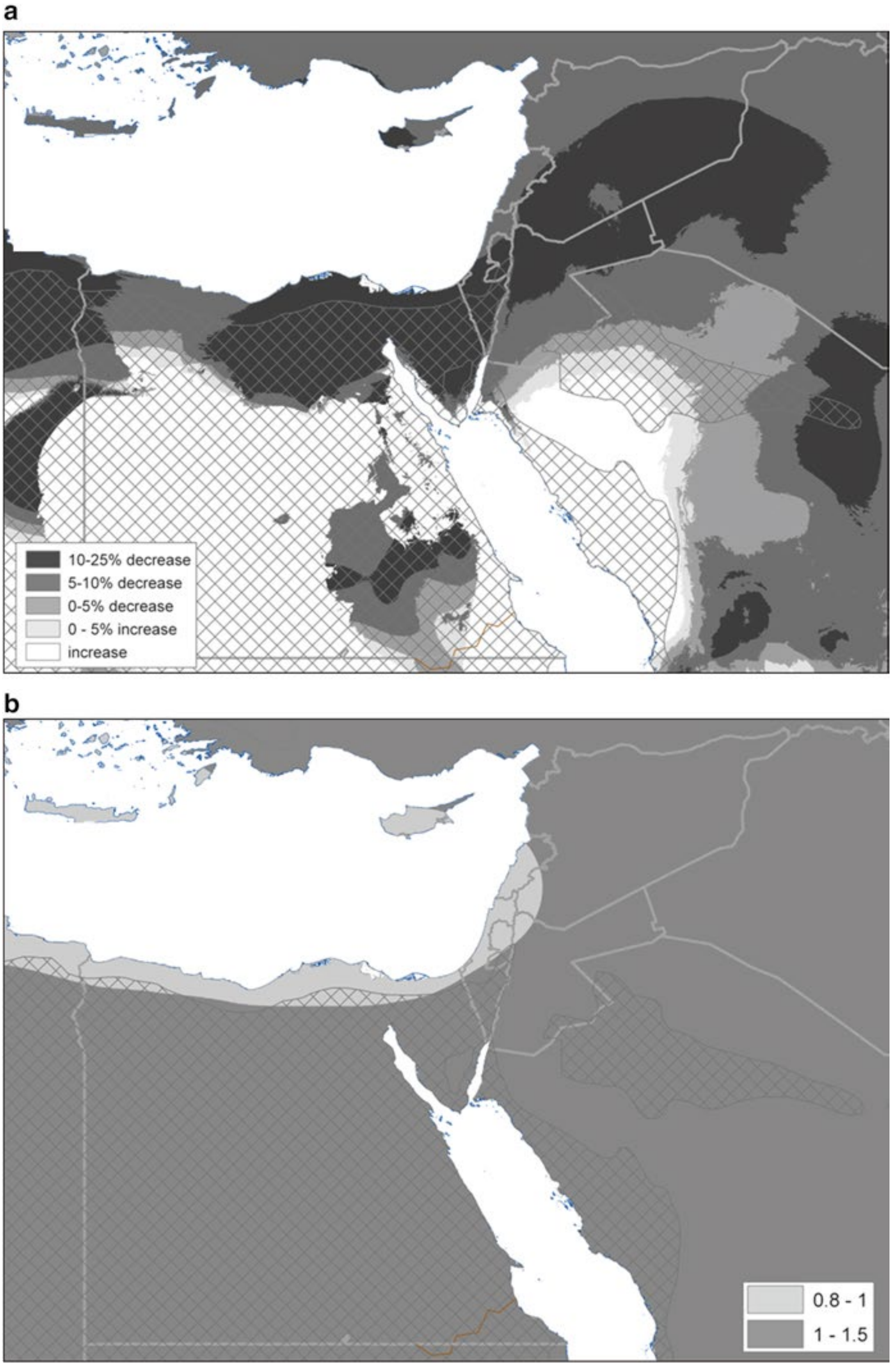
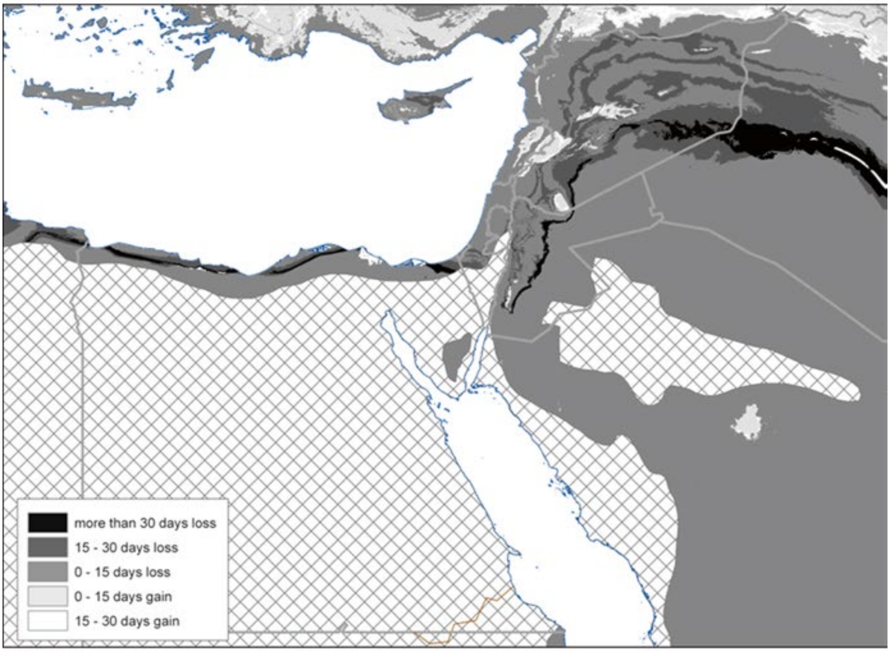


Fig. 10.3 Downscaled climate change maps, 2010–2040 compared to current climate under emission scenario A1b. (**a**) Percentage change in annual precipitation; (**b**) increase in mean annual temperature (°C); (**c**) change in growing period length (in days); (**d**) areas in which the current climatic zones will remain stable or change. *Cross-hatched* are the hyper-arid (desert) areas

c



d

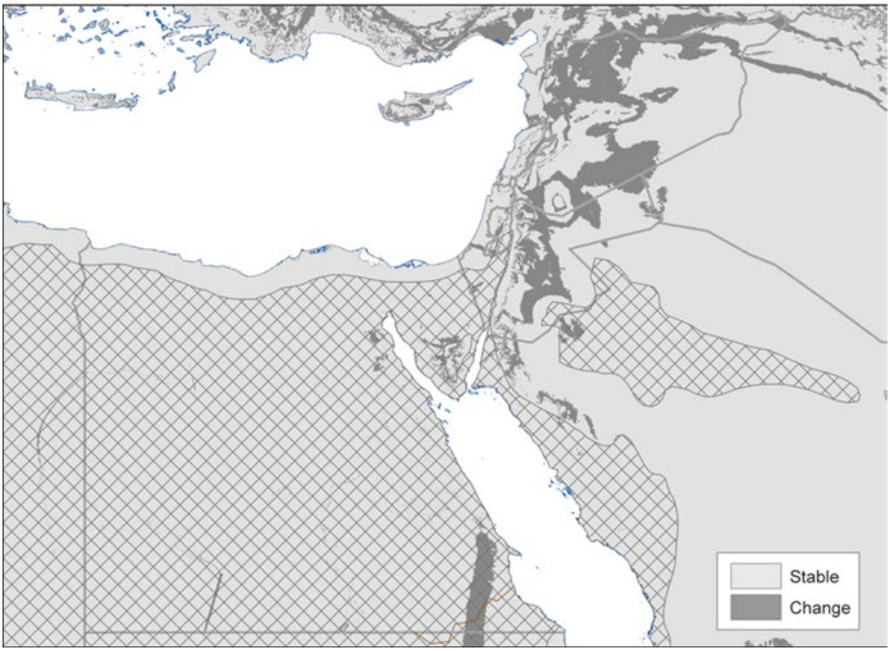


Fig. 10.3 (continued)

10.4.3 Climatic Zones

Ninety percent of the lands in the study area will remain in the same climatic zone according to the classification of Köppen, 10 % will change into another climatic zone. Most affected will be Syria and Jordan, where 30 % of the land will change from a steppe (BS) to a desert (BW) climate (Fig. 10.3d). Lebanon and the West Bank will also witness substantial changes due to shifts of climate zones. The predicted changes of climate zones are very similar for both scenarios, A1B and A2.

10.4.4 Annual Potential Evapotranspiration (PET)

PET will increase by 2–4 %, slightly more under scenario A2 than under scenario A1B, particularly in Syria. Overall, this represents a very modest increase only in evaporative demand for both rainfed winter crops and irrigated crops.

10.4.5 Aridity

Declining precipitation and increased PET both work towards more arid conditions as witnessed by the change in the aridity index. The trend is similar under scenarios A1B and A2. It is most pronounced in Lebanon, the West Bank, and Cyprus.

10.4.6 Growing Periods

The changes of the lengths of the growing periods (Fig. 10.3c), too, are very similar for both scenarios examined. Most of the study area is likely to experience moderate reductions of up to 15 days, but in parts of Syria, the West Bank and Cyprus the decline will be more pronounced and in the range of 15–30 days. Only in some of the high mountain areas of Lebanon, the length of the growing period will actually increase due to the rise in temperature as this will reduce the number of days when low temperatures limit growth.

10.5 From Impact Assessment to Adaptation Strategies

Since time immemorial the agricultural systems of the Mediterranean drylands have been coping with the key ecological constraints of their environment: aridity, pronounced precipitation variability, drought, and restricted water resources for irrigation. The key to adaptation will be in reviewing how these agricultural systems have been coping in the past, revisiting the recommended practices established after decades of dryland agricultural research, and fine-tuning these dryland management principles in order to deal with the additional challenges imposed by climate change. In developing adaptation strategies, it is of paramount importance to recognize that the drylands and the agricultural systems that developed within them are extremely diverse, and that, hence, adaptation measures cannot be of the 'one-size-fits-all' kind and that planning for climate change needs to take into consideration the site-specific constraints and potential for adaptation.

10.5.1 Geographical Shifts of Agricultural Systems

With the expected increase of aridity in the Mediterranean Zone, shifts are likely in the geographical location of the agricultural systems: those that currently occur within a particular aridity class will tend to occupy the agroecological niche of those systems currently in a more humid zone, and will themselves be substituted by systems currently in a more arid climate. In this scenario of shifting systems, given the diversity of crops they can support, the *rainfed mixed systems* are more likely to maintain themselves, albeit in a modified form, than the *dryland mixed systems*. In fact, with declining precipitation and increased risk of drought, it is likely that parts of the dryland mixed systems will no longer be able to support wheat and will be replaced by the more hardy barley crop, itself coming under threat at the low rainfall margins of the dryland mixed systems. As barley-based systems have to abandon these low rainfall areas, pastoral systems can occupy them, but they too will be forced to leave behind previously productive steppe areas that are likely to become too dry to produce biomass for animals. Possibly the only systems to benefit from climate change could be the *highland mixed systems* due to an extension of the thermal growing period, a reduction of the number of frost days and a topography conducive for water harvesting and diversion.

A second option is to look at the response mechanisms available in each agricultural system. In a general way, the agricultural systems of the drylands can be subdivided into three response groups: (a) rainfall-based systems; (b) irrigated systems; and (c) intermediate systems. The latter rely on spatially and temporally variable mixes of rain and irrigation water.

10.5.2 Climate-Proofing Rainfall-Based Systems

The rainfall-based systems are the ones most likely to come under pressure by climate change and, in order to retain their productivity, will need to draw inspiration from the established principles for successful dryland crop management: retain the precipitation on the land, reduce evaporation, and use crops with drought tolerance and that fit the rainfall pattern (Stewart 1988).

As climate change is likely to be accompanied by an increase in high-intensity precipitation events, the retention of precipitation on the land will require more control of runoff. This could be achieved through adapted tillage practices, covering the soil surface, land shaping, and use of ponds for storage.

Improved water conservation leading to higher soil moisture, another dryland management principle, could be achieved by reducing evaporative losses through weed control -manual, mechanical or chemical, depending on the system – and surface mulches. However, the use of mulches will need to be balanced with the dependence of some agricultural systems on stubble grazing and the complexities of soil surface management for evaporation control. Under climate change the traditional practice of fallow to conserve water may again need to be revived in areas with marginal precipitation. With the expected decrease in precipitation, a price has to be paid in terms of lost productivity, as the efficiency of fallow systems generally decreases with increases in length of the fallow period.

The growing period in drylands is short and limited by soil moisture availability, and in the colder areas also by temperature. In dryland agricultural research, drought avoidance by the development of high-yielding short-maturing varieties for the main crops, in combination with statistically-based recommendations for optimum sowing periods, has been the preferred strategy so far. However, as climate change is likely to be accompanied by more severe intra-seasonal drought, more salvation may come in the future from incorporating drought tolerance in traditional crops through breeding or genetic manipulation, trading off productivity against security. There is also scope, if markets can be created, for introducing drought-tolerant crops that are part of local farming systems or have shown high potential under research conditions, in other places where they are currently not known. Hinman and Hinman (1992) mention a number of fairly unknown crops in this category, such as grain amaranth (*Amaranthus* spp.), quinoa (*Chenopodium quinoa*), the prickly pear cactus (*Opuntia* spp.), the bambara groundnut (*Voandzeia subterranea*), the marama bean (*Tylosema esculentum*), the tepary bean (*Phaseolus acutifolius*), the buffalo gourd (*Cucurbita foetidissima*), and halophytes, such as the pickle weed (*Salicornia* spp.) and salt bushes (*Atriplex* spp.). Their successful introduction in other environments is obviously subject to similarity in agro-ecological conditions with the 'home' location, social acceptance, economic attractiveness, ability to fit in the new farming environment, and availability of markets for the new crops.

10.5.3 Making Irrigated Systems More Efficient

As a result of limits on the water supply and increasing water demand, irrigated systems in the Mediterranean Zone are already under considerable pressure to become more efficient. While there are major differences between countries, periodic water shortages are already common in some, particularly in the south and east, and are exacerbated during drought years. The ability to tap additional supplies is limited, as the scope for building more major dams is restricted by lack of suitable dam sites: there are few places left where the ratio of storage volume to flooded area is still acceptable.

It is now also recognized that in the medium to long-term water storage in small and medium reservoirs is unsustainable owing to heavy sediment loads in floods and active siltation and, with climate change, more frequent droughts and higher evaporation rates. As a result, there has been a growing tendency to go for other supply situations that are basically unsustainable, such as the increasing use and over-exploitation of groundwater. In coastal areas this has in most cases resulted into salt water intrusion, which is often irreversible because the balance between saline and fresh water has been disrupted. In other places there has been an exhaustion of shallow aquifers, leading to exploitation of deeper ones with fossil water. Although there are differences between countries, on average 80 % of the water in the countries south and east of the Mediterranean is used in agriculture, nearly all for irrigation (Margat and Vallée 2000).

Within these trends of ceilings on the total water supply and growing competition from other water users (urban users, industry, tourism etc.), climate change is an additional driver in forcing agricultural systems relying on irrigation water to become more efficient. To continue its paramount role in stabilizing crop production and improving livelihoods for the farmers of the region, irrigation will need to produce more with less water. This process is already happening: irrigation systems are adjusting, in the first place by reducing distribution losses through the modernization of existing schemes. The conversion to drip or sprinkler systems of gravity irrigation schemes can lead to field application efficiency rates of 70 %, which would constitute gains that compensate for more than the eventual losses to be expected under climate change.

The irrigation systems are also adjusting to changes in the amount of available irrigation water by shifting emphasis from more water-demanding systems based on relatively low-value staple crops, such as cereals and cotton, to vegetables, fruits and other niche crops serving the growing needs of nearby urban agglomerations or even global markets. Climate change will necessitate changes in crop calendars to avoid extreme heat and evapotranspiration losses. Dryland regions with the financial resources for wastewater treatment may use treated sewage effluent as an important source of irrigation water. In others, more use can be made of irrigation return flow runoff, agricultural subsurface drainage water, and saline groundwater aquifers for salt-tolerant crops.

10.5.4 Expanding the Role of Intermediate Rainfed-irrigated Systems

The increased stress on rainfed dryland systems expected under climate change, the need for stabilization of production and diversified farm income, as well as the pressure on irrigated systems to become more efficient in response to growing water shortages, is likely to promote the growth of so-called ‘hybrid’ systems, which are neither fully irrigated nor fully rainfed.

The alternating use of rainfall and irrigation water is a potentially valuable management principle under conditions of water scarcity. Supplemental irrigation is the addition of small amounts of water to essentially rain-fed crops during times of serious rainfall deficits. The aim is to reduce risk of crop failure, where rainfall is normally sufficient but vulnerability to drought high, and thus to stabilize yields.

The water use efficiency of supplemental irrigation can be very high. Obviously supplemental irrigation is only practical where rainfall is high enough to count as a significant water source.

A spatial variant of supplemental irrigation is water harvesting. This practice covers various techniques to collect rainwater from natural terrains or modified areas and concentrating it for use on smaller sites or cultivated fields to assure economic crop yields. Collected runoff is stored in the soil, behind dams or terraces, cisterns, gullies or recharged to aquifers. Water harvesting systems come in a variety of implementations, but the common components are invariably a catchment or source area, a storage facility and use area. In *micro-catchment systems* the source and target areas are essentially that close together that they cannot be separated at scales larger than the field level, and the storage facility is either the soil's root zone for immediate or a small reservoir for later use. In *macro-catchment systems*, run-off water is collected from a relatively large catchment outside a relatively small target area with storage provided by surface structures, such as small farm reservoirs, subsurface structures, such as cisterns, or the soil in the target area itself.

Water harvesting systems are relevant in moisture-deficit areas and constitute a compromise: a choice is made to sacrifice part of the land, on which (in theory) a crop could be grown, yielding poorly in most years, in order to concentrate water on a smaller fraction of the land, where a higher soil moisture supply would allow for better yields in most years. Water harvesting systems remain dependent on precipitation and therefore offer no panacea for prolonged droughts. Nevertheless, they certainly offer a useful dryland land management practice that may gain in relevance under the climate change future envisaged for the Mediterranean Zone.

As for all alternatives to traditional practices, the feasibility of water harvesting needs to be assessed not only from a technological perspective (suitable catchment areas, soils, storage sites etc.) but also an economical (is it attractive in comparison to other land use options?) and cultural one (is it acceptable?).

10.6 Conclusions

In a context of global warming and precipitation increase, the drylands around the Mediterranean are, due to a projected precipitation decline, likely to become one of the regions most severely affected by climate change. In its current setting this region, characterized by one of the most variable climates in the world and with precipitation and drought trends in the recent past that are already very similar to the projections for the near future, has a great diversity of agricultural systems that are adapted to their agroecological niches and are able to cope with their climatic constraints.

At least for the near future, there appears no particular reason why the agricultural systems of the region would be unable to cope with climate change. The irrigated systems are already forced into greater efficiency due to increasing pressure on water supplies and demand, in which the projected precipitation decline is an additional, but not dominant, stress factor. The rainfed systems may have some adaptive capacity by moving their agroecological niche with the shift in precipitation zones. However, it is unsure whether a rigorous implementation of the tested dryland management principles, explained earlier, will be sufficient to compensate for the additional stress of higher aridity and more severe droughts. It is therefore likely that innovative hybrid systems, partially irrigated, partially rainfed, will become more prominent, as they offer high water productivity in an age of increasing water shortage and the prospect of greater yield stability than under rainfed conditions.

References

Christensen JH, Hewitson B, Busuioc A, Chen A, Gao X, Held I, Jones R, Kolli RK, Kwon W-T, Laprise R, Magaña Rueda V, Mearns L, Menéndez CG, Räisänen J, Rinke A, Sarr A, Whetton P (2007) Regional climate projections. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK/New York

De Pauw E (2004) Technologies integration in Mediterranean rainfed conditions a spatial perspective on the results from the MEDRATE project. In: Cantero-Martinez C, Gabina D (eds) Mediterranean rainfed agriculture: strategies for sustainability, Options méditerranéennes. CIHEAM, Zaragoza, pp 269–281. ISBN 2-85352-294-6

De Pauw E (2008) Climatic and soil datasets for the ICARDA wheat genetic resource collections of the Eurasia region: explanatory notes. Technical Note, GIS Unit, ICARDA, Syria

Dixon J, Gulliver A, Gibbon D (2001) Farming systems and poverty. FAO and World Bank, Rome/Washington, DC, p 412. ISBN 92-5-104627-1

Doorenbos J, Pruitt WO (1984) Guidelines for predicting crop water requirements, vol 24, FAO irrigation and drainage paper. FAO, Rome

FAO (1978) Reports of the agro ecological zones project. World Soil Resources Report No.48, vol 1 Africa. Food and Agriculture Organization of the United Nations, Rome

Göbel W, De Pauw E (2010) Climate and drought atlas for parts of the Near East: a baseline dataset for planning adaptation strategies to climate change. Final report, GIS Unit, ICARDA, Syria

Hinman CW, Hinman JW (1992) The plight and promise of arid land agriculture. Columbia University Press, New York, 253 pp. ISBN 0-231-06612-0

IPCC (2007) Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds). Cambridge University Press, Cambridge, UK/New York

Keatinge JDH, Dennett MD, Rogers J (1986) The influence of precipitation regime on the crop management in dry areas in northern Syria. Field Crops Res 12:239–249

Köppen W, Geiger H (1930–1939) Handbuch der Klimatologie. Gebrüder Bornträger, Berlin

Margat J, Vallée D (2000) Mediterranean vision on water, population and the environment for the XXIst century. PNUE. PAM. Plan Bleu, Valbonne. On-line. http://www.planbleu.org/publications/vision_eau_eng.pdf

Ryan J, De Pauw E, Gomez H, Mrabet R (2006) Drylands of the Mediterranean zone: biophysical resources and cropping systems. In: Peterson GA, Unger PW, Payne WA (eds) Dryland agriculture, 2nd edn. ASA, CSSA and SSSA. Agronomy Monograph 23:577–624

Stewart BA (1988) Dryland farming: the North American experience. In: Unger PW, Jordan WR, Sneed TV, Jensen RW (eds) Proceedings of the international conference on dryland farming, Amarillo/Bushland, 15–19 Aug 1988, pp 54–59

UNESCO (1979) Map of the world distribution of arid regions. Map at scale 1:25,000,000 with explanatory note. United Nations Educational, Scientific and Cultural Organization, Paris, 54 pp. ISBN 92-3-101484-6

Chapter 11
Climate Change and Food Security in the Nile Valley and Red Sea

Ayman F. Abou Hadid

Abstract Water is the most important resource for agricultural development in the region of Nile Valley and Red Sea. Climate change has posed an additional threat to water availability in the region that added to the competition for water for the ever-growing population, and the possible increase in temperature that may result in increased evapotranspiration and elevate the level of demand for water. The Nile valley and Delta, which is the major irrigated agricultural area in the region, is irrigated by surface irrigation. Water use efficiency is as low as 45–50 % in several cases. Fragmentation of land ownership is adding to the management problems and results in more wastes in water use. Due to the need for more land to produce more food to feed the population, land reclamation seems to be the only solution. The reclaimed land will depend on rainfall in some countries but will need more dependence on the surface water as well as underground water in other countries that is classified within the hyper arid zones. The situation may get worse under climate change conditions. Saving agricultural water is therefore a must. The Egyptian sustainable agricultural strategy has included several measures to adapt to climate change and increase water use efficiency including the reduction of area cultivated with rice; improving farming systems for animal husbandry; introducing the cropping pattern with improved agricultural extension service; improving on-farm water management in the old lands; concentrating on the agro-industrial complexes in the new land reclamation projects; improving the capacity building for human resources working in agricultural sector; and increasing the public awareness on climate change through integrated programs including private and public sectors. One of the most important issues in this effort is the National program for improving on-farm water management. The program has started in 2009 and will finish the first phase by 2017 and the second phase by 2030. The program depends on improving the

A.F. Abou Hadid (✉)
Arid Lands Agricultural Studies and Research Institute (ALARI), Faculty of Agriculture, Ain Shams University, Cairo, Egypt
e-mail: ayman_abouhadeed@agr.asu.edu.eg

M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_11,

soil conditions through laser leveling and changing the old surface irrigation system to modern water saving systems that suits different crops. Besides, the program will help in adapting to possible climate change. The program will also create new job opportunities for about three million families; control the water infectious diseases by covering the branch canals and limiting human direct contact with untreated surface water. Several legislations and policies will be subject to changes to facilitate the implementation of the program. To support these activities, the Climate Change Information Center (CCIC) was established in cooperation with stakeholders of the agricultural sector to provide networking within the country that could be easily reformed into a Regional Climate Change Information Center for south Mediterranean region and Nile Valley and Red Sea regions.

Keywords Climate change • Adaptation • Greenhouse gases • Sea level rise • Information dissemination • Nile Valley and Red Sea • Sustainable agriculture • Water use efficiency • Economic impact of climate change

11.1 Introduction and Background

The issue of climate change has been increasingly discussed by both scientists and industry since the early 1990s. The comprehensive package of instructional resources is designed to help peoples to develop and understand the concepts of climate change and the skills to deal with the issues involved. Climate change is a natural process but recent trends related to climate change are alarming mainly due to anthropogenic reasons. Climate change has already affected people, their livelihoods and ecosystems and presents a great development challenge for the global community in general and for the poor people in developing countries in particular.

The levels of greenhouse gases (GHGs) – mainly carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) – have been rapidly increasing after the industrial revolution. The increased level of GHGs has created a greenhouse effect which subsequently altered precipitation patterns and global temperatures around the world. Impacts have been witnessed in several areas due to changes in precipitation and temperature. The impact areas include, among others, agriculture, forestry, water resources, biodiversity, desertification, human health, and ecosystems goods and services globally. Researches revealed that rate and extent of climate change effects have increased significantly over the years with the increasing weather variability and extreme events.

Clear impacts from climate change are being witnessed in agriculture. Impacts are both positive as well as negative. They are, however dependent on latitude, altitude and type of crop. There have been noticeable impacts on plant production, insect, disease and weed dynamics, soil properties and microbial compositions in farming systems (Eid and El-Marsafawy 2002). According to IPCC (2007a), a temperature change in tropical areas has in general had a negative impact on food production and it is estimated that food production within South Asia will decrease

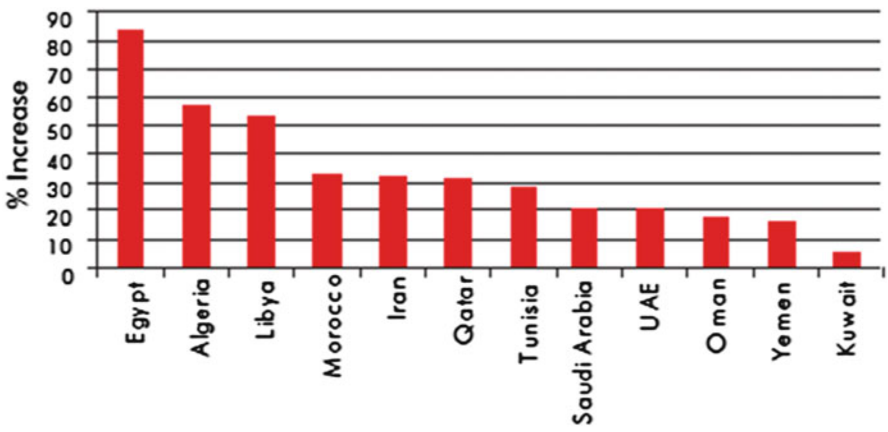


Fig. 11.1 Expected increase of storm surges in some countries as affected by climate change

by about 30 % by 2050. Although the cause and effect relations of climate change and agriculture are seen in many forms and extent, the assessment of those relations and effects of climate change on agriculture and the impact of (both conventional and organic) agriculture on climate change are not properly documented. Understanding of this nexus is vital not only to improve the agricultural sector productivity but it is also important to positively contribute to the environmental management regime at large.

Climate change and agriculture are closely linked and interdependent. Compared to conventional agriculture, organic agriculture is reported to be more efficient and effective in reducing GHG emissions, mainly due to the less use of chemical fertilizers and fossil fuel. Organic agriculture also was reported to be climate change resilient farming systems as it promotes the proper management of soil, water, biodiversity and local knowledge, thereby acting as a good option for adaptation to climate change. But, due to lack of proper research, the contribution of organic agriculture for climate change adaptation and mitigation is yet to be known in many areas. It is argued that organic agriculture positively contributes to offset negative impacts of climate change, but there is inadequate systematic data to substantiate this fact.

In the same direction, extreme weather events such as droughts, floods, storms and hurricanes, and spells of extremely high or low temperatures are becoming more frequent and more severe. Current observations indicate increased occurrence of such events, and model predictions suggest that this trend will continue. Famines, as pointed out by Sen (1981), are really man-made disasters that are the result of climatic risks (e.g., prolonged periods of low rainfall and high temperatures) and human failures to respond to resulting declines in food production and increased malnutrition. Humanitarian disasters caused by weather related shocks are therefore likely to increase in number and severity.

Dasgupta et al. (2009) reported that the potential impact of increasing frequencies and severities of storm surges is evident in most of the countries in the MENA region (Fig. 11.1).

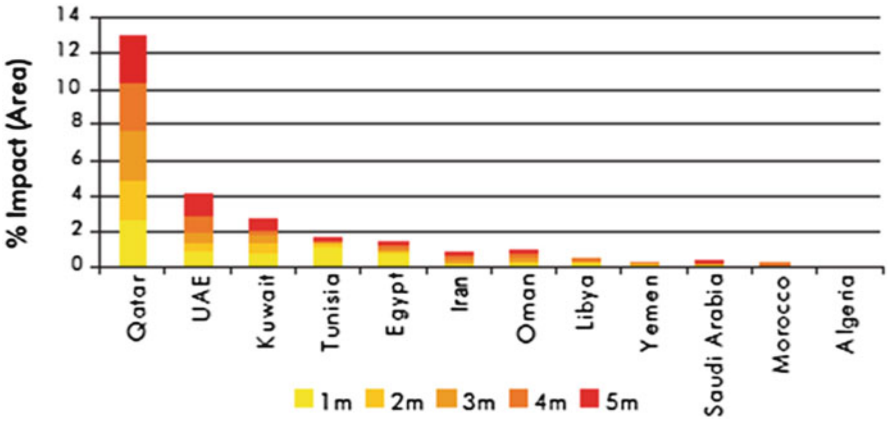


Fig. 11.2 A comparison of percentage impacts of sea level rise on land areas of Arab countries (After Dasgupta et al. 2007)

Climate change may affect food systems in several ways ranging from direct effects on crop production (e.g. changes in rainfall leading to drought or flooding, or warmer or cooler temperatures leading to changes in the length of growing season), to changes in markets, food prices and supply chain infrastructure. The impacts of climate change on agricultural activities have been shown to be significant for low input farming systems in developing countries in Africa (Rosenzweig and Parry 1994; McGuigan et al. 2002). Furthermore, tropical regions in developing countries are usually characterized by poor marginal soils that cover extensive areas, making them unusable for agriculture, leaving the developing countries particularly vulnerable to potential damage from environmental changes (Mendelsohn and Dinar 1999). The expected sea level rise due to climate change will affect several countries in the MENA region.

The area lost due to sea level rise ranges between less than one percent of the total country area in Algeria to 12 % in case of Qatar (Fig. 11.2). But the impact on national economy is different, where Egypt will be most affected due to its dependence on agricultural activities in the Nile Delta (Fig. 11.3).

According to Abou Hadid (2009), food security in the Arab world and Nile valley has experienced a long history of environmental and socio-economic pressures. The dominant arid conditions, limited water resources, erratic cropping patterns, low knowledge and technology levels are the main factors presently affecting food production systems in the region. Most recent assessments have concluded that arid and semi-arid regions are highly vulnerable to climate change (IPCC 2007a). On the other hand, at a high level conference of the Food and Agriculture Organization (FAO) held in Rome in June 2008, the delegates asserted that agriculture is not only a fundamental human activity at risk from climate change, but it is also a major driver of environmental and climate change itself. The projected climate change will be among the most important challenges for agriculture in the twenty-first century, especially for developing countries and arid regions (IPCC 2007a).

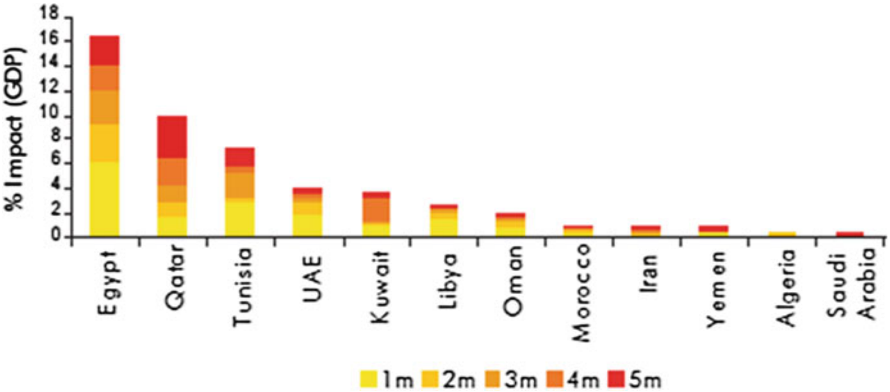


Fig. 11.3 A comparison of percentage impacts of sea level rise on the GDP of Arab countries (After Dasgupta et al. 2007)

By the end of the twenty-first century, the Arab region will face an increase of 2–5.5 °C in the surface temperature. This increase will be coupled with a projected decrease in precipitation up to 20 %. These projected changes will lead to shorter winters and dryer summers, hotter summers, more frequent heat wave occurrence, and more variability and extreme weather events occurrence (IPCC 2007b).

Climate change could exacerbate the food security issues that North Africa and Nile valley region already faces. Egypt's report to the UNFCCC states that "climate change may bring about substantial reductions in the national grain production." Grain is only one of Egypt's food sources endangered by unmitigated climate change. Even without climate change, by 2020 Egypt is projected to import 300–360 thousand metric tons of fish, which is a third of its projected domestic production. However, climate change could drastically increase Egypt's trade imbalance in fish products while simultaneously tightening the global fish market. As the sea level rises, salt water will infiltrate the North Egyptian lakes where 60 % of Egypt's fisheries are located. The situation in other countries of the region is similar, and due to political and socio-economic conditions, could even be worse.

Abou Hadid (2009) reported that impacts of climate change on agricultural activities in term of yield reduction and increasing of water needs have been studied for the last two decades in Egypt. Climate change could decrease the national production of rice *(Oryza sativa)* by 11 % and soybeans (*Glycine max*) by 28 % by the year of 2050, compared with their production under current conditions. It could reduce national maize *(Zea mays)* and sorghum (*Sorghum bicolor*) production by about 19 % and wheat (*Triticum sp.*) and barley (*Hordeum vulgare* L.) production by 18 %. Cotton (*Gossypium sp.*) seed yield would increase by 17 % if the temperature increased by 2 °C and by 31 % with a 4 °C increase. By the year 2050, climate change could increase water needs by up to 16 % for summer crops and by about 2.5 % for wheat crop.

Abou Hadid (2010) reported that water is the most important resource for agricultural development in the region of Nile Valley and Red Sea. Climate change has

Table 11.1 The date of publishing the first national communication in Arab countries (Adapted from http://unfccc.int/national_reports/non-annex_i_natccm/items/2979.php)

Country	First national communication
Algeria	2001
Bahrain	2005
Egypt	1999
Jordan	1997
Lebanon	1999
Mauritania	2002
Morocco	2001
Saudi Arabia	2005
Sudan	2003
Tunisia	2001
United Arab Emirates	2007
Yemen	2001

posed an additional threat to water availability in the region that added to the competition for water due to the ever-growing population, and the possible increase in temperature that may result in increased evapotranspiration and elevate the level of demand for water. The Nile valley and Delta, which is the major irrigated agricultural area in the region, is irrigated by surface irrigation. Water use efficiency as low as 45–50 % in several cases. Fragmentation of land ownership is adding to the management problems and results in more wastes in water use. Due to the need of more land to produce more food to feed the population, land reclamation seems to be the only solution. The reclaimed land will depend on rainfall in some countries but will need more dependence on the surface water as well as underground water in other countries that is classified within the hyper arid zones. The situation may get worse under climate change conditions. Saving agricultural water is therefore a must.

The objective of this chapter is to stress upon the need to establish a regional Climate Change Information Center. Table 11.1 indicates that the countries of the region submitted their first national communications between the year 1997 (Jordan) and the year 2007 (United Arab Emirates) and some of the countries did not issue the second national communication yet. One of the reasons for the delay could be the availability of information and therefore, the establishment of a climate change network and the Climate Change Information Center for the region could help in keeping the region updated about this serious issue.

11.2 Impact of Climate Change and Adaptation Measures and Approaches

The Egyptian sustainable agricultural strategy has included several measures to adapt to climate change and increase water use efficiency including the reduction of area cultivated with rice; improving farming systems for animal husbandry; introducing the cropping pattern with improved agricultural extension service; improving on-farm water management in the old lands; concentrating on the agro-industrial complexes in the new land reclamation projects; improving the capacity building for human resources working in agricultural sector; and increasing the public awareness on climate change through integrated programs including private and public sectors. One of the most important issues in this effort is the National program for improving on-farm water management. The program was started in 2009 and will finish the first phase by 2017 and the second phase by 2030. The program depends on improving the soil conditions through laser leveling and changing the old surface irrigation system to modern water saving systems that suits different crops. Besides, the program will help in adapting to possible climate change. The program will also create new job opportunities for about three million families; control the water infectious diseases by covering the branch canals and limit human direct contact with untreated surface water. Future climate change will lead to reduction in productivity of crops, increase in crop water needs and decreases in crop water productivity. To cope with the adverse impact of climate change on the previous characters, more adaptation strategies will be suggested and each one will be evaluated to reduce vulnerability and realize opportunities associated with climate change effects and hazards. There are numerous examples of successful adaptations that would apply to climate change risks and opportunities. Substantial reductions in climate change damages can be achieved, especially in the most vulnerable regions, through timely deployment of adaptation measures.

Development decisions, activities, and programs play important roles in modifying the adaptive capacity of communities and regions, yet they tend not to take into account risks associated with climate variability and change. This omission in the design and implementation of many recent and current development initiatives results in unnecessary additional losses to life, well-being, and investments in the short and long term. Enhancement of adaptive capacity is necessary to reduce vulnerability, particularly for the most vulnerable regions, nations, and socioeconomic groups. Activities required for the enhancement of adaptive capacity are essentially equivalent to those that promote sustainable development and equity (El-Shaer et al. 1997; IPCC 2001; Abou-Hadid et al. 2003; Leary et al. 2007).

11.3 Economics of Climate Change Impact

According to Stern (2006), the costs of taking action are not evenly distributed across sectors or around the world. Even if the rich world takes on the responsibility for absolute cuts of 60–80 % in GHG emissions by 2050, developing countries must take significant action too. But developing countries should not be required to bear the full costs of this action alone, and they will not have to. Carbon markets in rich countries are already beginning to deliver flows of finance to support low-carbon development, including through the Clean Development Mechanism. A transformation of these flows is now required to support action on the scale required. Action on climate change will also create significant business opportunities, as new markets are created in low-carbon energy technologies and other low-carbon goods and services. These markets could grow to be worth hundreds of billions of dollars each year, and employment in these sectors will expand accordingly. The world does not need to choose between averting climate change and promoting growth and development. Changes in energy technologies and in the structure of economies have created opportunities to decouple growth from greenhouse gas emissions. Indeed, ignoring climate change will eventually damage economic growth. Tackling climate change is the pro-growth strategy for the longer term, and it can be done in a way that does not cap the aspirations for growth of rich or poor countries.

11.4 Proposal for Climate Change Information Center

The need for exchanging information and increasing awareness on climate change issue is a major point all over the Red Sea, Nile Valley, and North Africa region. Several legislations and policies will be subject to changes to facilitate the implementation of greenhouse gases reduction and other related programs. To support these activities, a Climate Change Information Center (CCIC) is proposed to be established in cooperation with stakeholders in the agricultural sector to provide networking within each country and also at the regional level. The center will be a focal point for collecting data, generating information, and disseminating knowledge to stakeholders in the region. The center will be created in Egypt within the activities of the Arid Lands Agricultural studies and Research Institute (ALARI) of Ain Shams University and will be linked to a similar center in Agricultural Research. The center could be easily reformed and expanded to act as a Regional Climate Change Information Center for the south Mediterranean region and the Nile Valley and Red Sea regions.

11.4.1 Objectives of CCIC

- Develop an integrated approach of good agricultural management to cope with future climate change negative impacts on agriculture.
- Analyses of different scenarios of higher temperatures on crop productivity in different agro-climatic zones
- Create an inventory of different crop varieties and cultivars, and animal genetic lines vulnerable to possible climate change in the region.
- Integrate the negative impact of climate change on various components of agricultural sector (plant and animal production – water use – diseases and insects) to create and update assessment of the negative impacts on the net income from the agricultural sector.
- Facilitate the conduct of future climate change economic studies for the region in cooperation with the relevant institutes of agricultural and environmental research.

- Study the impact of climate change on crop combinations and determine the best crop rotations that could achieve better profitability for farms in different agro-climatic zones.
- Conduct training courses and transfer experience about climate change phenomena and their impacts on the agricultural sector.
- Produce guidance bulletins for the best possible agricultural operations under future conditions to reduce the negative impact of climate change on crop productivity.

11.4.2 Methodologies of the Regional Climate Change Information Center

The proposed CCIC will undertake innovative actions on the regional basis through strengthening and promoting reforms in policies and investments that indirectly reduce vulnerability to climate change (e.g. improved water demand management, agriculture diversification through cereal production improvement, and supply chain development); or that promote reduction of GHG emissions; and undertake innovative action in climate change which poses new challenges that require adequate responses. CCIC will develop new types of analytical services (to assist stakeholders to better evaluate magnitude and distribution of climate impacts); will engage in the support of new technologies for both mitigation and adaptation; and will support innovative mechanisms to spread climate risks (e.g. insurance and contingent financing.).

11.4.3 How CCIC Would Operate

Climate change is a serious and complex challenge for any single actor to operate in isolation, or to address all of its dimensions especially in the developing countries. CCIC will therefore actively seek partnerships with the relevant institutions in all countries of the region. CCIC will undertake high- level consultations with its stakeholders to agree on priorities for action on climate change, and will seek collaborations with regional and international organizations and funding agencies. It will also assist in the preparation of the different reports and assist countries in meeting their obligations to international protocols. It will facilitate the update of methodologies of data collection and handling. It will also assist in the identification of research gaps and prioritize study needs for climate change issues in the agricultural sector. It is proposed that data and information will be circulated through a central database available to the beneficiaries in several forms to be used for several applications such as: digital tabular data, digital maps, graphs and demonstrative formats, and text reports. CCIC will establish an interactive high speed web site to facilitate data sharing and assure its availability.

11.4.3.1 Data Sources

CCIC will depend on following sources at national and regional institutes and organizations to obtain needed information for the center: Ministry of Agriculture and Ministry of environment; Economic Sector and organizations responsible for mobilization and mass surveys; Agricultural Extension systems; Ministry of Irrigation and water resources; Ministry of international cooperation, organization for planning and administration; National and international development projects; International interested organizations and donors; Coasts protection organization; Meteorological Authority; and Geographical survey authority. The cooperation between these authorities and the center will be specified in protocols or letters of agreements that describe the duties and gains of each partner to exchange information between the center and interested organizations and authorities at the national and regional levels and to protect the intellectual property rights. CCIC is expected to make available data and information related to the following issues:

- Classification for cultivated land (accurate and detailed classification in the form of digital maps or satellites images).
- Irrigation sources (type and capacity).
- Cultivated Crop Areas with different sorts and different lugs (digital data or satellite images).
- Productivity of different crops (the main and the secondary crop).
- Planting and harvesting dates.
- Quantities of used irrigation water and irrigation systems.
- Amounts of fertilizers and pesticides used.
- Restriction of morbidity and insect damages.
- Restriction of energy resources and machines used in the agricultural production.
- Data related to environmental problems (sea-level rise, ground water, land and water salinity, water pollution).
- Data on greenhouse gas emissions.
- Data related to influence of climate change on agricultural sector.
- Data of population in rural areas and agricultural employment.
- Data associated with agricultural production economics.
- Data of global indicators of agricultural production.
- Data related to previous global and national climate change studies (DSSAT simulation models and other models will be used to achieve some of the previous issues)

11.4.3.2 Proposed Institutional Structure of the CCIC

It is suggested that the center may consist of four main working groups in addition to administrative and service components:

- Programming and technical support group: concerned with establishing, operating and maintaining central data base as well as associated applied programs.

- Data collection and handling group: concerned with inserting data into central data base, data correction and disseminating data to the stakeholders.
- Research monitoring group: to collect the research activities, reports, and research articles from different sources, and prepare metadata files and archives.
- Science supporting group: to determine the kind of data required for conducting studies, setting priorities, applying various studies, and offering technical and scientific consultations associated with climate change researches.

11.4.4 Key Elements of Future Benefits

The proposed center could assist the member countries and institutions in the following fields:

- Emissions trading: Expanding and linking the growing number of emissions trading schemes around the world to promote cost-effective reductions in emissions and to bring forward action in developing countries. Also, it is needed to synchronize action to obtain financial and technical support for the processes of the transition to low-carbon development paths.
- Technology cooperation: Informal co-ordination as well as formal agreements can boost the effectiveness of investments in innovation around the world. Globally, support for energy R&D could increase, and the increasing support for the deployment of new low-carbon technologies needs to be used for the region. International cooperation is a key word for the success of improving technology.
- Action to reduce deforestation: The loss of natural forests around the world contributes more to global emissions each year than the transport sector. Curbing deforestation is a highly cost-effective way to reduce emissions; large scale international pilot programs to explore the best ways to do this could get underway in a timely manner.
- Adaptation: The poorest countries are most vulnerable to climate change. It is essential that climate change be fully integrated into development policy, and that rich countries honor their pledges to increase support through overseas development assistance. International funding should also support improved regional information on climate change impacts, and research into new crop varieties that will be more resilient to drought and flood.

11.5 Avoiding the Risks of Climate Change

The risks associated with agriculture and climate change are a result of the strong complicated relationships between agriculture and climate system, plus the high reliance of agricultural system on the natural resources. The projected increase in temperature is perceived to increase the gap between water resources and demands, decrease the overall agriculture productivity, and increase the competition over the natural resources. The effects of sea level rise on the coast of the Nile Delta would reduce the area under cultivation. The impact of climate change is most likely to hit the rural communities in the country severely, due to the fragile socioeconomics of the rural people.

The vulnerability of agriculture in the region to climate change is mainly attributed to both biophysical and socioeconomic parameters. Changes in crop productivity are mainly attributed to the projected temperature increase, crop-water stress, pests and diseases, which are seen as challenges for the agricultural sector in the future to find a balance between reducing use of pesticides and appropriate pest management practices. The intensity of the heat and cold waves increased in the past 20 years which will cause several harmful impacts in crops productivity, especially for fruits and vegetables.

Projected future temperature rises under climate change conditions are likely to increase crop-water requirements thereby directly decreasing crop water use efficiency and increase the irrigation demands of the agriculture sector. Crop water requirements of the important strategic crops in Egypt are going to increase under all IPCC SRES socioeconomic scenarios of climate change, by a range of 5–13 % by 2100 and lead to a high vulnerability of on-farm irrigation system. Using different combinations of different levels of improved surface irrigation system efficiencies and applying deficit irrigation could improve the efficiency of surface irrigation system in old land in order to overcome the negative impacts of climate change.

Current evidence shows that increase in temperature implies higher harmful heat stress impacts on animal productivity. New animal diseases emerged in North Africa which carry strong negative impacts on livestock productivity. Possible increase in disease transfer from animals to humans will be a possible threat. The availability of fodders may be subjected to decrease. The most likely adaptation options for livestock are: improving the current low productivity cattle and buffalos breeds of cattle and buffalos, and improving the feeding programs to be better adapted for warmer climate conditions.

Climate change is expected to increase sea temperature causing fish distribution to shift northwards and to go deeper into water. Aquaculture projects may suffer from water shortages due to climate change and the increased temperature. The increased salinity of water in the coastal lakes may gradually reduce the existence of fresh water fish and increase the portion of saline water fish which is more sensitive to environmental changes. There are no clear adaptation options defined for this important sector. Further studies on the impacts, vulnerability, and adaptation to climate change are still needed, but the lack of availability of information, data, and networks is a strong obstacle in this direction.

11.6 General Remarks and Recommendations

Designing and applying national adaptation strategies for the agricultural sector is facing a group of barriers and limitations which include existing scientific information and policy perceptions; poor adaptive capacity of the rural community; lack to financial support; and absence of the appropriate institutional frameworks and linkages. The following consideration could be included to enhance the planning to adaptation and mitigation strategies for agricultural sector under Egyptian conditions: improve the scientific capacity; use the bottom up approach of adaptation planning; develop community-based measures by stakeholders' involvement in adaptation planning; increase the public awareness about climate change and its relation to human systems; and improve adaptive capacity of the communities. The recommended priorities of the agriculture sector in the adaptation to climate change could be summarized as follows:

– Conduct a national program for improving the current crop pattern and calendar to be adapted to the incoming projected climate changes. This program should include developing and testing heat, water, salinity and pest- and disease stress-tolerant cultivars of the major crops. Dissemination of the results to the farmers should be one of the important objectives of this program.
– Implement nation-wide project targeted at improving the on-farm irrigation system in order to tackle the expected increase in pressures and demands on water availability, and meet the higher irrigation demands under climate change conditions.
– Assuring sustainable adaptation funds and climate hazards insurance systems are among the important cross cutting issues related to adaptation planning.
– Establishment of a strong regional information dissemination system regarding climate change and its impacts on agriculture which targets all stakeholders in order to assist them in developing their appropriate adaptation measures. This may start by establishing a regional network for climate change among all the countries of the region and supported as much as possible by the international organizations involved in the issues of climate change to support multi-disciplinary action for climate change and to establish the needed mechanism for sharing climate change information.

References

Abou-Hadid AF (2009) Arab environment: climate change. Impact of climate change: vulnerability and adaptation, Chapter 5. http://www.afedonline.org/afedreport09/english/Char5.pdf

Abou-Hadid AF (2010) Climate change and the Egyptian agriculture conundrum. In: Ninth IDDC international conference on development of dry land: sustainable development in the dry lands-meeting the challenge of global climate change, Alexandria, pp 161–170, 7–10 November 2008

Abou-Hadid AF, Raoudha M, Mokssit A, Iglesias A (2003) Assessment of impacts, adaptation, and vulnerability to climate change in North Africa: food production and water resources. AIACC AF90 semi-annual progress report. http://sedac.ciesin.columbia.edu/aiacc/progress/AF90_July03.pdf

Dasgupta S, Laplante B, Meisner C, Yan J (2007) The impact of sea level rise on developing countries: a comparative study. Policy research working paper 4136. World Bank. http://www-wds.worldbank.org/servlet/WDSContentServer/WDSP/IB/2007/02/09/000016406_20070209161430/Rendered/PDF/wps4136.pdf

Dasgupta S, Laplante B, Murray S, Wheeler D (2009) Sea-level rise and storm surges: a comparative analysis of impact in developing countries. Policy research working paper 4901. WorldBank. http://elibrary.worldbank.org/docserver/download/4901.pdf?expires=1368041675&id=id&accname=guest&checksum=DCD77FE464A5386B66688763051EE128

Eid HM, El-Marsafawy SM (2002) Adaptation to climate change in Egyptian agriculture and water resources. In: 3rd international symposium on sustainable agro-environmental systems: new technologies and applications AGRON, Cairo, 26–29 Oct 2002

El-Shaer MH, Rosenzweig C, Iglesias A, Eid HM, Hillel D (1997) Impact of climate change on possible scenarios for Egyptian agriculture in the future. Mitig Adapt Strat Global Change 1:233–250

Intergovernmental Panel on Climate Change (IPCC) (2001) Climate change 2001. Synthesis report a contribution of working groups I, II, III, IV to the third assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge

IPCC (2007a) Climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds). Cambridge University Press, Cambridge, UK

IPCC (2007b) Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds). Cambridge University Press, Cambridge, UK/New York

Leary N et al (2007) A stitch in time: lessons for climate change adaptation from the AIACC Project. AIACC working paper no. 48. http://www.aiaccproject.org/working_papers/Working%20Papers/AIACC_WP48_Leary_etal.pdf

McGuigan C, Reynolds R, Wiedmer D (2002) Poverty and climate change: assessing impacts in developing countries and the initiatives of the international community. London School of Economics Consultancy Project for the Overseas Development Institute. http://www.odi.org.uk/sites/odi.org.uk/files/odi-assets/publications-opinion-files/3449.pdf

Mendelsohn R, Dinar V (1999) Climate change, agriculture, and developing countries: Does adaptation matter? World Bank Res Obser 14:277–293

Rosenzweig C, Parry ML (1994) Potential impact of climate change on world food supply. Nature 367:133–138

Sen A (1981) Poverty and famines: an essay on entitlement and deprivation. Oxford University Press, New York

Stern N (2006) Review on the economics of climate change. H.M. Treasury, UK. http://www.sternreview.org.uk

Chapter 12
Food Security and Climate Change in West Asia

Ibrahim Ortas and Rattan Lal

Abstract The population of West Asia was merely 51 millions in 1950, and progressively increased to 232 million in 2010 and is projected to increase to 560 million by 2050, with an average growth rate of 2.1 % per annum. The rapid increase in population will increase pressure on the finite soil resources, which are also being converted to other uses. The problem of the imbalance between population and food will be confounded by the projected climate change. Because of the geographical location and other drivers prevalent in many West Asian countries the climate varies from arid and semi-arid, temperature from moderate to high, precipitation from low to scarce, and soils moderately to severely depleted of their organic carbon and plant nutrient reserves. Both water and wind erosion and salinity are the major types of land degradation. The problems of food scarcity and degradation of natural resources in the West Asia region are apparent in the regional and global political, legislative and social framework. The average grain yields have stagnated between 1980 and 2010. Agronomic yields of most food staples (i.e., maize, wheat, rice) and the corresponding rates of fertilizer use per ha are lower than those in developed countries. In addition to soils of low fertility, soil and crop management practices used are also inadequate. The biggest obstacle to advancing production in West Asia is the lack of agricultural inputs. Crop productivity in degraded soils can be greatly enhanced by using modern innovations such as soil biotechnology, useful soil organisms and integrated nutrient management (INM).

I. Ortas (✉)
Department of Soil Science and Plant Nutrition, Faculty of Agriculture,
University of Cukurova, Adana, Turkey
e-mail: iortas@cu.edu.tr

R. Lal
Carbon Management and Sequestration Center, School of Environment
and Natural Resources, The Ohio State University, 2021 Coffey Road,
422B Kottman Hall, Columbus, OH 43210, USA

M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_12,

Keywords West Asia • Food security • Food production and consumption • Climate change • Land use • Soil degradation • Science in agriculture and climate change

12.1 Introduction

12.1.1 West Asia

The West Asia region comprises of fifteen countries including Bahrain, Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, Turkey, United Arab Emirates (UAE), West Bank and Gaza, and Yemen, and represents ecologically and economically diverse group. These countries are characterized by large differences in land area, natural resources endowment, population, income, and level of socio-economic development. The main source of income of those countries, apart from the oil producing Gulf countries, is agriculture and the related industry. All countries are located in the arid and semi-arid climates, with more than 70 % of the region being arid (UNEP/WMO 1991). The climate is characterized by low, unpredictable, and variable rainfall, and by high evaporation rates. Most of the rainfall occurs during winter, and early spring. There is high rainfall variability, making it difficult to plan for rain-fed agricultural activities (UNEP/WMO 1991).

The West Asia region has several environmental priorities and concerns. The major problem limiting agricultural production is soil degradation, desertification, and deforestation (Table 12.1). The region has a wide range of diverse crops such as wheat, barley (*Hordeum vulgare*), forage legumes and fruit trees. However, the productivity of these crops is affected by the severe depletion of natural resources. Because of the drought, there is a large yield gap between the wheat (*Triticum aestivum*) grain yield in rain-fed and irrigated systems.

West Asian countries have diverse income which is characterized by high, middle and low income countries, and with highly diversified economies including agriculture, manufacturing and several service sectors. For example, Israel is among the most innovative countries in agriculture and high-technology manufacturing. Some countries have also benefitted from the spill-over effects of the high income of the wealthier fossil-fuel-producing countries to import food (e.g., Yemen, Afghanistan and Armenia) and find it difficult to get sufficient income for food.

Countries in West Asia differ widely in land area, natural resources, population, income, and level of socio-economic development. However, the crop productivity is low in the entire region. Apart from natural environments characterized by harsh climate and fragile soils, anthropogenic activities are also significantly affecting climate change in West Asia. Important among these activities are land misuse, and soil mismanagement leading to excessive exploitation of the soil, over grazing, and large deforestations. These issues of human dimensions are the major causes and the principal reasons of the widespread problems of degraded soils and impoverished people. Thus, examples of adverse effects of climate changes on food security are conspicuously observed in many countries of West Asia and the Middle East regions.

Table 12.1 General characteristic of the West Asia region

Agriculture	Cereal-based production system involving wheat, barley, chickpea (*Cicer arietinum*), maize (*Zea mays*) faba bean (*Vicia faba*), lentil (*Lens culinaris*), melon (*Momordica charantia*), sunflower (*Helianthus annuus*), sesame (*Sesamum indicum*) and fruit trees
Forestry	1 % of world forestry
Livestock	Sheep, goats, cow and camel
Soil type	Xerosols, Lithosols, Cambisols
Soil fertility	Low soil organic matter (SOM), low N and P, High pH, Zn and Fe deficiency, high $CaCO_3$
Soil limitations	Variable texture, depth, slope, and stoniness
Climate	Arid and semi arid climate, low precipitation, high temperature
Soil problems	Water and wind erosion, salinization, chemical pollution
General education level	Low and intermediary
Economic situation	For many Gulf countries depends on oil production
Technology production and use	Limited

The aim of this chapter is to identify and suggest appropriate strategies of advancing food security in the West Asia region. The specific objective is to assess the potential adverse effects of climate change on soil fertility, crop yields, and food supply. The overall goals of this chapter are to:

(a) Describe the general situation in West Asia, about population, land and food supply and their temporal trends,
(b) Assess the potential adverse effects of climate change on land use, soil fertility, crop yields, and food supply,
(c) Identify some options of increasing agronomic yield and advance food security in the West Asia region, and
(d) Evaluate the role of fertilizer use in agricultural development in the West Asian countries in term of food security and climate change.

12.1.2 Population Growth

The population of West Asia was merely 51 millions in 1950 and progressively increased to 58 million in 1960, 166 million in 1990 and 232 million by 2010 (Table 12.2). The population of West Asia is projected to increase to 277 million in 2020 and 400 million by 2050 at an annual growth rate of 2.2 % between 2005 and 2020. Countries like Turkey and Iran have the largest population. Several countries (e.g., Afghanistan, Qatar, Syria, UAE, Yemen) have annual growth rates exceeding 2.5 %. Population growth of the region was estimated with two different projections for 2010 and 2050 (Table 12.2). In another projection, the population growth ratio in the region will be 1.1 by the year 2050. Thus, the rate of urbanization in West Asia is high. In the countryside, the growth rate is high and income is low.

Table 12.2 Population growth and estimation with projection of year 2050 for West Asia

Years	Population (million)	Ratio for 2010	Estimated ratio for 2050
1961	58.6	4.0	6.8
1970	74.6	3.1	5.3
1980	99.7	2.3	4.0
1990	167.0	1.4	2.4
2000	184.5	1.3	2.1
2010	234.1	–	1.7
2020	277.5	–	1.7
2030	320.4	–	1.4
2040	360.2	–	1.2
2050	395.9	–	1.1

Source and calculated from FAOSTAT 2011

Table 12.3 Yield (kg ha^{-1}) of wheat in West Asia and other regions (FAOSTAT 2011)

	1961	1970	1980	1990	2000	2005	2009
World	1,088.9	1,494.1	1,855.4	2,561.2	2,718.6	2,852.7	3,038.8
Africa	692.9	870.3	1,098.8	1,598.1	1,752.5	2,111.8	2,543.8
Americas	1,298.1	1,870.6	1,981	2,411.2	2,666.6	2,744.6	2,772.4
Asia	748.6	1,112.9	1,612.2	2,384.2	2,590.6	2,684.4	2,957.3
West Asia	849.9	1,037.9	1,674.7	2,112	2,065.7	2,196.7	2,463.4
Europe	1,256.2	1,734	2,189.1	3,086.7	3,321.4	3,496.2	3,741.3
Oceania	1,156.9	1,241.4	981.8	1,647.9	1,839.8	2,040.1	1,626.7

12.1.3 Crop Yield

Wheat is a strategic food crop in West Asia. Between 1961 and 2009, the yield of cereals in the region increased three times. The wheat grain yield increased three times from 850 kg ha^{-1} in the early 1960s to more than 2,463 kg ha^{-1} in 2009 (Table 12.3). The yield of wheat in West Asia is among the lowest in the world.

Although wheat is the food staple in West Asia, the area under wheat production has not increased over the last five decades. The area under wheat was 10.86 million ha (Mha) in 1961 compared with 12.15 Mha in 2009 (Table 12.4). Total production, a product of the area and yield, has also stagnated since 1961 (Tables 12.3 and 12.4).

Data in Table 12.5 show that yield of several crops has increased since 1960s. The yield increased rather slowly between 1960 and 1970, and increased at a relatively higher rate between 1980 and 1990. However grain yield has not increased since 1990. Despite some increase in total production of wheat and other crops (Table 12.5), the supply is lagging behind the demand in several regions and is exacerbating the food insecurity. With the projected increase in population, the food demand in the region is likely to increase drastically. Wheat and maize are the staple food grains of West Asia. Yet, grain yield of these staples in the West Asia region is lower than that of the world average. The global average cereal yield was

Table 12.4 Total area under wheat cultivation in West Asia and other regions of the world (FAOSTAT 2011, Mha)

	1961	1970	1980	1990	2000	2005	2009
World	204.2	208.0	237.3	231.3	215.4	219.7	225.6
Africa	7.39	9.28	8.12	8.57	8.14	9.96	10.23
Americas	39.12	30.64	50.07	52.74	41.58	38.87	39.13
Asia	61.18	68.95	80.05	85.17	98.25	98.81	101.63
West Asia	10.86	11.93	12.18	13.00	13.62	15.28	12.15
Europe	90.50	92.52	87.65	75.53	55.28	59.62	61.08
Oceania	6.03	6.59	11.37	9.26	12.19	12.50	13.56

Table 12.5 Temporal trends in production of major crops between 1961 and 2007 in West Asia, (million Mg) (FAOSTAT 2011)

	1961	1970	1980	1990	2000	2007
Wheat	8.37	11.14	19.42	26.27	27.76	26.12
Barley	3.61	3.71	7.10	8.74	8.73	8.96
Maize	1.06	1.07	1.36	2.45	3.08	4.51
Cereals - Excluding Beer + (Total)	15.66	18.43	29.96	38.85	41.09	41.54
Cotton Lint	0.35	0.59	0.70	0.87	1.29	0.98
Fruits, Other	1.16	1.36	2.09	3.19	4.54	5.65
Tomatoes	1.60	2.49	5.10	8.25	13.03	14.57
Vegetables + (Total)	8.90	11.65	19.06	25.83	37.88	39.79
Vegetables, Other	6.77	8.31	12.70	15.69	21.91	22.53
Fruits – Excluding Wine + (Total)	6.82	9.55	12.23	15.49	19.51	22.34
Total	54.32	68.30	109.70	145.63	178.81	186.99

1,829 kg ha^{-1} in 1970 compared with 1,097 kg ha^{-1} in West Asia. The global average cereal yield in 2009 was 3,282 kg ha^{-1} compared with 2,135 kg ha^{-1} in West Asia (Table 12.6).

The data in Table 12.6 show that those countries which use agricultural inputs such as fertilizer, high quality of seed and irrigation have higher national average yields than those for the low income countries. Under the irrigation, using new genotypes and high level of fertilizer and other agrochemicals the attainable cereal yield can be 6,000–7,000 kg ha^{-1} in some countries such as Turkey, Iran and Israel.

12.1.4 Food Production in West Asia

Compared with Asia as a whole, total food production in West Asia is extremely low (Fig. 12.1). While the total food production is increasing in Asia, Africa, America, it is decreasing in Europe. However the rate of increase is rather low in West Asia, mainly because of changes in the land area under cereal production, slow rate of economic growth and low level of adoption of improved technologies.

Table 12.6 Temporal changes in the yields of cereals in West Asian countries (kg ha^{-1}) (FAOSTAT 2011)

Countries	1970	1980	1990	2000	2005
Afghanistan	1,105	1,349	1,201	806	179
Azerbaijan	0	0	0	2,335	2,593
Iran	885	1,067	1,445	1,833	2,300
Iraq	1,012	826	1,061	363	948
Israel	1,186	2,317	3,484	2,443	2,952
Jordan	226	933	122	1,726	1,525
Kuwait	2,000	3,188	3,653	2,324	2,753
Lebanon	933	1,169	1,878	2,415	2,698
Saudi Arabia	1,277	588	4,245	3,516	4,753
Syrian	347	142	750	1,149	1,711
Turkey	1,215	1,855	2,214	2,311	2,624
UAE	0	241	2,216	2,500	2,000
Yemen Rep.	781	1,016	908	1,085	713
Mean	1,097	1,336	2,107	1,908	2,135
World	1,829	2,306	2,882	3,064	3,282

Source: http://databank.worldbank.org/ddp/home.do?Step=3&id=4

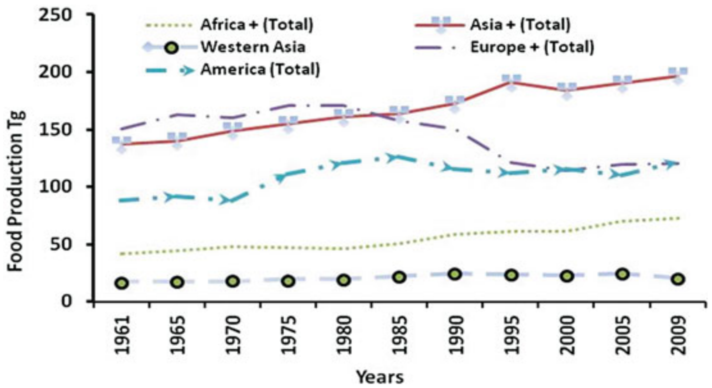


Fig. 12.1 Global trends in food production on continental basis (FAOSTAT 2011)

Despite these constraints, the food production can be strongly increased in some countries even with slow economic growth. Globally, food consumption has increased by about one-third since 1960 through use of improved agricultural technology. Since the population in West Asia is growing fast, the levels of food consumption is expected to be high. Because the production is lagging behind the demand in West Asia, there is a need for important policy interventions to address this issue.

The data in Fig. 12.1 shows that food production in West Asia has not significantly increased compared to Asia, America and Africa continents. The increasing trend in food production in West Asia mainly is seen in Turkey Iran and Israel.

Table 12.7 Total food and wheat import in West Asia between 1961 and 2007 (million Mg year^{-1}, FAOSTAT 2011)

	1961	1970	1980	1990	2000	2007
Wheat	2.1	3.4	3.5	7.7	11.1	15.5
Total food	5.7	9.6	19.6	33.3	57.6	87.9

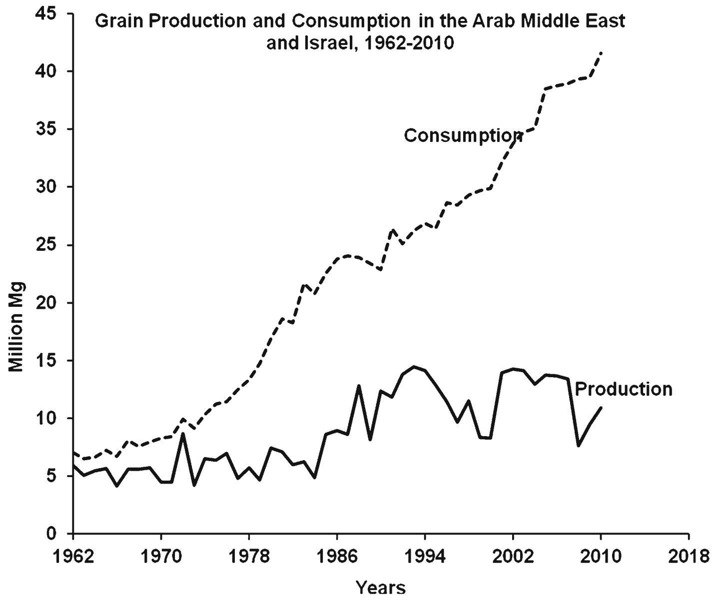


Fig. 12.2 Grain production and consumption in Middle East (Source: Earth Policy Institute - http://www.earth-policy.org/data_center/C24)

In contrast, production is low in Gulf countries. With the limited irrigation potential in arid and semi-arid climate, West Asia is unable to produce enough cereals to meet its own demand.

West Asia is highly dependent on agriculture for food security. The regions wheat import of 2.1 million Mg in 1961 increased to 15.5 million Mg in 2007. Total food import also increased several times. Total food import increased from 5.7 million Mg in 1961 to 87.9 million Mg in 2007 by a factor of 15 (Table 12.7). The food import in West Asia is projected to reach 100 million Mg per year by 2020.

The import of cereals may increase even more with climate change because of lower rainfall, low irrigation potential and high risks of drought and degradation.

The difference between production and consumption in West Asia has widened since 1960. By the year 2010, the difference between grain production and consumption increased to almost 30 million Mg in Middle East (Earth Policy Institute 2012) (Fig. 12.2). In most Middle Eastern countries, grain consumption far exceeds the production. The cereals trade balance in South and West Asia was −1,877 × 1,000 Mg

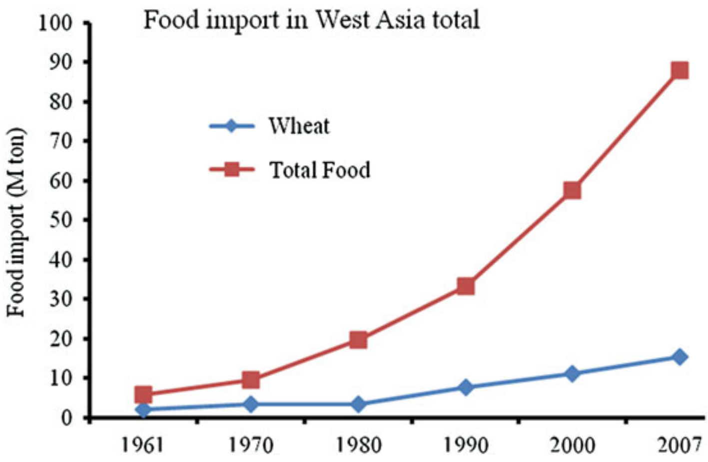


Fig. 12.3 Wheat and food import of West Asia between 1961 and 2007

Table 12.8 The difference between food import and export between 1961 and 2009 (US $ billion, FAOSTAT 2011)

	1961	1970	1980	1990	2000	2009
Food import (I)	2.1	3.3	7.8	10.5	18.7	26.7
Food export (E)	1.2	2.1	3.5	5.3	6.9	11.5
I–E	0.9	1.2	4.3	5.2	11.8	15.2

during 1996 compared with −8,300×1,000 Mg in 2004, and the gap is increasing every year. The data in Fig. 12.2 shows that dependency on food import is increasing in most countries of the region.

12.1.5 Agricultural Trade Deficits of West Asia

The food security in West Asia countries is strongly dependent on agriculture. Because of the increasing gap between demand and production, the food import is increasing (Fig. 12.3). There is a net deficit in favor of export and the gap between import and export has widened in many West Asia countries. Consequently, the food gap between import and export has widened between 1961 and 2009 (Table 12.8).

The trade deficit has persisted and widened. The differences between import and export were US$0.8 billion in 1961 has widened to US$ 15.2 billion in 2009. The food import is likely to increase because of increase in desertification coupled with the high population growth rates. Increase in urbanization is also accentuating the rate of deforestation.

Table 12.9 The relationship between production and population change from 1960 to 2000 compared with the year 2010 (Calculated from FAOSTAT 2011)

	1960	1970	1980	1990	2000
Total production change	3.20	2.67	1.77	1.34	1.14
Crop plants yield change	6.33	3.88	2.45	1.70	1.25
Population change	3.97	3.11	2.33	1.39	1.26

Table 12.10 Temporal changes in per capita food consumption (kcal/capita/day) between 1964 and 2030 (FAOSTAT 2011)

	1964–1966	1974–1976	1984–1986	1997–1999	2015	2030
World	2,358	2,435	2,655	2,803	2,940	3,050
Developing countries	2,054	2,152	2,450	2,681	2,850	2,980
West Asia	2,280	2,541	2,958	3,000	3,070	3,100
Industrial countries	2,947	3,065	3,206	3,380	3,440	3,500

http://www.fao.org/docrep/004/y3557e/y3557e15.htm#a3

The recent spike in food prices has encouraged some of the Gulf countries to invest in agricultural projects in other regions where land and water resources are in abundance. The goal is to equitably increase access to food with the increase in income, because poor people spend a higher proportion of their income on food. Poor people in even oil-rich countries are food insecure, because of low income. This overall food and agricultural trend has a complex picture which varies from one commodity to another and from one country to another. In countries with a high proportion of urban population, the food insecurity is high in population with low income.

12.1.6 Population Growth, Agronomic Yield and Food Security

The rate of population growth in the West Asia countries is higher than rest of the world. Differences in population growth rates among the developing countries in West Asia will persist until 2030. About 3.5 % of the world population lives in the West Asia and the annual rate of increase is 2.2 % compared with 1.5 % for the world. In contrast, the rate of food production is much less. According to FAO data in Table 12.9, from 1961 to 2010, total production in West Asia increased 3.2 times, crop yield 6.3 times and population 4 times Between 2000 and 2009, total food production in West Asia increased 1.1 times, crop yield 1.2 times, and population 1.3 times. It seems that still population growth change is over food production change. This relationship also depends on changes in consumption pattern.

The daily average per capita food energy intake is <2,500 kcal in many countries in the West Asia region, and is projected to increase by 1.3 % from 3,000 kcal in 1997–1999 to 3,100 kcal in 2030 (Table 12.10). In West Asia, the average per capita

Table 12.11 Temporal changes in total undernourished population in World and West Asia region (%) (FAO 2012)

Country groups	1990–1992	1995–1997	2000–2002	2006–2008
WORLD	16	14	14	13
Developing regions	20	17	17	15
Oceania	12	11	13	12
Africa	26	26	24	23
Asia	20	16	16	15
Western Asia	6	8	8	7
Armenia	45	36	28	21
Azerbaijan, Republic of	27	27	11	–
Jordan	–	5	5	–
Kuwait	20	5	6	5
Palestine, Occupied Tr.	10	10	15	21
Yemen	30	31	31	30

food consumption was 2,280–2,958 kcal per day between 1966 and 1986 and 3,000 kcal/capita/day since 1999 (Table 12.10). The actual food intake may be adversely affected by desertification and land degradation, including soil erosion (FAO/UNEP 1997).

The number of undernourished people in West Asia is high. FAO (2011) reported a high percentage of food insecure and undernourished population in Armenia and Yemen between 1990 and 2008 (Table 12.11). Many poor countries such as Yemen and Armenia do not grow enough food to be self-sufficient. Furthermore they not have sufficient money and income to import food for the poor people.

The data in Fig. 12.4 show that the number of undernourished people may increase by the year 2030 because of increase in population and the poverty. Therefore, the rate of decline in the number of under-nourished population between now and 2030 is expected to be low. Thus, a large proportion of population in the region will remain food insecure between 2015 and 2030. Consequently, the demand for food import will remain high.

12.1.7 Food Security and Sustainable Agriculture

In West Asia, the problem of food insecurity persists at the household or national level. Some West Asian countries (e.g., Afghanistan, Armenia, Yemen, Syria and Jordan) have no petrol reserves, and are poor compared with the other Gulf countries which have petrol to buy food. During the two decades ending in 2010, the West Asian cities have undergone the most radical transformation. The annual urban growth rate in the region was 4.2 % between 1990 and 1995 (UN-ESCWA 1994). Unemployment rate is high and income is low. An official unemployment rate in several countries in the region is ~11–15 % compared with the actual rate of >20 %.

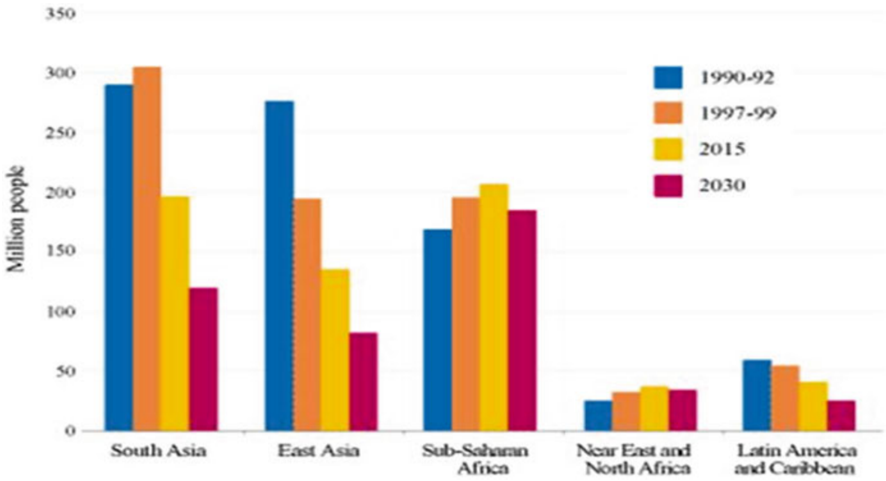


Fig. 12.4 Undernourished population in different region of world (Source: FAO data and projections (FAO 2012))

Achieving food security and improving the sustainability of food production systems under changing climatic conditions is a major challenge. Factors that influence sustainable food security include: levels of farmer education; and agricultural research and extension capacity. In general, adequate availability of food depends on efficient agricultural production. There are four sets of factors that influence agricultural productivity and availability:

- Soil factors: physical, chemical and biological properties of soil;
- Plant factors: species and the genetic variation that may exist within species;
- Climatic factors: temperature, water, solar radiation and carbon dioxide concentration; and
- Socioeconomic factors: price of agricultural inputs and produce, land tenure, social equity etc (Bender and Smith 1997).

12.2 Land Use and Land Use Change in West Asia

World agricultural production increased between 2.5 and 3 times over the last 50 years (Fig. 12.1, Table 12.3), while the cultivated area increased by only 12 %. Of the total land area of 714.9 Mha, arable land in West Asia was 68.1 Mha, in 1988 compared with 63.1 Mha in 2012. The actual cultivated land area was 74.7 Mha in 1988 and 70.7 Mha in 2012 (Table 12.12). It is estimated that between 1988 and 2012, 4.9 Mha of arable land and 3.9 Mha cultivated land were lost (Table 12.12). The loss of cultivated and arable land is more in the East Mediterranean countries such as Turkey, Syria. In Turkey cultivated area was 27.5 Mha in 1988 compared

Table 12.12 Land use in West Asian Countries (FAOSTAT 2011)

Countries	Total area (1,000 ha)	Arable land (000 ha) 1988–1992	Arable land (000 ha) 2008–2012	Cultivated area (000 ha) 1988–1992	Cultivated area (000 ha) 2008–2012
Afghanistan	65,223	7,910	7,793	8,030	7,910
Armenia	2,974	423	457.5	483	510.5
Azerbaijan	8,660	1,704	1,874	2,014	2,101
Bahrain	71	2	1	5	4
Iran	174,515	16,969	17,205	18,287	18,991
Iraq	43,832	5,770	4,500	6,070	4,750
Israel	2,207	347	304.3	432	382.6
Jordan	8,878	259.7	200.8	329.7	283
Kuwait	1,782	4	0	5	15
Lebanon	1,045	180	145	306	288
Palestinian	602	104	100	220	217
Oman	30,950	35	99	83	136
Qatar	1,159	12	12	14	15
Saudi Arabia	214,969	3,650	3,200	3,746	3,435
Syrian	18,518	4,766	4,670	5,554	5,664
Turkey	78,356	24,514	21,351	27,526	24,294
UAE	8,360	38	64	69	264
Yemen	52,797	1,378	1,171	1,481	1,452
West Asia	714,898	68,065.7	63,147.6	74,654.7	70,712.1

Table 12.13 Per capita land area in West Asia and the world

	Area per person (ha)		
	1950	2010	2050
Afghanistan	0.36	0.10	0.04
Iran	0.21	0.12	0.09
Iraq	0.43	0.10	0.05
Turkey	0.40	0.16	0.13
Yemen	0.21	0.03	0.02
World average	0.23	0.10	0.08

Note: 2010 data were used for 2050 projection. Database at http://esa.un.org/unpp, updated in 2009

with 24.3 Mha in 2012, with a loss of nearly 3.2 Mha. The per capita grain production area is also decreasing (Table 12.13) especially in countries with high rate of population growth such as Yemen and Afghanistan.

The per capita grain harvested area (ha) has decreased between 1950 and 2010, and will decrease more by 2050. Globally the per capita cultivated land area gradually declined from 0.44 ha to less than 0.25 ha. The rate of decline is much higher in West Asia' because of the high rate of population growth. Therefore, it is important to bridge the gap between the experimental and national average yield to sustain production in the face of a high population growth. Thus, sustainable intensification of agriculture is the only option.

Table 12.14 Area under different land uses in West Asia (FAOSTAT 2011)

	Area (Mha)			
	1961	1990	2000	2009
Land area	462.7	462.7	480.8	480.5
Agricultural area	173.9	214.7	274.6	272.8
Arable land	37.2	41.3	42.5	38.7
Forest area	–	13.6	17.8	18.9
Other land	–	234.8	188.4	188.8
Inland water	1.7	1.7	2.3	2.3

In Central Anatolian region of Turkey, where potential evaporation exceeds the precipitation during the year, and dry farming is extensively practiced, water and wind erosion are common, and proper application of water- and soil-conserving tillage technology is critical (Avci 2011). Since 1960, as the number of tractors in agriculture dramatically increased, soil tillage or plowing expanded and soil erosion increased. The changes in land use and mismanagement of agriculture as a result of human and other natural activities could have strong adverse impact on the environment. Above all, increasingly more and more agricultural land is used for non-agricultural purposes such as new shopping malls, industrial complex, motorways, and use of the top soil for brick making. Land degradation is also exacerbated by inappropriate subsidies, and rangelands have been converted into croplands. The use of conservation agricultural technologies is a high priority for the region (Avci 2011).

The problems of food scarcity and degradation of natural resources in the Western Asia region are also aggravated by the harsh climate, fragile soils, and global political, legislative and social framework. Because of supra-optimal temperatures, high concentrations of $CaCO_3$ and excessive heavy tillage, SOM decomposes rapidly and low soil fertility is rather common throughout the West Asia region.

12.2.1 Forest Potential of West Asia

Most countries in West Asia have limited forest resources, with only 3.2 % of the total areas under forest cover and < 1 % of the world's forest cover. Forest areas in West Asia increased between 1990 and 2009 (Table 12.14). The net rate of increase of forest was 0.5 Mha $year^{-1}$ between 1990 and 2000, compared with 0.1 Mha $year^{-1}$ between 2000 and 2010. This trend is likely to continue slowly except in the low-income and predominantly agricultural countries. Reforestation has increased in Turkey and many East Mediterranean countries. Iran and Turkey are the only countries practicing plantation forestry (Bashour 2006), and have the largest area under forest (FAO 2011). In countries with low forest cover (i.e., Jordan, Saudi Arabia, Iraq) area under forest is not likely to increase because of rapid urbanization and

Table 12.15 Total naturally and human induced land degradation in West Asia countries

Country	Total area	Land degradation				Land degradation due to agricultural activities				
		000 km^2	000 km^2	000 km^2	%	000 km^2	000 km^2	000 km^2	%	%
Afghanistan	641	127	54	181	28	4	0	4	2	1
Iran	1,623	674	282	956	58	35	38	73	8	4
Iraq	431	196	149	344	79	4	141	145	42	33
Israel	21	0	0	0	0	0	0	0	NA	0
Jordan	90	14	16	30	31	0	0	0	0	0
Kuwait	17	0	1	1	2	0	1	1	100	2
Lebanon	10	26	0	26	25	0	0	0	0	0
Oman	312	107	0	107	39	0	0	0	0	0
Qatar	12	0	0	0	0	0	0	0	NA	0
Saudi Arabia	1,954	660	142	802	33	0	0	0	0	0
Syria	187	78	33	112	60	8	33	41	37	22
Turkey	781	535	235	770	99	24	6	30	4	4
UAE	79	3	0	3	4	0	0	0	0	0
Yemen	421	217	0	217	45	0	0	0	0	0
West Asia total	6,579	2,637	912	3,549	36	75	219	294		5
World total	–	27,033	7,971	35,005	26	10,552	1,838	12,391	35	9

(http://www.fao.org/ag/agl/agll/terrastat/wsr.asp#terrastatdb)

constraints on agricultural expansion especially water scarcity. Extensive date plantations have improved the landscape and generated income in Kuwait, Israel, Jordan the United Arab Emirates (FAO 2011).

12.2.2 Land Degradation and Desertification in West Asia

Desertification is defined as land degradation in arid, semiarid and dry sub-humid areas due to climate variation and/or human activity (UNCCD 1994). It is a combined impact of human activities and drought. Land degradation is a common problem throughout the West Asian countries, resulting both from environmental factors and human induced misuse of land (Lal 2002). Abahussain et al. (2002) indicated that land degradation in the Arab countries is widespread and is accelerating. Nearly one third of West Asia land is affected by severe degradation (Table 12.15). The problem is severe in Saudi Arabia, Iraq, Iran, Syria, Turkey and some of the Gulf coast countries. The region on the whole is characterized by severe problems of accelerated erosion, nutrient imbalance, depletion of SOM and salinity.

The desertification in arid and semi-arid areas is caused by the long term occurrence of several causes. Principal causes include a combination of climate, high population growth rates and intensive agriculture. The specific desertification in the region includes vegetation degradation, wind and water erosion and soil salinization. Overgrazing and mismanagement of rangelands have reduced the natural plant cover throughout the region. Thus, deforestation is a major concern in the highlands of Yemen, Oman, Syria and Jordan where the area under forest has decreased.

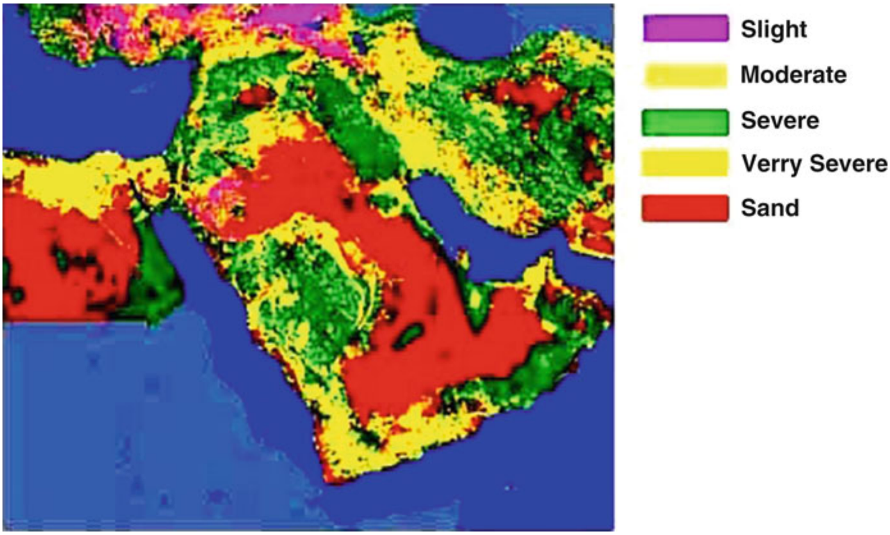


Fig. 12.5 Desertification map of West Asia (Harahsheh and Tateishi 2000)

Grazing, a principal cause of land degradation in the Middle East (Abahussain et al. 2002) has more than doubled in the past four decades, mainly because of subsidized feeding, provision of water points and mechanization. Thus, judicious management and appropriate policy interventions are very important.

The vegetation cover is characterized by low tolerance, low plant density and coverage, and low species variability and plant productivity per unit area in West Asia. Drought, overgrazing, uprooting of woody species for use as fuel, tillage, and mismanagement of water resources are the principal causes of rangeland deterioration. Shorbagy (1986) reported that more than 30 % of the grazing land in Saudi Arabia is degraded. The grazing intensity in most West Asian countries has more than doubled over the past four decades, mainly as a result of subsidized feeding, provision of water points and mechanization. Mass migration of population begins as a result of over grazing and land degradation. Principal animals in many West Asian countries are sheep, goat and camel exacerbate the over grazing. Consequently plant spices are removed and land degradation is accelerated.

Unsustainable irrigation practices, overgrazing, uncontrolled cultivation, wood gathering for fuel, salinity and water logging are the main factors that are contributing to the degradation of land area (Kanbour 2003). Harahsheh and Tateishi (2000) produced several maps of the Arabian peninsula regions showing land and vegetation degradation. Major land cover types in the studied area include 30 % (6,653,037 km^2) of desert or desert rangeland 32 % of sand or sand, dunes, 20 % of permanent pasture, and 8 % of arable land (Fig. 12.5).

Land degradation and desertification, continue to be the most significant environmental issues. On average 10 % of land area in Syria and nearly 100 % in Bahrain, Kuwait, Qatar and the United Arab Emirates are under desertification. Desertification has also affected wide areas of rangelands in Turkey, Iraq and Jordan.

Harahsheh and Tateishi (2000) reported that 6 % of land area in West Asia is slightly decertified, 21 % is moderately decertified, 31 % is severely decertified and 11 % is very severely decertified.

There has been a drastic change in soil and crop management systems. The nutrient removal by crops exceeds nutrient input in developing countries. El Hassan (2004) indicated that this region is also affected by severe sand dune movements that cause environmental degradation and resource depletion that threaten present and future economic growth. Solh et al. (2003) reported the high significance of dry lands biodiversity to agricultural production, other human needs, and environmental protection in West Asia.

12.2.3 Soil Erosion

Land degradation leads to a significant reduction in the productive capacity of soil. Soil erosion is a major factor in land degradation and has severe effects on quality and quantity of agronomic yields. The loss of topsoil by the degradation is accentuated by erosion. In addition to being a media for food production, soil is also an important moderator of climate. Accelerated soil erosion depletes soil fertility and increases emission of CO_2 and CH_4 from erosion –induced transport of SOM (Lal 2003). The direct loss of agricultural land is most acute in Jordan, Iraq, Lebanon, the Syrian Arab Republic, and Yemen, where fertile land is scarce and concentrated in the narrow coastal strip and river valleys (ESCWA 1995).

Lack of data on land cover/use and soil biogeochemistry in arid steppe and grassland environments limits understanding of soil degradation at landscape scales, and constrains assessment of how national land use and agro-economic policies affect soils on the ground (Conant and Paustian 2004).

Nearly 55 % of West Asia is affected by moderate to severe soil erosion, which represents about 3.58 million km^2. Losses of its topsoil material from 50 to 150 Mg ha^{-1} $year^{-1}$ are common. Soil degradation is a national problem in Turkey (Cangir et al. 2000). The vegetation degradation has the same range of importance as soil erosion, in fact 50 % of land area is subject to moderate to severe vegetation degradation. Harahsheh and Tateishi (2000) reported that about 40 % of West Asia land area is under severe and very severe vegetation degradation, followed by that under wind erosion process (27 % severe and very severe wind erosion).

12.2.4 Soil Salinity

Salinity is a common problem in the area where evapotranspiration exceeds rainfall. Dry land salinity, mainly due to high evaporation, is another serious problem, particularly in the low-lying parts of West Asia. Because of aridity, irrigated land is prone to salinization. Further, salinization is increased because the irrigation water contains appreciable level of soluble salts. In the South Part of Anatolia-Turkey salinized land area increased from 5,500 ha, to 7,400, 11,000, 15,000 and 18,000 ha

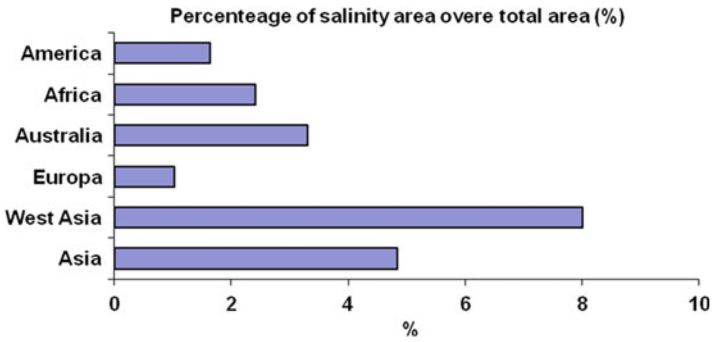


Fig. 12.6 Percentage of saline area in several continents (Produced from FAOSTAT 2011 data)

in 1987, 1997, 2000, 2004 and 2010, respectively (Cullu et al. 2010). Similarly, (Abul-Gasim and Babiker 1998) reported that in Iraq, salinity and water logging have affected 8.5 Mha or 64 % of the total arable land, while 20–30 % of irrigated land has been abandoned due to salinization.

Harahsheh and Tateishi (2000) reported that salinization, which is the most important cause of degradation in irrigated soils, has affected about 42.5 % of the desert area in West Asia. Saline soils cover up to 22 % of the arable land in West Asia, ranging from none in Lebanon to 55–60 % in Kuwait and Bahrain. The data for Yemen show that the average annual rate of cultivated land abandoned due to soil degradation has increased from 0.6 % in 1970–1980 to about 7 % in 1980–1984 (CAMRE et al. 1996). The largest % (8 %) of the total land area affected by salinization anywhere in the world is in West Asia (Fig. 12.6).

In Turkey,(Cullu 2003) used GIS and remote sensing to estimate the effect of salinity on crop yield The results showed that increasing EC values up to 14.4 dS m^{-1} caused decreases in yield of cotton (*Gossipium hirsutum*) and wheat. Increases in salinity above the threshold EC values from 9.2 dS m^{-1} to 13.4 dS m^{-1} decreased cotton and wheat yields by 29.6 % and 35.4 %, respectively.

12.2.5 Depletion of Soil Organic Matter and Soil Fertility Decline

Most of the soil of Western Asia region has low SOM ranging from 1 % to 2 % (USDA 2007). Thus, SOM concentration has a strong influence on soil fertility and yield. The low soil organic carbon (SOC) stock and poor soil fertility are attributed to harsh climate and soils of low inherent fertility. The severe depletion of SOC is attributed to extractive farming practices and mismanagement of soil and crops. Appropriate use of organic and inorganic fertilizers and adoption of techniques which enhance water use efficiency can accentuate food production, while mitigating climate change by sequestering atmospheric CO_2 in agro ecosystems.

Soil degradation processes lead to decline in soil structure, compaction and accelerated runoff and erosion, reduction in soil biotic activity, leaching of nutrient and serious depletion of soil fertility. The stock of SOC plays a key role in the global C cycle and strongly impacts soil biological fertility. The SOC stock is reduced by excessive tillage (Lal 1989). In the rain fed cereal belt crop rotation, incorporation of nitrogen fixing plant species in the rotation cycle increases SOM concentration (Ryan et al. 1997).

A major effect of climate change in the West Asia region may be the depletion of the SOC stock and soil fertility. The rate of depletion of SOC depends on soil and crop management. Ryan et al. (2009) observed seasonal changes in SOC under Syrian conditions decreasing from 1.48 % in February to 1.15 % in August after cropping. Soil degradation processes caused by low use of organic and inorganic fertilizers reduce SOC stocks. In contrast, judicious use of fertilizers can increase the biomass and SOC (Ortas and Lal 2012). Long-term fallowing and melon cultivation increased SOM concentration from 1.08 % to 1.13 %. The highest SOM concentrations were observed when forage legumes were included in the rotations: vetch (1.21 %) and medic (1.32 %).

Decline in soil structure leading to compaction and accelerated runoff and erosion, leads to reduction in soil biological quality, and depletion of soil fertility (Ortaş 2006). Consequently, the agronomic yield is decreased over time. Thus, it is important to improve the fertilizer use and efficiency in order to advance food security and achieve land stabilization. It takes a long time to increase SOC concentration because of high temperatures and unfavorable soil characteristics. Agricultural practices including the use of organic and inorganic fertilizers have a significant effect on SOC. Increase in SOC stock also have significant contribution on yield increase and soil quality. Kanchikerimath and Singh (2001) indicated that increase by 1 Mg ha^{-1} of SOC stock of degraded soils may increase crop yield by 20–40 kg ha^{-1} for wheat, 10–20 kg ha^{-1} for maize, and 0.5–1 kg ha^{-1} for cowpeas.

Hartemink et al. (2008) indicated that soil fertility in tropical regions is affected by rapid land cover changes .Both natural and human induced deforestation as well as agricultural intensification have caused a significant decline in soil fertility. Severe decline in soil fertility is a serious global issues, and it has reduced global agricultural productivity by 13 % over the last 50 years (Shiklomanov 2000). In many countries of the WANA region, net nutrient depletion due to soil degradation or over exploitation of cultivation ranges from 30 to 100 kg NPK ha^{-1} $year^{-1}$ because of the extractive farming practices (Cakmak 2002). The loss of soil fertility is a major concern in the West Asia region.

12.2.6 Water Scarcity and Water Use in Agriculture in West Asia

Water scarcity is a major problem in West Asia, is also one of the major limiting factor in crop production. Water requirements for all sectors are met mainly from

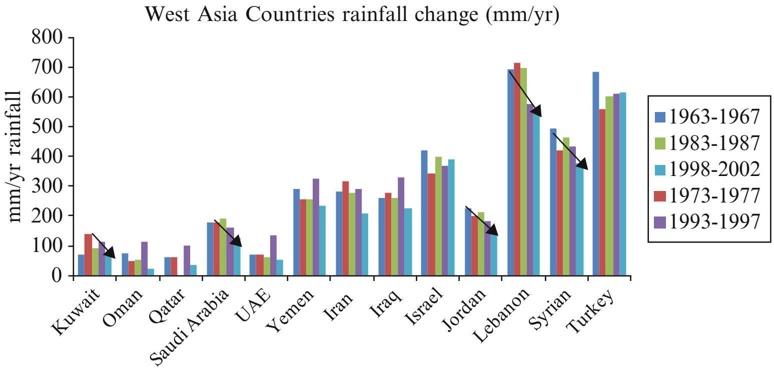


Fig. 12.7 Rainfall for the West Asia countries from 1963 to 2002 (Produced from FAO 2011 data)

river flow, but ground water is also used for irrigation and drinking. The major problem associated with the management of renewable water, particularly rivers, is its trans boundary nature. Agricultural production mainly depends on rainfall and rainfed cropping predominantly involves cereals and legumes. The cropping season commences with the onset of rains when soil has little or no residual moisture because of the long dry seasons.

The region receives only 1 % of the world precipitation and <1 % of its renewable water resources. Harahsheh and Tateishi (2000) indicated that 5 % of the agricultural area in Middle East are under irrigation. The per capita water availability in the region is projected to fall by 50 % by 2050 (Bank 2012). Karam (2010) indicated that in Lebanon an average rainfall decline over the past 50 years ranges from 285 to 150 mm, corresponding to about a 25 % decrease in annual rainfall. Many Mediterranean countries are facing water resource scarcity due to its arid to semi-arid conditions, aggravated by recent climatic changes. The climate change significantly affects both surface and ground water resources and consequently the yield of many crops is reduced. Majority of water is used for agriculture and domestic use, and a little for industrial use. According to FAO (2009), around 75 % of the water in the West Asia region is used in agriculture (irrigation), 4.3 % for Industrial and 19.5 % for domestic needs.

Most areas of the West Asia where rainfall is limiting are characterized by low agricultural output (Ryan 2008). Given the harsh climatic conditions in areas such as West Asia, where less than 10 % of the land area is amenable to rainfed cropping. . However, rainfall is decreasing in West Asia, especially in East Mediterranean countries such as Jordan, Lebanon, Syria and Turkey (Fig. 12.7). More than 72 % of countries in the Arabian Peninsula receive annual rainfall of <100 mm (El Hassan 2004). The water demand for irrigation in arid and semi-arid regions will increase by at least 10 % with increase in temperature by 1 °C (Fischer et al. 2002; Liu 2002).

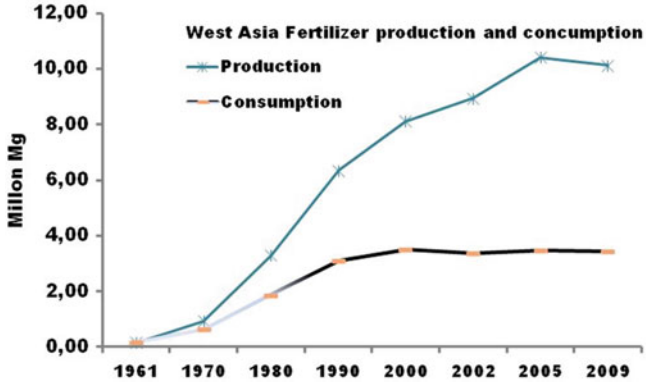


Fig. 12.8 Fertilizer production and consumption in the West Asia region (Produced from FAOSTAT 2011)

12.2.7 Fertilizer Consumption in West Asia

Total fertilizer consumption increased by 3.5 % year^{-1} between 2008 and 2012, and will increase by 2.2 % year^{-1} between 2010 and 2014. The expected annual average increase in fertilizer consumption in the sub region in the next 5 years is: 4.5 % for N, 1.5 % for P and 2.3 % for K. The demand for NPK is expected to grow by 1.4 %, 2.9 % and 7.7 %, respectively during the same period (FAO 2011). In many Asian countries, the fertilizer use is unbalanced in favor of N. Ryan et al. (2012) indicated that in soils of the Mediterranean-type climate, the rate of fertilizer is low but has increased rapidly over the past few decades.

There is a large contrast in fertilizer usage per unit area in the region: from 9.8 kg ha^{-1} in Yemen to 255 kg ha^{-1} in Qatar. Because of the widening gap between food production and demand, there is a growing demand for fertilizer use in the West Asia region.

Appropriate agricultural operations (i.e., fertilizers and other inputs), land use, and ecosystems are important factors affecting vulnerability to climate change and risks of food insecurity. Improving soil fertility and increasing fertilizer use are essential to advance global food security.

The data in Fig. 12.8 shows that West Asian countries produce more fertilizer than they consume. The overall fertilizer production in West Asian countries in 2002 was about 8.2 million Mg of which 2.9 million Mg were used locally and about 5 million Mg were exported to other countries. In 2009, the production was 10.3 million Mg and consumption was 3.4 million Mg. Turkey and Iran are the major fertilizer consumers. Yet, the average rate of fertilizer use is lower than the global average. Probably because of low availability of water for irrigation. With increasing use of drip irrigation, more soluble fertilizer is used in Israel, Jordan and Turkey.

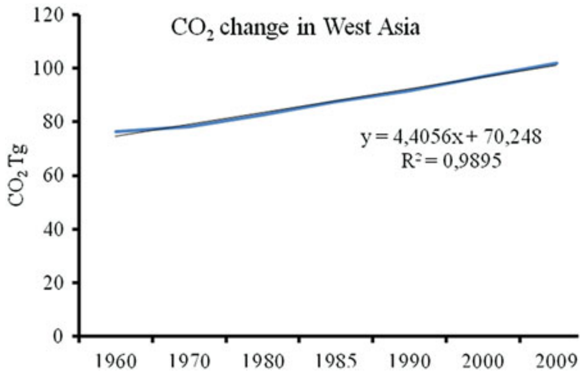


Fig. 12.9 CO_2 production change in West Asia from 1960 to 2009. (http://data.worldbank.org/indicator/EN.ATM.CO2E.PC/countries)

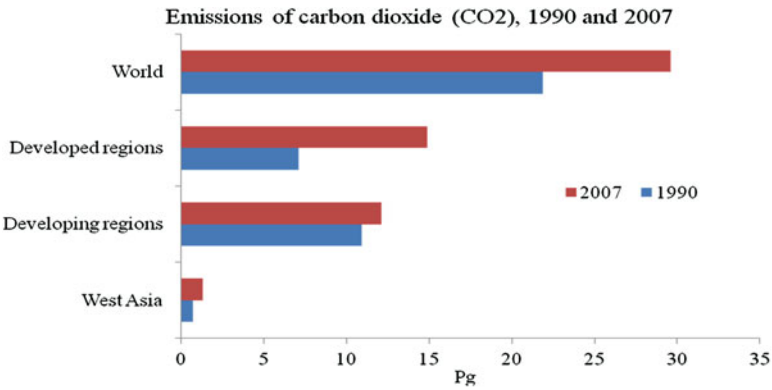


Fig. 12.10 CO_2 emission in the world and West Asia (Data of FAOSTAT 2011 used)

12.2.8 Carbon and CO_2 Emission

Global emissions of carbon dioxide (CO_2) in 2009 increased by 5.05 % compared with 2000. The per capita emissions remain the highest in the oil producer and industrial countries. Among the West Asian countries, Iran, Saudi Arabia, Azerbaijan, Israel and Turkey are the largest CO_2 emissitters. The data in Fig. 12.9 indicate a linear increase in emission between 1960 and 2009 from 76 Tg CO_2 emissions in 1960, 101.9 Tg CO_2 in 2009.

While advancing food security, SOC sequestration also has the potential to offset fossil fuel emissions by 0.4–1.2 Pg C $year^{-1}$ or 5–15 % of the global fossil-fuel emissions (Lal 2004; Rusinamhodzi et al. 2011). In West Asia, emissions of CO_2 increased from 0.7 Gt in 1999 to 1.3 Gt in 2007 (Fig. 12.10).

12.3 Climate Change and Food Security

12.3.1 Sustainable Agriculture and Climate Change

The increases in world population along with the use of modern technologies that disregard inherent ability of natural resources will aggravate risks of degradation and desertification. Because of the close relationship between climate and the soil; changes in climate can alter soil quality and agronomic productivity. Improved systems of soil management and adoption of best management practices (BMPs) to improve agriculture in West Asia are integral to mitigating climate change. Inappropriate use of technologies might enrich radiatively active gases such as CO_2, and CH_4 which have direct effect on climate change.

Adaptation to climate change may alter the choice of crop types, nutrient cycling by changing SOC dynamics and elemental cycling. Sustainable management of natural resources is the key to both mitigation of emissions and adaptation to changing climate. Unsustainable exploitation of soil, land and water also degrades ecosystem, depletes nutrient reserves and reduces net primary production.

The terrestrial life depends on water, C and nutrient cycles. The integrity of these cycles determines the resilience of ecosystems. Since there is a strong relationship between the C cycle and climate change, agricultural production depends on manipulating parts of these cycles. Over the last 150 years, mainly through loss of SOC, land-use change and burning of fossil fuels have greatly disturbed the global C cycle and this has been responsible for about one-third of the increase in atmospheric CO_2. Land-use change has caused significant increases in the emissions of CO_2 and CH_4 into the atmosphere.

Climate change could influence food security, by altering availability and supply systems through direct and indirect effects on agricultural production, and interrelationships among several ecosystems factors such as quality of soil and water resources.

Agricultural sustainability involves maintaining and enhancing soil nutrient reserves, increasing SOC concentration and stock above the threshold level by technological interventions which do not depend on fossil fuels (petrol, fertilizer and agrochemical), and those which do not cause serious adverse environmental impacts (i.e., large emissions of greenhouse gases, polluting water, and degrading air quality).

12.3.2 Land Degradation and Food Demand

West Asia is one of the fragile area in terms of soil degradation and food insecurity. With increasing world population and increasing food demand, and pressure on agricultural land have increased. There is an overlap of long-term changes in climate and human activities. With the rising population and, therefore, growth in use of the limited natural resources, intensity of interface with ecosystems by human activities have rapidly grown, leading to severe degradation of vegetation, soil and water resources.

Population growth and other demographic changes have led to losses of land to urbanization, industrialization and non-agricultural purposes. Agricultural use is directly related with environmental issues because of sensitive equilibrium between water, air and soil. Availability of food will be critically affected by desertification. Food security, poverty and desertification are strongly interlinked. Desertification is directly linked with climate change, which in turn is linked with poverty and consequently with the migration of population to urban areas.

12.3.3 Food Security

Food security is closely linked to sustainability of agricultural production. At present, food security, as influenced by agricultural sustainability under the conditions of changing climate, is an issue of global importance. Thus, the food price is getting expensive and affecting food security. Some oil-reach countries (i.e., Kuwait, Saudi Arabia and UEA) are in search of land elsewhere for agricultural production. Food security of West Asia countries depends heavily on land use and management. Compared with the rest of the world, there is less data availability about land use, management, water and fertilizer use. The data are rather scanty about soil, water, climate and agriculture production. The research information is also scarce about better prediction to advance food security in a changing climate.

Food security is now being threatened by climate change which will have many complex positive and negative effects. While the atmospheric CO_2 increase can bring advantages in some crops (i.e., wheat and rice) thereby boosting yields, but disadvantages in others by the effects of higher temperatures and more variable rainfall and extreme weather conditions. Uncertainties in climate can adversely affect food production globally and in West Asia. Production from dry land agriculture is constrained due to the limitations of soil fertility, drought and mismanagement.

Agricultural sector is also a significant contributor to greenhouse gas emissions, but can also be a major sink of atmospheric CO_2. The SOC stock is a dynamic and an integral part of the global C cycle (Lal 2010). Thus, agriculture in general and agricultural soils in particular must be integral to any strategy of mitigation of greenhouse gases. There is a strong need to implement research at the national and international levels to assess the global perspective, highlight major knowledge gaps on the impacts of climate change on food production and security in a global context, and implement appropriate policies. It is widely recognized that the relative costs of reducing greenhouse gas emission is low for different agricultural options. Palm et al. (2010) reported that in sub-Saharan Africa, achieving food security and reducing greenhouse gas emissions require use of mineral fertilizers to spare land for reforestation.

12.3.4 Food Production and Biomass Production

Photosynthesis based biomass production is important for sustainable food security. The sustainability and economics of the biomass production are also important to sequestering SOC and improving soil quality. Biomass production depends on soil fertility and water availability. Photosynthesis base biomass (food) production is important for CO_2 fixing and protecting soil quality. Since SOC is based on humification of biomass produced by photosynthesis, it is important to increase the biomass for sustainable food security of all living organisms.

Productivity of food plants (e.g., amount of biomass) depends on the followings:

- The capacity of plants to fix atmospheric C into biomass through photosynthesis, and capacity of plant for C fixation depends on mineral nutrients.
- Translocation of the carbohydrates from source into sink organs, and then transferred into soil as humus and formation of stable soil aggregates.

Both steps are strongly influenced by soil-plant-atmosphere continuum. Soil degradation, and the increasing atmospheric CO_2 level, can increase temperature and cause water deficiency and reduce the agronomic yield over time. A modeling study indicated that increase in air temperature of 2–3 °C by 2070 can reduce yield of wheat and maize by 4–17 %, and increase the water demand (Aydin et al. 2011). Crop yields declined between 1990 and 2010 in many countries of West Asia (i.e., Iran, Turkey, Saudi Arabia, Iraq,) primarily because of increase in frequency of extreme events and irregular and highly variable precipitation. (Nogués-Bravo et al. 2007)reported that predicted temperature increase beyond 3 °C in most regions is likely to have very adverse impacts on agriculture, water resources, ecosystem production and human health (Hitz and Smith 2004). Also it has been predicted that in West Asia, climate change scenarios predict a decrease of over 170,000 km^2 in viable rain-fed agriculture land by the end of the twenty-first century.

12.4 Future Directions for Sustainable Agriculture and Food Security

12.4.1 Integrated Soil, Water and Crop Management

In Western Asia, soils are affected by serious wind and water erosion. The severity of soil erosion is extremely high in the entire region. Accelerated soil erosion affects directly the vegetation cover, and it is the main cause for vegetation degradation. Thus, there must be increase in focus on re-vegetation and natural regeneration, using organic and inorganic fertilizers and use of an integrated soil and crop technology in order to protect the ecosystems and increase food security.

Reduction of losses by erosion, moderation of temperature and humidity regimes, and addition of biomass through retention of residues from previous crops in rotation can increase stocks of SOC and soil total N (STN) with the use of conservation agriculture (Sainju et al. 2008). Conservation agriculture systems which involve reduction of tillage and leave residues of previous crops on the soil tend to enhance SOC and STN stocks (Ortas and Lal 2012), and improve other chemical, physical and biological characteristics of the soil.

Continued high demographic pressure, unbalanced use of nutrients, low water use efficiency, soil erosion, degradation and poor health, changes in pest/disease patterns, etc. would further aggravate the situation. Climate change predictions in this area indicate that the frequency of dry years will likely increase in the future. Improved technology include promoting an efficient use of land and water, adopting new genotypes, and growing xerophytic and salt tolerant new species along with the new technology.

In many semi-arid areas of the West Asia, the majority of people still depend on local agriculture for food and/or livelihoods. However, the potential of local resources to support further increases in production is limited. The existing agricultural technological conditions such as irrigation, using fertilizer and other inputs are not sufficient to produce as much as is demanded by the growing population. Fertilizer and water use are the major sources which must be efficiently managed. Because the fertilizer use is expensive and crop yields are low, there is a growing need for judicious management of soil fertility and cropping systems following a holistic approach involving new crop breeding and improved cultivars, conservation tillage, rotations for increasing the production while improving soil quality for advancing food security. The use of irrigation has considerably increased crop yields in the area, but surface and ground water resources are severely limited. Applied research has shown that nutrient management with soil specific fertigation can enhance crop yield.

Despite the technological advances (i.e., use of, biotechnology and nanotechnology to develop new varieties, multi-nutrients fertilizer, drip and fertigation systems used in agriculture), environment and climate remain the key factors affecting sustainable agricultural productivity. For example, food production in Turkey was drastically reduced during the early 2000s primarily because of low precipitation and severe drought. Principal yield determinants in the West Asia region are water deficit and drought, high temperatures, and low SOC concentration and stock. Being principal determinants of plant productivity, more attention must be given to identifying soil-specific sustainable agronomic practices. Specifically for the West Asia region, there is an urgent need to develop integrated soil and crop management systems not only to increase food production per unit area but also to advance food security for the coming generations. Use of science-based technology is important to increasing agronomic production. Israel is a good example in the Middle East of using precision farming, drip irrigation, fertigation, and INM to obtain high yields even in the arid environments.

A judicious use of fertilizer is essential to increasing food production in West Asia. High agronomic yields and use of cover crop is also essential to building to building of soil organic carbon pool adaptation to and mitigation of climate change. Thus, increase in the use of mineral fertilizers in the developing countries is inevitable for enhancing food production. However, the use efficiency of fertilizer and water can be increased by promoting the adoption of fertigation. The latter has both economic and ecologic advantages and low ecological footprint. The rate of fertilizer use must be decided on the basis of soil and plant analyses. Achieving food security implies sustainable management of nutrients, water and soil. In this context, the beneficial effects of organic fertilizers and organisms/biodiversity on soil quality cannot be over emphasized for improving the quality of nutrient-deficit and degraded soils of West Asia.

Arresting land degradation should be one of the first steps to increase food production. Needs of local farmers and producers for food, fiber, energy sources must be adequately met within their income status in order to stop desertification. Use of innovative indigenous practices can contribute to integrated management of soil and crop. Site specific experiences, success stories and lessons learned from the previous interventions must be replicated in the entire region.

Enhancing water harvesting recycling, use of micro and macro fauna to improve soil physical properties in relation to water retention and conservation in the root zone, promoting transfer of improved technology for agriculture and ecosystem sustainability, enhancing use efficiency of water and fertilizer through education and community participation, using municipal wastes as an organic material in depredated area to improve soil quality and sequester carbon in agro ecosystems and creating new technology for using wastewater as source of water and nutrients are some of the options available for enhancing food production and food security.

Restoration of degraded lands, should preferably be done by using native plant species adapted to the region. Thus, managing soil biodiversity may be an important tool for biological nitrogen fixation and using mycorrhizae. These options of managing native biological resources may be crucial to improving soil, water and biological resources of the West Asia region. Furthermore, water and fertilizer use efficiency can be increased by drip irrigation, fertigation, partial root dry technique are very important inputs for atmospheric CO_2 mitigation and food production. In this connection, the followings are important considerations:

- Crop residue management and mulching
- Soil organic matter management
- Irrigation and fertilizer management
- Grazing management, and
- Conservation tillage and its variance including no tillage and reduced tillage used in conjunction with diverse rotation and integrated nutrient management.

12.4.2 Contribution of Innovative Technologies to Food Security

The current state of agricultural technology seems to be insufficient for the West Asia region. Innovative technologies (i.e., modern agriculture mechanization, organic and chemical fertilizers, new variants of seed and biotechnology-nanotechnology) must be promoted throughout the West Asia. The technology transfer is expensive and many countries depend on the developed countries for agricultural technology.

Science and technology can make a major contribution, by providing practical solutions to sustainable agriculture and food security. Beddington (2010) postulated that we need a new, 'greener revolution'. Despite the green revelation in the 1960s and biotechnological applications in the 1980s, crop yields have stagnated even with several folds increase in the fertilizer use. Because there is no additional land available that can be brought under cultivation, new and innovative scientific techniques must be applied to improve the use efficiency of water and fertilizers while simultaneously increasing the crop yields.

Important areas for focus include: crop improvement; smarter use of water and fertilizers; new pesticides and their effective management to avoid the resistance problems; introduction of novel non-chemical approaches to crop protection; reduction of post-harvest losses; and more sustainable livestock and marine production (Beddington 2010). Ryan (2008) indicated that the future challenge in soil fertility-crop nutrition lies as much in overcoming obstacles to technology transfer as in the generation of new knowledge. Evolving scientific, technological, economic and political solutions to address the climate change and food security the region is of high priority.

Plant species selection and breeding programme should explicitly consider the climate change impacts. Incorporation of indigenous and local plants in improvement of the germplasm and development of new cultivars from indigenous species in relation to the specific environment, promoting measures to adapt to climate change by addressing problems such as water deficiency, soil erosion, and droughts would assist to advance adaptation to climate change. Strengthening of research on wild plant and fruit tree cultivation, development of new crop varieties for tolerant to drought, and expansion of agro-forestry and reforestation with native species would provide opportunities to reduce the impact of climate change.

12.4.3 Policy Development, Extension and Education

The future outlook for agriculture and forests will depend on diversification of the economy, which in turn will depend on political stability, institutional development and investment in human resources. State policies are also important in the region. It has been indicated that a reduction in subsidies for high-input agriculture in dry areas of Saudi Arabia, has resulted in a shift of agriculture to areas with a more favorable climate, including forested zones and resulting in severe deforestation.

A number of non-fossil-fuel-producing, low-income countries will continue to depend on agriculture and animal husbandry as a main source of livelihood. Thus, country such as Jordan, Israel, Lebanon and Turkey are providing more subsides for agricultural production.

(a) Assist farmers adapt their agricultural systems to changing climate conditions,
(b) Strengthen national capacities to manage degradation and droughts and production shortfalls,
(c) Provide effective safety networks for the poor against low soil fertility and high risks of droughts.

Within this context, ensuring food security in West Asia region requires that governments give high priority to policies and investments towards:

- Agriculture and forestry sectors at all levels.
- Land use policy to enhance social and gender equity,
- Creating and promoting strong organization as links between local communities, government agencies and scientific bodies.
- Providing technology and policy choices for advancing food security, and
- Strengthening institutions.

Creating training opportunities especially in soil-productivity improvement through farmers' participation, strengthen education for protection of wild life from agricultural management, promoting a holistic approach to management of agro ecosystems while protecting the environment, and educating the community to pro-actively management the impacts of climate change and food security is necessary.

References

Abahussain AA, Abdu AS, Al-Zubari WK, El-Deen NA, Abdul-Raheem M (2002) Desertification in the Arab region: analysis of current status and trends. J Arid Environ 51:521–545

Abul-Gasim S, Babiker M (1998) Iraq's food security: the sand dunes fixation project. Desertification Control Bull 33:2–10

Avci M (2011) Conservation tillage in Turkish dryland research. Agron Sustain Dev 31:299–307

Aydin M, Yano T, Koriyama M, Haraguchi T (2011) Impacts of climate change on crop growth and soil-water balance in Çukurova region. In: Ok SS, Arcak S, Cayci G (eds) Prof. Dr. Nuri Munsuz soil science and water symposium. Ankara, Turkey, pp 129–136

Bank TW (2012) World development report 2012: gender equality and development. http://publications.worldbank.org/index.php?main_page=product_info&cPath=0&products_id=24225

Bashour L (2006) Forestry Outlook Study for West and Central Asia (FOWECA) thematic paper. Land use dynamics and Institutional changes in West Asia. FAO, Rome

Beddington J (2010) Food security: contributions from science to a new and greener revolution. Philos Trans R Soc B 365:61–71

Bender W, Smith M (1997) Population, food, and nutrition. Popul Bull 51:2

Cakmak I (2002) Plant nutrition research: priorities to meet human needs for food in sustainable ways. Plant Soil 247:3–24

CAMRE, UNEP, ACSAD (1996) State of desertification in the Arab region and the ways and means to deal with it. Arab Centre for Studies on Dry Areas and Arid Lands, Damascus

Cangir C, Kapur S, Boyraz D, Akca E, Eswaran H (2000) An assessment of land resource consumption in relation to land degradation in Turkey. J Soil Water Conserv 55:253–259

Conant RT, Paustian K (2004) Grassland management activity data: current sources and future needs. Environ Manage 33:467–473

Cullu MA (2003) Estimation of the effect of soil salinity on crop yield using remote sensing and geographic information system. Turk J Agric For 27:25–28

Cullu MA, Aydemir S, Qadir M, Almaca A, Ozturkmen AR, Bilgic A, Agca N (2010) Implication of groundwater fluctuation on the seasonal salt dynamic in the Harran plain, South-Eastern Turkey. Irrig Drain 59:465–476

Earth Policy Institute (2012) http://www.fao.org/hunger/en/

El Hassan IM (2004) Desertification monitoring using remote sensing technology. In: International conference on water resources & arid environment, Kingdom of Saudi Arabia

ESCWA (1995) Survey of economic and social developments in the ESCWA Region 1995. United Nations Publication, New York, Sales No. E.96.II.L.18

FAO (2009) FAO data yearbook 2009. Food and Agriculture Organization of the United Nations, Rome, http://www.fao.org/statistics/en/

FAO (2011) Food and Agriculture Organization of the United Nations, Rome, Italy. http://www.fao.org/

FAO (2012) FAO statistical yearbook. Food and Agriculture Organization of the United Nations, Rome, http://www.fao.org/docrep/015/i2490e/i2490e00.htm

FAOSTAT (2011) http://faostat.fao.org/site/339/default.aspx

FAO/UNEP (1977) Assessing soil degradation. FAO Soils Bull 34, FAO, Rome, Italy

Fischer G, Shah M, van Velthuizen H (2002) Climate change and agricultural vulnerability. A special report, prepared by the International Institute for Applied Systems Analysis under United Nations Institutional Contract Agreement No. 1113 on "Climate Change and Agricultural Vulnerability" as a contribution to the World Summit on Sustainable Development, Johannesburg, Publications Department, Printed by Rema*print*, Vienna

Harahsheh H, Tateishi R (2000) Environmental GIS database and desertification mapping of West Asia. Paper presented at the workshop of the Asian region thematic programme network on desertification monitoring and assessment, Tokyo, p 15

Hartemink AE, Veldkamp T, Bai ZG (2008) Land cover change and soil fertility decline in tropical regions. Turk J Agric For 32:195–213

Hitz S, Smith J (2004) Estimating global impacts from climate change. Global Environ Change 14:201–218

Kanbour F (2003) The international convention on desertification: the preservation of indigenous technologies in Arab countries of West Asia. A.A Balkema Publishers, Leiden, pp 375–379

Kanchikerimath M, Singh D (2001) Soil organic matter and biological properties after 26 years of maize-wheat-cowpea cropping as affected by manure and fertilization in a Cambisol in semiarid region of India. Agr Ecosyst Environ 86:155–162

Karam F (2010) Strategic planning for water resources management and agricultural development for drought mitigation in Lebanon. In: International conference on food security and climate change in dry areas, Amman, Jordan

Lal R (1989) Conservation tillage for sustainable agriculture - tropics versus temperate environments. Adv Agron 42:85–197

Lal R (2002) Soil carbon sequestration in China through agricultural intensification, and restoration of degraded and desertified ecosystems. Land Degrad Dev 13:469–478

Lal R (2003) Global potential of soil carbon sequestration to mitigate the greenhouse effect. Crit Rev Plant Sci 22:151–184

Lal R (2004) Soil carbon sequestration impacts on global climate change and food security. Science 304:1623–1627

Lal R (2010) Managing soils and ecosystems for mitigating anthropogenic carbon emissions and advancing global food security. Bioscience 60:708–721

Liu CZ (2002) Suggestion on water resources in China corresponding with global climate change. China Water Resour 2:36–37

Nogués-Bravo D, Araujo MB, Errea MP, Martínez-Rica JP (2007) Exposure of global mountain systems to climate warming during the 21st century. Global Environ Change 17:420–428

Ortaş I (2006) Soil biological degradation. In: Lal R (ed) Encyclopedia of soil science. Marcel Dekker, New York, pp 264–267

Ortas I, Lal R (2012) Long-Term phosphorus application impacts on aggregate-associated carbon and nitrogen sequestration in a vertisol in the Mediterranean Turkey. Soil Sci 177:241–250

Palm CA, Smukler SM, Sullivan CC, Mutuo PK, Nyadzi GI, Walsh MG (2010) Identifying potential synergies and trade-offs for meeting food security and climate change objectives in sub-Saharan Africa. Proc Natl Acad Sci USA 107:19661–19666

Rusinamhodzi L, Corbeels M, van Wijk MT, Rufino MC, Nyamangara J, Giller KE (2011) A meta-analysis of long-term effects of conservation agriculture on maize grain yield under rain-fed conditions. Agron Sustain Dev 31:657–673

Ryan J (2008) Crop nutrients for sustainable agricultural production in the drought-stressed Mediterranean region. J Agric Sci Technol 10:295–306
Ryan J, Masri S, Garabet S, Harris HC (1997) Changes in organic matter and nitrogen with a cereal-legume rotation trial. In: Ryan J (ed) Accomplishments and future challenges in dryland soil fertility research in the Mediterranean area. ICARDA, Aleppo
Ryan J, Masri S, Singh M (2009) Seasonal changes in soil organic matter and biomass and labile forms of carbon as influenced by crop rotations. Commun Soil Sci Plan 40:188–199
Ryan J, Sommer R, Ibrikci H (2012) Fertilizer best management practices: a perspective from the dryland West Asia-North Africa region. J Agron Crop Sci 198:57–67
Sainju UM, Senwo ZN, Nyakatawa EZ, Tazisong IA, Reddy KC (2008) Soil carbon and nitrogen sequestration as affected by long-term tillage, cropping systems, and nitrogen fertilizer sources. Agric Ecosys Environ 127:234–240
Shiklomanov IA (2000) Appraisal and assessment of world water resources. Water Int 25:11–32
Shorbagy MA (1986) Desertification of natural rangelands in the Arab world, 4, 68, 83. ACSAD, Damascus
Solh M, Amri A, Ngaido T, Valkoun J (2003) Policy and education reform needs for conservation of dryland biodiversity. J Arid Environ 54:5–13
UNCCD (1994) Status of ratification and entry into force. United Nations Convention to Combat Desertification, Paris
UNEP/WMO (1991) Scientific assessment of ozone depletion. WMO, Geneva
UN-ESCWA (1994) Desertification in the Arab countries (FAO/RONE). In: JCEDAR meeting of the Arab experts on 'Sustainable agricultural and rural development in the Arab countries', Cairo
USDA (2007) Soil organic carbon map. http://soils.usda.gov/use/worldsoils/mapindex/soc.html

Part IV
Mitigation and Adaptation Options for Different Agroeconomic Sectors in WANA

Chapter 13
Mitigation and Adaptation Options for Rainfed Agriculture in West Asia and North Africa

Awni Taimeh

Abstract Climatic change and land degradation are the most serious threats affecting the sustainability of land resources in West Asia and North Africa (WANA) region. Mitigation or adaptation interventions should be implemented using database on climate and climatic variation, characterization of local climatic changes, rainfall variability, drought occurrence and probability of extreme weather events, impacts on food production and security, and health of rural communities. Technologies for improving rainfed farming need to focus on optimizing the use of water runoff, innovative soil moisture conservation practices, developing new cropping system, management practices adapted to new temperature and moisture regime, innovative packages for production of high cash crops suitable for small holdings and tolerant to moisture and temperature stresses, conservation of agro-biodiversity, and low cost and energy efficient-farming system. Governments are called to establish national system to implement drought mitigation strategy that covers disaster risk management and treat it as top national priority. Plans to help farmers to endure extreme events should be among sustained institutional national policy. Emergency plan to provide aid to rural farmers during such events should help them to stay on their farms and avoid forced migration and accelerating land degradation. Improving farmer's livelihood under stress conditions may be achieved by adopting broad base food security strategy integrating rainfed sector with others such as livestock in order to increase products' added values and obtain better return.

Keywords Climate change impacts • Carbon sequestration • Institutional policy options • Farmer livelihoods

---

A. Taimeh (✉)
The University of Jordan, Amman, Jordan
e-mail: ataimeh@ju.edu.jo

M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_13,

13.1 Background

West Asia and North Africa (WANA) region is rated as the second highest population growth rates in the world. In the early 1960's, the total population was 200 million people, and it is projected to approach 930 million by the year 2020 (El-Beltagy 1999). Water poverty is widespread in this region with many countries are already below the water poverty line, and suffer from associated environmental degradation and social problems. The average annual per capita renewable supplies of water is now below 1,500 m^3, well below the world average of about 7,000 m^3 (World Water Council 2002). This level has fallen from 3,500 m^3 in 1960 and is expected to fall to <700 m^3 by the year 2025. In 1990, only 8 of the 23 WANA countries had per capita water availability of >1,000 m^3 (Margat and Vallae 1999). The situation of water scarcity is predicted to worsen significantly over the next 25 years.

The region's area is about 1.7 billion ha, of which, 7.5 % of the total land resources is arable land (FAO 2005) Irrigated area covers about (22 % of arable lands) 27 mha of 119 mha, and contributes to >50 % of agricultural production. Almost 35–50 % of area cultivated with crops is irrigated, and agriculture consumes about 75 % of water resources (Lal 2002). Renewable water resources exceeds 50 % in some countries (Egypt, Syria, Tunisia), or 100 %, in Jordan where wastewater reuse has rapidly increased (Hamdy and Lacirignola 1998, 2002). With rapid industrialization, urbanization, and population growth (double the world average), economic realities seem certain to reallocate water increasingly away from agriculture to other sectors. Agricultural production in this region is highly variable due to unpredictable rainfall and periodic droughts. The dominant climate is Mediterranean arid and semi-arid climate. Rainfall is erratic in space and time. Permanent pastures and rangelands cover about 30 %, and only 14 % of the land area is suitable for rainfed cropping (Casass 1999). Soil degradation and water scarcity characterizes much of the region and an estimated 45 % of the total area of irrigated and rainfed arable land together with rangelands is subjected to some degree of land degradation. This is also coupled with losses of valuable source of genetic materials needed for future germplasm enhancement. This region is the home of enormous number of wild races and their relatives. Unfortunately this rich biodiversity is increasingly lost by agricultural expansion, degradation and overgrazing (ICARDA 2003).

Agriculture represents the most important sector in WANA region, in social terms, as it still mobilizes an average of 42 % of the labor force. The socioeconomic importance of the agricultural sector has rapidly declined in the last three decades and is still decreasing (ICARDA 2003).

Low productivity also is a major concern. Production of rainfed wheat in WANA region reveals large yield gap with farmers' yields being a factor of 2–4 lower than achievable yields for major rainfed crops grown in Asia and Africa (Rockström et al. 2007).

The region comprises extreme diversity from some of the poorest and most malnourished developing countries to some of the richest (WHO 2000). About 40 %

of the total population lives in rural areas, 70 % of the poor population found, in rural areas, suffers from increasing droughts and desertification.

The region suffers from several developmental problems such as poverty, lack of gainful livelihoods, shortage of water, droughts and desertification, high population growth, wide spread agriculture and rangeland degradation. Climate in this region is projected to become warmer and drier with reduced crop productivity, about 35 % of total cropped area in the region was under irrigation (ICARDA 2003; El-Beltagy 1999). Land fragmentation (1.7 ha of arable land per capita) is expected to be <0.6 ha in 2025. In the higher rainfall areas receiving more than 400 mm, intensification poses the least risk of desertification, although soil erosion on slopes and hilly land is a persistent problem. The threat of desertification is greatest in the zone lying approximately between the 100 and 400 mm rainfall isohyets (Dregne 1992). This area represents about 80 % of the land area outside the hyper-arid desert environments of WANA. The area most threatened with desertification represents two distinct land use patterns lying approximately between the 200 and 400 mm rainfall isohyets is an area traditionally used for extensive cereal cultivation combined with animal production (Rockström et al. 2007). Areas threatened with desertification largely use cereal cultivation. Much of the estimated 9 % increase in total WANA annual cropped area has occurred in these marginal agricultural environments (Lal 2000, 2002).

13.2 Climate Change Impact on WANA Region

13.2.1 General Regional Impacts

The majority of drylands, in WANA region, are dominated by rangelands which occupies 828 mha. Marginal rainfed areas and rangelands provide less than 10 % of the agricultural production. Barley is the main crop. Such areas will become affected by more frequent droughts, increased evapotranspiration, changes in rainfall patterns. FAO's report on State of Food Insecurity in the World (FAO 2010) estimated that a total of 37 million people are undernourished in the Near East and North Africa; and climate change may further aggravate the food insecurity situation in this region.

According to IPCC regional assessment, temperature is expected to increase by 2–2.5 °C by 2050, and general decrease in annual precipitation by 10.5 %, but up to 30–40 % in Morocco, Saudi Arabia, Yemen and UAE (IPCC 2000).

13.2.2 Specific Regional Impacts

According to IPPC predictions (IPCC 2007a), climate change is expected to have the following regional impacts:

13.2.2.1 Africa

Mediterranean Africa is likely to experience as much as 20 % drying, hotter summer temperatures, decreased precipitation, increased likelihood of summer droughts, more frequent droughts. Agricultural production will be severely compromised due to loss of land, shorter growing seasons and more uncertainty about what and when to plant. Yields from rainfed crops could be halved in some countries by 2100. Threats of inundation for coastal deltas, such as the Nile, and degradation of marine ecosystems and other physical and ecosystem changes, deforestation, degradation and increase in forest fires, grassland degradation, with widespread drying, and desertification are expected (World Bank 2005a). Due to more frequent droughts and heat waves, rainfed yields will become less reliable, and average yields are expected to fall by 20 % for the region and nearly 40 % in Algeria and Morocco (World Bank 2005b).

13.2.2.2 Asia

Crop yield will decrease in many areas and will put many millions of Asians at risk from hunger. Water stress will affect more than 100 million people due to reduction of freshwater availability, land degradation, and desertification may increase due to reduced soil moisture and increased evapotranspiration. Grassland productivity is expected to decline by as much as 40–90 %, with a temperature increase of 2–3 °C, combined with reduced precipitation in the semi-arid and, arid regions.

13.3 Role of Agriculture in WANA

Agriculture plays a key role in economic development (World Bank 2007) and poverty reduction (Irz and Roe 2000). For example, it has been shown that every 1 % increase in agricultural, yields translate into a 0.6–1.2 % decrease in the absolute poverty (Thirtle et al. 2002).

Agriculture plays a significant role in climate change. Cost-effective reductions in greenhouse gases can be achieved by better managing agricultural soils, rangelands, and forests, improving the efficiency of fertilizer use, restoring degraded agricultural lands and rangelands, and improving ruminants' digestion through better feed.

The need for developing agriculture also steams from the steady increase of demand for food and feed products. The region is the highest in level of imports of food grain globally. Demand will rise while regional production will be increasingly affected by water scarcity, and increasing challenges to maintain crop productivity in the face of shifts and variability in environmental conditions, limited water resources to expand land under irrigation, lack of necessary infrastructure to convey water on a large scale, and the need to face increasing variability of rainfed yields as environmental conditions continue to change (World Resource Institute 2010).

Rangelands cover 828 mha in WANA region (Lal 2002). Accordingly, it has been suggested that drylands may have good potential to sequester carbon (Scurlock and Hall 1998). Lal indicated that the amount of carbon that is contained in the soil of this region is significant on a global basis (Lal 2000, 2002).

13.3.1 Role of Rainfed Agriculture (RA)

Rainfed agriculture plays a crucial role in achieving food security and will continue to play an important role in global food production as 80 % of agriculture production is rainfed, which contributes about 58 % to the global food basket (FAO 2002b). The FAO foresees that the contribution to global food supply from rainfed areas will decline from 65 % today, to 48 % in 2030 (Bruinsma 2003). Seckler et al. (1999) are less optimistic concerning the potential of rainfed areas. They foresee that only 5 % of the increase in future grain production will come from rainfed agriculture, while the major part will originate from irrigated areas.

The significance of Rainfed Agriculture (RA), however, varies regionally, but most food for poor or communities in the developing countries is produced under rainfed conditions (Rockstrom et al. 2007). In sub-Saharan Africa, more than 95 % of the farmed land is rainfed, while the corresponding figures for East Asia are 65 % and for the Near East, and 75 % for North Africa (FAOSTAT 2005). In addition, rainfed areas are also the hot-spots of poverty, malnutrition, water scarcity, severe land degradation, and poor physical and financial infrastructure. The proportion of RA has risen over time, in response to the limited opportunities for expanding the area under irrigation, and the steady increase of demand for food and feed products. The majority of poor people in the world are dependent on RA for food and income and thus livelihood security (FAO 2002b). The importance of rainfed sources of food weighs disproportionately on women, given that approximately 70 % of the world's poor are women (WHO 2000).

Rainfed agriculture is a risky business due to high spatial and temporal variability of rainfall (Barron et al. 2003). Current yields generally is < 1/2 of those of the irrigated areas (Wani et al. 2004). Investments in RA have been very small, and mainly targeted to soil conservation rather than water harvesting (Rockstrom et al. 2007), or due to the fact that farmers are less likely to invest in inputs and land management due to the high risk of crop failure. Harvesting scarce rain water from a larger unproductive area to a smaller area where commercially viable crops, shrubs and trees can be grown under normally prohibitive amounts of annual rainfall (Wani et al. 2004).

The adoption of supplementary irrigation, i.e., the addition of a limited amount of water to otherwise rainfed crops during water stress periods and critical plant growth stages, has been shown to increase the water productivity under dryland conditions when water is available (Oweis et al. 2005). High rainwater use efficiency in RA, however, cannot be achieved by water management alone, because yield is limited by other factors. Since production is dependent on low and extremely variable rainfall, productivity is low and unstable (Barron et al. 2003). Weak farmers and community participation, unstable governmental policies, incentives and investment directed toward irrigated areas because of higher returns, poor RA lobby to influence decision makers, weak extension systems and ineffective dissemination of new technology, weak seed production, and delivery systems for improved crop varieties are among constraints affecting RA in WANA region. Other biophysical, socioeconomic, and policy and institutional factors prevent rainfed agriculture from reaching its full potential (Barron et al. 2003; Rockstrom et al. 2007).

13.3.1.1 Why Should We Invest in Improving RA

As indicated earlier, the contribution to global food supply from RA will decline from 65 % today to 48 % in 2030 (Bruinsma 2003). It is estimated that only 5 % of the increase in future grain production will come from RA (Seckler and Amarasinghe 2000).

Those countries which rely primarily on RA production, and have limited opportunities to bring land under irrigation, will face increasing challenges to maintain crop productivity in the face of shifts and variability in environmental conditions (FAO 2010).

Moreover, RA is the life line for most small and marginal farmers in many countries in WANA region. There are compelling reasons to invest in upgrading RA. Among these reasons: many rural poor depend on RA rather than irrigated agriculture. Targeting the poor implies focusing on smallholders in rainfed areas, investment costs per ha to upgrade rainfed areas tend to be relatively low, particularly where most rural poor live in rainfed areas, more poor persons are lifted out of poverty by focusing investment to rainfed areas rather than irrigated agriculture. Interest in RA had risen in response to the limited opportunities for expanding irrigated areas (Seckler and Amarasinghe 2000). There is good potential to improve harvests and output per unit of rainwater since yield of rainfed wheat in WANA yield being a factor of 2–4 lower than achievable yields in Asia and Africa (Rockström et al. 2007) Current yields in many rainfed settings are low, suggesting that there is good potential to improve harvests and output per unit of rainwater.

13.4 Mitigation Options for RA in WANA Region

Mitigation of climatic change is a human intervention aimed at reducing the sources, or enhancing the sinks of greenhouse gases (IPCC 2007a).

IPCC strategies (IPCC 2007a) for mitigating climatic changes suggested to focus on the following areas:(a) Increasing carbon stocks in agro-ecosystems, (b) Improving N-use efficiency and reducing nitrous oxide emissions, (c) Improving water-use efficiency, and (d) Promoting increased C-sequestration through improved management. IPCC strategy also identified research components to be given attention.

In principle, mitigation for agriculture in dry region should: (1) Ensure efficient use and application of fertilizers through, for example, precision agriculture, (2) Conserve ecosystems to reduce CO_2 emissions, from forests, wetland areas, etc., (3) Promote conservation tillage, agro-forestry, and rehabilitation of degraded crop and pasture land, (4) Reduce practices of "Slash and Burn" especially in range land areas as well to crop residue burning, (5) Monitor seasonal variability and integrate improvement and rehabilitation of rangeland for the benefits and improvement of livestock production, (6) Improve nutrition and genetics of ruminant livestock, technologies for manure, and conversions of emissions into biogas, and (7) Adopt livestock production technologies that reduce GHG.

According to FAO, in general, a comprehensive drought mitigation action plan implies adopting of the following six components (FAO 2002a): (a) Drought resilience policies, (b) Early warning and monitoring systems, (c) Drought contingency planning, (d) Drought mitigation measures, (e) Relief measures, and (f) Rehabilitation measures.

Governance and policies also play a crucial role in the success of any mitigation efforts. Policies should provide environmentally effective policies, measures and instruments, and financial incentives to: increase forest area, reduce deforestation, maintain and manage forests, land-use regulation and enforcement while introducing regulation for improving land management, maintaining soil carbon content, and efficient use of fertilizers and irrigation water.

13.4.1 Carbon-Sequestration Potential and Mitigation Opportunities WANA Region

Soils of WANA can sequester 200–400 Tg C year^{-1} or 20 % of the global dry land ecosystems. Soils of WANA have lost 6–12 Pg C. A sink capacity could be 3–7 Pg C or 0.2–0.4 Pg C year^{-1} through remedial interventions to control or reverse desertification (Lal 2002).

Generally, there are numerous technologies that are available for mitigating climatic changes and relevant to WANA region. These technologies include: (a) Improved crop and grazing land management to increase soil carbon storage, (b) Restoration of cultivated soils and degraded lands, (c) Improved nitrogen fertilizer application techniques, (d) Improved energy efficiency, (e) Mulch farming, (f) Conservation tillage, (g) Cover cropping and recycling of bio-solids, (h) Energy crops to replace fossil fuel use (i) Afforestation, forest management, reduction of deforestation, (j) Forest products for bio-energy to replace fossil fuel use, and (k) Land-use change (Lal 2001, 2002, 2003). Examples of such technologies examined in this region and in other areas with similar conditions indicated that legume-based systems, particularly with pigeonpea, could sequester 330 kg C up to 150 cm depth in Vertisols. Investment in degraded land, and options to increase the investments payment for environmental services, are among these technologies (Adeel et al. 2007).

Conservation agriculture (CA) had been cited as one of the technologies to be adopted for reducing CO_2 emission (FAO 2002a; Dumanski et al. 2006). It has been successfully applied in many parts of the world and is proposed as a practice for carbon sequestration in soils (Lal 2002). Others indicated that over the last 20 years conservation agriculture can function in 270–358 mm rainfall (Mrabet et al. 2003), but it did not show any significant benefits in area receiving around 330 mm rainfall (Pala et al. 2000). These results showed that conservation tillage practices are profitable only in terms of energy and conservation of soil.

On the positive side, legume-based cropping systems that are gradually replacing cereal–fallow systems in drylands generally have reduced carbon and nitrogen losses compared with conventional nitrogen-fertilized systems (Drinkwater et al. 1998; Jenkinson et al. 1999). Others indicated that emissions of nitrous oxides from legumes are likely to be small in dry aerobic environments, conversion of unproductive croplands and grasslands to agro-forestry to soak up maximum amounts of atmospheric carbon of 3 t of carbon per hectare per year. Additional emissions of nitrous oxides from legumes are likely to be small in dry aerobic environments (Sprent 1987).

Technologies to reduce vulnerability to climatic changes include preventing and reversing land degradation, sequestering carbon in dry lands (mitigation), maintaining vegetative cover, grazing management, water management and salinity control, mulching and residue management, soil fertility management, crop rotations, improved fallows, and shrub, halophyte and forestry plantations (Lal 2001, 2002, 2003).

13.5 Adaptation

According to Intergovernmental Panel on Climate Change (IPCC 2007a), adaptation to climatic change is defined as “An adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities”.

FAO (2008b) distinguished three types of adaptations: Anticipatory adaptation (referred to as proactive adaptation), Autonomous adaptation (referred to as spontaneous adaptation) and Planned adaptation (referred to as adaptation that is the result of a deliberate policy decision)

Adaptation strategy should minimize the potential impacts of extreme events, climate variability and climate change. It should include measures that lead to real development, adaptation to short-term climate variability and extreme events, and a step towards reducing vulnerability (IPCC 2007c) to longer-term climate change that covers adaptation, at all levels, ranging from local to national, and international levels.

The most effective adaptation approaches in developing countries, as highlighted in the UN Framework Convention on Climate Change (UNFCCC 2011), are those addressing a combination of environmental stresses. Strategies need to link with coordinated efforts aimed at alleviating poverty, enhancing food security and water availability, combating land degradation and soil erosion, reducing loss of biological diversity and ecosystem services as well as improving adaptive capacity and improving the food production chain within the framework of sustainable development, social inequalities, lack of access to resources such as credit, education and decision-making that affects people's ability to adapt.

Mitigation and adaptation should also be treated within the framework of sustainable development planning within any country, and that addressing climate change should be considered an integral element of sustainable development policies. However, it is worth noting that climate change and other sustainable development policies are often, but not always, synergistic. There is growing evidence that policy decisions about macroeconomic and agricultural policies, which are often treated as being apart from climate policy, can significantly reduce emissions. For example, reducing both loss of natural habitat and deforestation can have significant biodiversity, soil and water conservation benefits, and can be implemented in a socially and economically sustainable manner. Moreover, making development more sustainable can enhance both mitigative and adaptive capacity, and reduce emissions and vulnerability to climate change. Synergies between mitigation and adaptation can also exist, for example, land management.

The Fourth Assessment Report of the IPCC on climatic change released in 2007 (IPCC 2007a), suggested several adaptation strategies to deal with projected climatic changes which include: changing crop varieties; enhancing more efficient water use; appropriate scheduling of cropping activities; adoption of more effective pest, disease and weed management practices and insurance, and making better use of seasonal climate forecasts to reduce production risks. While IPCC AR4 report (IPCC 2007c) focused on climate change, future impacts, and potential adaptation strategies, the main determinant of agricultural production is still the seasonal variation of temperature, precipitation, and sunshine, etc. droughts, floods, frost-freezes, and heat waves stress both crops and livestock. It is the changing frequency of these events due to climate change that is the main concern.

Rainfed agriculture in the WANA region can employ several available measures to cope with future climate change (Oweis et al. 2001) such as: changing planting dates, crop diversification, developing new drought and heat-resistant varieties, intercropping, sustained fertilizer and tillage management practices, improved crop residue and weed management; use of water harvesting techniques, better pest and disease control for crops, and mulching. Attempts to help the rural poor adapt to climatic change must involve three elements, preparing for harsh climates by developing various types of insurances, coping with the stress when it happens, adapting and recovering from the stress (Dietz and Verhagen 2004).

13.5.1 Adaptation Strategy Within Dry Lands Regions

Agriculture adaptation to climate changes in dry regions requires special attention to several key issues which are incorporated into a broader socio-economic (agricultural, water resources, natural resources, etc.) (FAO 2008a) conditions which include building appropriate monitoring and data gathering system; undertaking an integrated research system focusing on priority issues including combination of social and economic issues with the aim to enhance wide range of participation of local societies in the implementation of various activities; promoting extension services with strong training on challenging issues; expanding on measures such as rainwater harvesting, water storage, conservation and reuse, desalination; sector-wide water reforms; provision of market services including marketing tools, post harvest infrastructures and farm processing facility to increase added values; and providing access to credits and crop insurance (Dietz et al. 2004a).

13.5.2 Specific Adaptation Measures at Farm Level

Several measures showed significant opportunities for adapting to climactic changes (Oweis and Hachum 2001). Although rainfed wheat yields in West Asia and North Africa are typically 0.5–1.5 t ha^{-1} (Oweis and Hachum 2009). Cooper et al. (1987) and Harris et al. (1991) showed the huge potential for improving water productivity in smallholder RA, with water savings of 15–20 % possible over the coming decade.

Research results at the International Center for Agriculture Research for Dry Areas (ICARDA) and other institutions, as well as harvests from farmers' fields, illustrated the substantial increases in yields in response to the application of relatively small amounts of supplemental irrigation. Iglesias and Minguez (1997) suggested the use of wheat and maize that included new hybrids, changes in sowing dates, double cropping vetch forage–barely mixtures, while intensifying water and land use as one possible package. However, adoption of water harvesting has been low due to: low profitability due to relatively high labor costs, high risks, yields that are highly dependent on economic incentives and crop prices, and lack of markets. High-yield scenario will only happen, if it is profitable for individual farmers (Bruinsma 2003).

Improving soil fertility water management methods and use of improved varieties also provide opportunities to deal with future climatic change, especially in low rainfall areas within WANA region. Research on supplemental irrigation at ICARDA which focused on two areas ie., the use of legumes in crop rotations to improve soil fertility, and technology packages that combine fertilizer application with supplemental irrigation in nitrogen-deficient Mediterranean soils, showed substantial increases in wheat yields and water productivity with a combination of supplemental irrigation and 50–100 kg ha^{-1} of nitrogen (Oweis 1997) and improving soil fertility water management methods and improved varieties (Wani et al. 2003).

Research also indicated that the addition of a limited amount of water to otherwise rainfed crops during water stress periods and critical plant growth showed that water is available to increase the water productivity (kg of biomass or kg of grain m^{-3} water) of wheat, barley, lentils, chickpeas and faba bean (Oweis and Hachum 2003; 2005). Substantial increases in yield in response to the application of relatively small amounts of supplemental water were also reported (Oweis et al. 2000). Yield of wheat grain under low, medium and high rainfall increased by 400 %, 150 % and 30 % with supplemental irrigation of 180, 125 and 75 mm, respectively (Oweis and Hachum 2003).

Conservation agriculture, a combination of reduced or zero tillage, mulch retention, crop rotations and cover crops, offers multiple benefits for farmers in dry rainfed areas. Among such benefits are control of soil erosion, better drought tolerance and improved soil nutrient levels (Mrabet 2008b). Introducing crop varieties and/or species with increased resistance to heat shock, salinity and drought, improving irrigation efficiency, altering amounts and timing, conserving soil moisture through appropriate tillage methods are proved to be viable options (e.g. crop residue retention, zero tillage) (Mrabet 2008a, c, d). Helping farmers adapt to climate change requires greater investment in research to develop drought-resistant varieties and conservation agriculture practices (World Bank 2007).

13.6 Measures to Cope with Future Climatic Changes

Measures to cope with future climatic change include: restoration of degraded lands; changing planting dates patterns intensity, sowing and harvesting; appropriate cultural practices for warmer and drier climates; efficient irrigation scheduling; weed management; planting different varieties or crop species; more use of intercropping; using sustainable fertilizer and tillage practices; improving soil drainage, no-till, etc.; improved crop residue and weed management; expanding the use of water harvesting techniques, water storage, conservation and reuse; better pest and disease control for crops; implementing new or improving existing irrigation systems; soil moisture conservation; mulching; development of germplasm adapted to drought and temperature extremes using traditional and participatory plant breeding methods; development and promotion of alternative crops, and developing new drought and heat-resistant varieties. Research results indicated that almonds and olive trees can be grown in Jordan in unproductive areas; shrubs and trees can be grown in Syria under 120–150 mm; and trees and shrubs can be grown in Morocco and Tunisia under 100–200 mm when combined with contour ridges (Oweis et al. 2004; Oweis and Taimeh 2001). Biotechnology may also provide an excellent opportunity to increase crop yields, produce disease-free seeds and seedlings and improve resistance to diseases and abiotic stresses.

Dietz et al. (2004a, b) suggested several technologies which offer suitable opportunities for adaptation to climatic changes under different rainfed conditions. These include: (a) Development of germplasm adapted to drought and temperature extremes using traditional and participatory plant breeding methods; (b) Enhancement of soil and water conservation (use of low cost structures) and adoption of conservation agriculture, (c) Better fitting of germplasm options to different climates and gene prospecting, and (d) Conservation of dry land biodiversity and diversification of production systems.

Anticipated climatic change (FAO 2008b) measures may include: development of cultivars resistant to climatic change; crop breeding to adapt to warmer environmental conditions; changing the cropping calendar; serious consideration to the protection of soils from degradation; utilizing genetic resources that may be better adapted to warmer and drier conditions; improvements in farming systems, fertilizer management, and soil conservation; a combination of farm level adaptations and economic investment in agriculture infrastructure; reallocation of land and water; investment in rainwater harvesting and other water conserving practices and conservation of biodiversity; and diversification of production systems.

13.6.1 Policy Options

Biophysical planning is never enough to meet the challenges imposed by climatic changes. Planners in WANA region had to deal with several issues considered as priorities ones. Such policies should deal with resource-poor people especially smallholders and resource-poor farmers; water scarcity; technology transfer adapted to climatic change impacts; climate forecasts; early warning; land use planning; advocacy on importance of climatic change to policy makers and politicians; use of local community-based knowledge; impact assessments of climatic changes; energy efficiency in agricultural production; promotion of carbon sequestration; and feasibility and opportunities for non-food bio-fuels.

Government response to challenges imposed by climatic change should cover decision makers at every level of government, and in every sector of the economy. Effective adaptation decision making requires (World Resources Institute 2011) a significant shift of most governments' plans for climate-related risks. Furthermore, policy makers should be aware that those affected by climatic change have legal rights to be consulted and engaged in policy and planning processes.

At farmers level, adopted policies should focus on improving on-farm water management (FAO and the World Bank 2001); sustainable crop improvement; genetic improvement; adoption of new biotechnological innovative tools; crop diversification and sustainable intensification of the production systems; combining the conventional research approach with modern tools; strengthening linkage between research and extension/dissemination system; inclusion of gender-sensitive strategies; empowerment of women and development of women's entrepreneurship; providing proper training to educate future generations to combat climate change and desertification risks; providing proper enabling environment to empower women participation in their community as decision-makers; encouragement of national agricultural research to focus on cost-effective practices which effectively contribute in reducing greenhouse gases such as: improved management of soils; rangelands, and forests; efficient fertilizer use; restoring degraded agricultural lands and rangelands; and slowing deforestation. Proposed technologies should also emphasize practices that keep RA economically viable.

13.6.2 Institutional Policy Options

Institutional policies should explore ways to provide better linkages with private sector; provide training and capacity building; analyses to assess preparedness of national institutions for climatic changes; strengthen social safety nets through insurance schemes; integration of scientific disciplines on knowledge of climatic variability, adaptation and mitigation; and decentralization of decision-making and policy formulation (Thomas 2008).

Institutional policy options to reduce the vulnerability of the rural poor to climate change in WANA (Adeel et al. 2007) region may require new measures such as the development of rainfall insurance whereby insurance contracts are written in relation to local rainfall. The concept of payment for environmental services as an option to increase the investments in dry areas subject to degradation and climate change (Adeel et al. 2007), is receiving increasing attention. International cooperation/coordination between farmers, government institutions, and research agencies will be critical in order to support moving production system from present status that become unsuitable to future conditions.

References

Adeel Z, Bogardi J, Braeuel C, Chasek P, Niamir-Fuller N, Gabriels D, King C, Knabe F, Kowsar A, Salem B, Schaaf T, Shepherd G, Thomas R (2007) Overcoming the greatest environmental challenge of our times: re-thinking policies to cope with desertification. United Nations University-International Network on Water, Environment and Health, Hamilton

Barron J, Rockström J, Gichuki F, Hatibu N (2003) Dry spell analysis and maize yields for two semiarid locations in East Africa. Agric For Meteorol 117:23–37

Bruinsma J (ed) (2003) World agriculture: toward 2015/2030, a Food and Agriculture Organization perspective. Earthscan, London

Casass J (1999) NARS Study economy and agriculture 2. Economy and agriculture of the WANA region: some basic data. INRA, Montpellier

Cooper P, Gregory P, Tully D, Harris HC (1987) Improving water-use efficiency of annual crops in the rainfed farming systems of West Asia and North Africa. J Exp Agric 23:113–158

Dietz T, Verhagen J (2004) The impact of climate change on drylands with a focus on West Africa. In: Dietz A, J Ruben R, Verhagen A (eds) Impact of climate change on drylands: With a focus on West Africa. Kluwer Academic, Dordrecht, pp 3–17

Dietz A.J, Ruben R, Verhagen A (eds) (2004b) The impact of climate change on drylands with a focus on West Africa. Kluwer, Dordrecht

Dregne HE (ed) (1992) Degradation and restoration of arid land. Texas, Technical University, Lubbock

Drinkwater LE, Wagoner P, Sarrantonio M (1998) Legume-based cropping systems have reduced carbon and nitrogen losses. Nature 396:262–265

Dumanski J, Peiretti R, Benites JR, McGarry D, Pieri C (2006) The paradigm of conservation agriculture. Proc World Assoc Soil Water Conserv P1:58–64

El-Beltagy A (1999) Can desertification trends be reversed in West Asia and North Africa? The International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo

FAO (2002a) Conservation agriculture: case studies in Latin America and Africa, FAO soils bulletin no. 78. FAO, Rome

FAO (2002b) World agriculture: towards 2015/2030: summary report. FAO, Rome

FAO (2008a) State of food insecurity in the world. FAO, Rome

FAO (2008b) Climatic change adaptation and mitigation in the food and agriculture sector technical background document from the expert consultation held on 5–7 March 2008. FAO, Rome

FAO (2010) Definitions of drylands and dryland farming. http://www.fao.org/docrep/012/i0372e/i0372e08.pdf. Accessed 5 Feb 2010

FAO and the World Bank (2001) Farming systems and poverty: improving farmers' livelihoods in a changing world. World Bank, Washington, DC
FAOSTAT (2005) UN Food and Agriculture Organization, Statistical Database, FAO Rome, Italy, Data from 2005. http://faostat.fao.org
Hamdy A, Lacirignola C (1998) Environment and water resources. Bari, Medit, No. 2, pp 6–18
Hamdy A, Lacirignola C (2002) Overcoming water scarcity and quality constraints: water pricing and cost recovery potentialities. Options Méditerranéennes, Series A: Mediterranean seminars. Number 49. CIHEAMIAMB/EC-DG.1, Bari
Harris HC, Cooper P, Pala M (eds) (1991) Soil and crop management for improved water use efficiency in rainfed areas. In: Proceedings of an international workshop sponsored by MAFRA/ICARDA/CIMMYT, ICARDA, Ankara/Aleppo, 15–19 May 1989
ICARDA (2003) Setting agricultural research priorities for the Central and West Asia and North Africa region (CWANA). Towards a new NARS/NARS and CGIAR/NARS collaboration spirit. ICARDA/AARINENA/CAC-NARS Forum, Aleppo
Igelsias A, Minguez MI (1997) Modeling crop climate interactions in Spain: vulnerability and adaptation of different agricultural systems to climate change. Mitig Adapt Strat Global Change 1:273–288
Intergovernmental Panel on Climate Change (IPCC) (2000) Special report on the regional impacts of climate change: an assessment of vulnerability, chap.7, Middle East and Arid Asia. Intergovernmental Panel on Climate Change, Geneva. http://www.ipcc.org
IPCC (2007a) Climate change 2007: synthesis report. Contribution of working groups I, II and III to the fourth assessment report of the intergovernmental panel on climate change. In: Core Writing Team, Pachauri RK, Reisinger A (eds). IPCC, Geneva
IPCC (2007b) Climate change 2007: mitigation. Contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA (eds). Cambridge University Press, Cambridge, UK
IPCC (2007c) Climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds). Cambridge University Press, Cambridge, UK
Irz X, Roe T (2000) Can the world feed itself? Some insights from growth theory. Agrekon 39:513–528
Jenkinson DS, Harris HC, Ryan J, McNeill AM, Pilbeam CJ, Coleman K (1999) Organic matter turnover in calcareous soil from Syria under a two-course cereal rotation. Soil Biol Biochem 31:643–649
Lal R (2000) Carbon-sequestration in drylands. Ann Arid Zone 39:1–10
Lal R (2002) Carbon sequestration in dryland ecosystems of West Asia and North Africa. Land Deg Develop 13:45–59
Lal R (2003) Importance of inorganic carbon in sequestering carbon in soils of the dry regions. Curr Sci 84:64–865
Margat J, Vallae D (1999) Water resources and uses in the Mediterranean Countries: figures and facts. Blue plan regional activity center. UNEP, Aleppo
Mrabet R (2008a) Lasting benefits from no-tillage systems: erosion control and soil carbon sequestration. In: Proceedings of the international workshop on conservation agriculture for sustainable land management to improve the livelihood of people in dry areas, pp 72–92. ACSAD & GTZ, Damascus, 7–9 May 2007, 288 pp
Mrabet R (2008b) Conservation agriculture in Morocco: a research review. In: The proceedings of the international workshop on conservation agriculture for sustainable land management to improve the livelihood of people in dry area, pp 183–208. ACSAD & GTZ, Damascus, 7–9 May 2007, 288 pp
Mrabet R (2008c) No-tillage systems for sustainable dryland agriculture in Morocco. Institut National de la Recherche Agronomique (INRA), Tangier, p 153

Mrabet R (2008d) No-till practices in Morocco. In: Goddard T, Zoebisch M, Gan Y, Ellis W, Watson A, Sombatpanit S (eds) No-till farming systems. Special Publication No. 3. World Association of Soil and Water Conservation, Bangkok, pp 393–412

Mrabet R, El-Brahli A, Anibat I, Bessam F (2003) No-tillage technology: research review of impacts on soil quality and wheat production in semiarid Morocco. In: Cantero-Martinez C, Gabina D (eds) Mediterranean rainfed agriculture: strategies for sustainability. CIHEAM-IAMZ, Zaragoza, pp 133–138

Oweis T (1997) Supplemental irrigation: a highly efficient water-use practice. ICARDA, Aleppo, 16 pp

Oweis T, Hachum A (2001) Reducing peak supplemental irrigation demand by extending sowing dates. Agric Water Manage 50:109–123

Oweis T, Hachum A (2003) Improving water productivity in the dry areas of West Asia and North Africa. In: Kijne J, Barker W, Molden D (eds) Water productivity in agriculture: limits and opportunities for improvement. CAB International, Wallingford, pp 179–198

Oweis T, Hachum A (2009) Supplemental irrigation for improved rainfed agriculture in WANA region. In: Wani SP, Rockström J, Oweis T (eds) Rainfed agriculture: unlocking the potential, Comprehensive assessment of water management in agriculture. Series 7. CABI, London

Oweis T, Taimeh A (2001) Farm water-harvesting reservoirs: issues of planning and management in dry areas, In: Adeel Z (ed) Integrated land management in dry areas. Proceedings of a joint UNU–CAS international workshop, UNU, Beijing/Tokyo, 8–13 Sept 2001, pp 165–182

Oweis T, Zhang H, Pala M (2000) Water use efficiency of rain-fed and irrigated bread wheat in a Mediterranean environment. Agron J 92:31–238

Oweis T, Prinz D, Hachum A (2001) Water harvesting: indigenous knowledge for the future of the drier environments. ICARDA, Aleppo

Oweis T, Hachum A, Bruggeman A (2004) Indigenous water-harvesting systems. ICARDA, Aleppo

Oweis T, Hachum A, Pala M (2005) Faba bean productivity under rainfed and supplemental irrigation in Northern Syria. Agr Water Manage 73:57–72

Pala M, Harris H, Ryan J, Makboul R, Dozom S (2000) Tillage systems and stubble management in a Mediterranean-type environment in relation to crop yield and soil moisture. Exp Agric 36:223–242

Rockstr.m J, Hatibu N, Oweis T, Wani S (2007) Managing water in rainfed agriculture. In: Molden D (ed) Water for food, water for life: a comprehensive assessment of water management in agriculture. Earthscan/International Water Management Institute (IWMI), London/Colombo, pp 315–352

Scurlock J, Hall D (1998) The global carbon sink: a grassland perspective. Glob Change Biol 4:229–233

Seckler D, Amarasinghe U (2000) Water supply and demand, 1995 to 2025: water scarcity and major issues. In: World water supply and demand. IWMI, Colombo, pp 9–17

Seckler D, Molden D, Barker R (1999) Water scarcity in the twenty first century. IWMI, Water Brief 1, pp 1–16

Sprent J (1987) The ecology of the nitrogen cycle. Cambridge University Press, Cambridge

Thirtle C, Beyers L, Lin L, Mckenzie-Hill V, Irz X, Wiggins S, Piesse J (2002) The impacts of changes in agricultural productivity on the incidence of poverty in developing countries, DFID Report No. 7946. Department for International Development (DFID), London

Thomas R (2008) Opportunities to reduce the vulnerability of dryland farmers in Central and West Asia and North Africa to climate change. Agric Ecosys Environ 126:36–45

UNFCCC (2011) United Nations framework convention on climate change, work program on impacts, vulnerability and adaptation to climate change. Bonn, Germany

Wani S, Singh H, Sreedevi T, Pathak P, Rego T, Shiferaw B, Iyer R (2003) Farmer participatory integrated watershed management: Adarsha watershed, Kothapally, India, an innovative and up scalable approach, case 7. In: Harwood RR, Kassam AH, (eds) Research towards integrated natural resources management: examples of research problems, approaches and partnerships in action in the CGIAR. Interim Science Council, Consultative Group on International Agricultural Research, Washington, DC, pp 123–147

Wani S, Balloli S, Kesava Rao, Sreedevi T (2004) Combating drought through integrated watershed management for sustainable dryland agriculture. In: Regional workshop on agricultural drought monitoring and assessment using space technology. National Remote Sensing Agency (NRSA), Hyderabad, 4 May 2004, pp 39–48

World Bank (2005a) Agricultural growth for the poor: an agenda for development. The international bank for reconstruction and development. World Bank, Washington, DC

World Bank (2005b) Making the most of scarcity: accountability for better water management in the Middle East and North Africa. World Bank, Washington, DC

World Bank (2007) World development report: agriculture for development. World Bank, Washington, DC

World Health Organization (2000) Gender, health and poverty, Factsheet

World Resources Institute (2011) World Resources 2010–2011 decision making in a changing climate adaptation challenges and choice. World Resources Institute, Washington, DC

World Water Council (2002) In: Abu-Zeid M, Hamdy A (eds) Water vision for the twenty-first century in the Arab World, World Water Council. Arab Countries Vision Consultations, CIHEAM/Mediterranean Agronomic Institute, Bari, Italy, Member, BoG Arab Water Council

Chapter 14
Mitigation and Adaptation Options of Climate Change in Irrigated Agriculture in Arab Countries

Dia El-Din El Quosy

Abstract Mitigation of climate change although extremely important, has little to do with irrigated agriculture except its contribution to methane emission by rice cultivation and animal manure. For this reason, this paper will only emphasize the importance of adaptation to climate change in irrigated agriculture in Arab Countries. Irrigated agriculture may depend on surface flows (from fresh water rivers, lakes etc.,); groundwater (both fresh, brackish or saline); conjunctive use of surface and groundwater or supplementary irrigation of rainfed lands provided with surface and/or groundwater supply during specific periods of crop growth when rainfall is scarce. Adaptation to climate change should, therefore, discuss: supply, demand and crop water requirements, cropping patterns and salt and drought tolerant crops, irrigation system both on the delivery and on the on-farm sides and finally the storage reservoirs and their operating rules. The major limitation of the influence of climate change on irrigated agriculture is the extent of uncertainty in supply. This difficult issue can only be overcome through intensive modeling techniques. Arab Countries are a very fragile region with respect to climate change and its effect on irrigated agriculture, due to the already scarce water resources, the high percentage of the water budget used for the irrigation of cultivated land, the high temperature climate which requires high water consumption, the prevailing culture of water ownership, marketing and use.

Keywords Hydrological division of Arab countries • Climatic observations • Vulnerability of water resources

---

D.E.-D. El Quosy (✉)
National Research Center for Water, Cairo, Egypt
e-mail: lmewp2000@gmail.com

M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_14,

14.1 Introduction

The Arab Countries fall among one of the most water stressed regions in the whole world and climate change, which is expected to result in increased magnitude and frequency of extreme weather events such as: high temperature, droughts, floods etc., will contribute to even worse water scarcity in the region. It is not only the quantity of fresh water that might be affected by climate change, but the quality of groundwater might also get contaminated by sea water intruding coastal aquifers affecting potable water supply for millions of inhabitants.

About two third of the renewable water resources of the Arab Countries originates outside the region. 80 % of the area is barren desert, and therefore, the region is mainly arid with small pockets of semi-arid climatic conditions. The average annual rainfall varies between “nil” and 1,800 mm while the average evaporation rate is more than 2,000 mm $year^{-1}$.

The area of the Arab Countries accounts for almost 10 % of the dryland on earth while water resources do not exceed 1 % of the world total. Despite this water poverty, 80 % of the water budget is allocated to agriculture, the highest water consuming development activity while industry consumes 12 % and the remaining 8 % is allocated to domestic and potable use. Although about 2,000 billion m^3 of rain falls every year on the region, the amount of effective rainfall that is beneficially utilized is much less than this figure, huge quantities are lost in evaporation from free water surfaces, evapotranspiration of aquatic plants in swamps and marches, or lost to the sea or to the ocean.

The total number of continuously flowing fresh water rivers in the Arab Countries is 34; their catchments may be as small as 86 km^2 in the case of River Zahrani in Lebanon; and 2.8 million km^2 in the case of the River Nile.

The percent of water used out of the total available is less than 50 % although food imports to the region is more than 50 % and only 25 % of arable land is cultivated.

Annual renewable water resources are about 244 billion m^3 $year^{-1}$ of which 204 billion m^3 $year^{-1}$ are surface flows and 40 billion m^3 $year^{-1}$ are renewable groundwater. Withdrawal in some countries exceeds the actual renewable supplies, while others are just at the limit.

The problems are not only the limited water resources, the harsh climatic conditions and the use of water in a high consuming activity like agriculture; but also the high population growth which adds to the chronic problem and aggravates its impact. If all this is crowned by climate change that might be due to natural variability or as a result of human activity which might cause additional water stress and create additional problems then the situation might reach an intolerable condition which may ultimately affect the environmental, economic, social, political and even security stability of the region.

One of the major drawbacks of the Arab Countries is data availability: regular measurements, continuous monitoring and neutral evaluation of water status in the area is either missing or available in isolated survey’s that might be separated by long time spans with non-available records. This adds to the uncertainty of the effect of climate change on water resources in most of the countries. This paper is an attempt to shed some light on the climate change and climate variability as phenomena that might affect water availability in the Arab Countries and how vulnerable countries can mitigate and adapt to their positive and negative impacts. Special reference will be devoted to irrigated agriculture as the main activity that consumes most of the Arabian water resources.

14.2 Hydrological Division of Arab Countries

From a hydrologic point of view, the Arab countries can be divided into the following sub-divisions:

- Al Mashrek countries: Iraq, Syria, Lebanon, Jordan and Palestine.
- Al Maghreb countries: Libya, Tunisia, Algeria, Mauritania and Morocco.
- Nile Basin countries: Egypt and Sudan.
- Arabian Peninsula: Saudi Arabia, Kuwait, United Arab Emirates, Qatar, Oman, Bahrain and Yemen.
- Sahel countries: Somalia, Djibouti and Comoros Islands.

Each of the above five regions has its distinct hydrological characteristics that can briefly be explained as follows.

14.2.1 Al Mashrek Region

– Iraq and Syria are partially dependant on rivers Tigris and Euphrates originating from Turkey and the two countries have rainfall of reasonable intensity and groundwater potential in both countries is relatively high. Syria enjoys small flows caused by snow melt from the peaks of some local mountains.
– Lebanon depends on a number of local rivers or rivers shared with one or more of the neighboring countries, however, the per capita share of water in Lebanon as well as in Syria and Iraq are the highest among all Arab countries.
– Jordan and Palestine are the two water poorest countries since they depend upon River Jordan and small quantities of rainfall and groundwater shared by the force of the Israeli occupation or even by the peace treaties signed after evacuation from occupied territories.

14.2.2 Al Maghreb Region

All five Maghreb countries depend mainly on rainfall and partially on modest groundwater reserves.

14.2.3 Nile Basin Region

The Southern part of Sudan (which is an independent state since July 2011) enjoys ample precipitation which can meet the prevailing evaporative demand; however, rain gradually vanishes north of the capital Khartoum. Following the signing of the Nile Water Agreement in the year 1959, Sudan and Egypt divided the average natural flow at Aswan (84 billion m^3 $year^{-1}$) to one quarter for Sudan (18.5 billion m^3 $year^{-1}$), three quarters for Egypt (55.5 billion m^3 $year^{-1}$) and the remaining 10 billion m^3 $year^{-1}$ were left for the evaporation from Lake Nasser. This division will be subject to modification following the separation of the two south and north Sudanese states.

The natural flow of the River Nile form 95 % of the Egyptian water budget, the remaining 5 % are composed of minor quantities of rain which falls on the coast of the Mediterranean and Red seas (about 1.5 billion m^3 $year^{-1}$) plus modest reserves of groundwater aquifers.

14.2.4 The Arabian Peninsula

Is the poorest region with respect to water resources, rainfall is rare by all standards, groundwater either does not exist or has already been depleted and surface water is almost not there. The region depends mainly on desalination of water from the Arabian Gulf. Yemen is the only country in the Arabian Peninsula which depends on rainfall and partially on groundwater.

14.2.5 Sahel Countries

Somalia, Djibouti and Comoros Islands are all dependant on rainfall with modest potential of groundwater.

The above brief description of the hydrological situation in the Arab countries reveals a number of important facts:

- The lowest vulnerability to climate change is in the case of the Arabian Peninsula where the internal renewable water resources in the region at the present time are very limited. Whatever happens is not going to reduce the already very low internal renewable water resources while the possibility of enhancement of these resources could be realized.
- The four countries largely dependent on river flows originating outside their boundaries namely Egypt, Sudan, Iraq and Syria are not only under the vulnerability of reduced or increased flows caused by climate change, they are also vulnerable to the actions that might be taken by upstream riparian countries which may affect their flows downstream. This is very clear in the existing stressed relationship between Egypt and Sudan on one side and the upstream

countries on the other side. Independence of southern Sudan may add to these stressed conditions. Again, the relationship between Turkey on one side and Syria and Iraq on the other is no exception to this tense situation

- Al Maghreb countries are the most vulnerable to climate change since they are almost fully dependant on rainfall. Libya is an exception with the man made river now forming the major source of water to the country. The river is fed by pumping water from the Nubian Sandstone aquifer shared with Egypt, Sudan and Chad. However, the life time of the project is only 50 years, after which the country has to find other alternative.
- Djibouti and Comoros Islands are more threatened by sinking caused by increased sea level rise than being affected by high or low natural fresh water flows.
- Jordan and Palestine exercise at the present time the lowest per capita share of water in the Arab Countries (100–200 m^3 per capita per year). The vulnerability of sharing their water resources with Israel which is expanding with space and population appears to overweight the vulnerability which might be caused by climate change.

14.3 Climatic Observations in the Arab Countries

The Arab Countries region is the poorest area in the whole world with respect to the intensity of climatic observation stations. The only cited stations are the one at the northern end of the Red Sea and two stations on the coast of the Atlantic Ocean.

In the meantime, there is no local circulation model that is developed to predict the future situation in the region when the Green House Gas (GHG) emissions increase could result in an increase in earth temperature and the consequent effects on spatial and temporal variability of rainfall and runoff. The only model under development at the present time is that prepared by the United Kingdom Meteorological Office (UKMO) for the purpose of prediction of Nile flows under different climatic scenarios. The model is developed by statistical and dynamic downscaling from a Global Circulation Model (UKMO) and is expected to be in practical use during the coming 12–24 months.

The extreme event of the tropical cyclone, GONO, which hit the coast of the Sultanate of Oman in the year 2008, the snow which covered the mountains of the United Arab Emirates, and the extremely low temperature which affected palm trees in the Arabian Peninsula and Jordan, drew the attention of the Arab Countries to the risk that might be escalated in the future.

In spite of the above; only few number of countries in the Arab region follow the requirements of the international community such as issuing the first and second national communications and to prepare a climate change strategy or a framework.

The coastal strip in the Arab Countries extends for a distance of 1,800 km from the Atlantic Ocean through the Mediterranean and the Red Sea (from both sides east and west). The Arabian Sea to the Arabian Gulf hosts millions of Arabs and large number of development activities. The initiative of the Saudi King HM who allocated funds for the purpose of climate change research was well received by most of Arab scientists and elites and fully appreciated by all.

14.4 Vulnerability of Water Resources in the Arab Countries to Climate Change

In our investigation of the vulnerability of water resources in the Arab Countries to climate change, it was found more convenient to divide the region into the following subdivisions:

(a) Mediterranean countries which include: Mauritania, Morocco, Tunisia, Algeria, Libya, Egypt, Palestine, Lebanon, Syria, Jordan and Turkey. Mauritania and Jordan are included because of their close proximity to the Mediterranean climate, especially with respect to the rain patterns. Turkey is included as the country of origin of the Rivers Tigris and Euphrates which forms a major source of water to Syria and Iraq.
(b) Egypt and Sudan as the downstream users of Nile Water, although Egypt forms one of the Mediterranean countries in the same time.
(c) Syria and Iraq as the downstream users of Rivers Tigris and Euphrates.
(d) The Arabian Peninsula which includes Saudi Arabia, Kuwait, United Arab Emirates, Qatar, Oman, Bahrain and Yemen.
(e) Somalia, Djibouti and Comoros Islands as African Sahel countries.

14.4.1 Mediterranean Countries

The term Mediterranean climate has been used for the characterization of other areas which are not necessarily located on both sides of the Mediterranean Sea. This climate is known with wet and mild winters; dry and generally warm summers. The Mediterranean Basin is considered a transitional region between mid-altitudes and subtropical climate regions, with a division line moving seasonally across the basin. The Mediterranean Sea itself exerts important influence in the environment, climate, economy and culture of the coastal areas providing them with an important source of moisture and heat reservoir. The situation in the Mediterranean region is very complex due to the large differences between different areas. While at the North West Coast population growth has practically stopped, a two-fold increase is expected in North African Countries during the first three decades of the twenty-first century, with an even larger growth taking place in Syria and Palestine; adding more stress to the already scarce water resources. Global projections present a remarkable agreement on the Mediterranean region, although warming is expected to be larger than the global average with a large percent reduction of precipitation and an increase in interannual variability (Giorgi 2006).

Global simulation can not be considered accurate for the description of the Mediterranean region and downscaling by statistical methods and dynamic models can, in some situations, be used to provide better insight and give results at high precision. Development of regional model simulation for the Mediterranean is actually missing and needs to be made in the future. Moreover, room should be left for different approaches such as statistical downscaling and other techniques.

Lebanon, regarded as one of the advanced countries with respect to climate change research, has pointed at the following vulnerability issues.

- Chaotic Urbanization at the expense of forests and wood lands.
- Air, water and soil pollution.
- Increasing frequency of fires due to prolonged dry seasons.
- Change of water table level due to excessive pumping and quarrying activities.
- Overgrazing of rangelands.
- Land fragmentation.

Morocco is another example of the Arab Mediterranean Countries in which climate change research is well advanced. The country has prepared its First National Communication; and is in the process of developing the Second National Communication Report (Dia El-Din El Quosy 2009, personal communication).

A map of composite indicators representing the vulnerability of both agriculture and domestic water uses to climate stress in the form of long hot and dry spells was generated to identify areas of high vulnerability. The results indicated that the ecosystem of the Tensift River Basin is very vulnerable with various degrees of vulnerability in different parts of the region.

Libya has a prevailing Mediterranean climate characterized with coastal valleys and heights, rainy cold winter and dry hot summer; and the existence of transferred two seasons of spring and autumn in which the khamasin winds resulting from the movement of general winds around the Netherlands to blowing hot dry southern wind accompanied by sandstorms known locally as Gebli Wind. The country has attested a number of United Nations agreements and protocols and is treated as one of the less Developed Countries in its mitigation and adaptation measures to climate change. Water Resources in Libya is limited to rainfall in the north and modest quantities of groundwater in the south. Abstraction of fossil groundwater will bring the aquifer to a state of low feasibility by 2050.

If the intensity of rainfall is reduced, as predicted by many sources, then the country will have no other option but to depend heavily on desalination or to import surface water from neighboring countries. Both alternatives are fairly costly especially as the country suffers a population growth which ranges between 2.5 % and 3 %.

Syria is more vulnerable to climate change because of the following reasons:

- More than 75 % of the cropped area is dependant on rainfall as the main source of water.
- Fluctuation in rainfall affects rainfed agriculture negatively.
- Fluctuation of temperature affects crop yields negatively.
- Increased frequency and duration of droughts affects negatively crop production and food availability.

In Egypt rainfed agriculture is limited to the north coast extended over a distance of 1,200 km where modest precipitation of 100–200 mm intensity falls every year in particular during winter months (December-February). If this little amount of rain is reduced further, life in these regions will be intolerable unless Nile water is conveyed from the east and west branches of Damietta and Rosetta of the River Nile.

If this solution proves to be expensive, the only remaining option would be desalination of sea and brakish groundwater which might be made cheaper if renewable energy (solar, wind, wave) is used, otherwise atomic energy which is a matter of controversy at the present time would be the ultimate resort.

In general, almost all Arab countries located on the Mediterranean will be affected by climate change at different levels. Countries which are more dependant on rainfall will certainly be affected more. Other countries which are less dependent on rainfall will be less affected; yet, water has to be made available for areas which are going to be affected from other parts and other sources inside or outside the country.

A common problem to all Arab countries located on the coast of the Mediterranean is the possibility of having coastal aquifers contaminated if the sea level water is increased particularly in low lying areas because of sea water intrusion. Coastal aquifers are very fragile systems of fresh water lenses sitting above huge body of brackish water of relatively high salinity. Over exploitation of fresh water lenses plus the action of sea water which is expected to intrude lands of low elevation will certainly affect the use of these aquifers and possibly the pollution of soil as well. If parts of the lands parallel to the sea shore are inundated, then it will not only be groundwater that is going to be affected, the whole landscape will be changed with vast areas of land abandoned and large number of citizens displaced.

14.4.2 Nile Basin

The Nile Basin is composed of three main sub-basins:

- Equatorial Lakes sub-basin.
- Ethiopian plateau sub-basin.
- Bahr El Ghazal sub-basin.

Precipitation on the Ethiopian Highlands comes in one season and takes almost 100–110 days starting from early June to mid September. The sub-basin is marked with steep slopes which cause heavy storms to erode vast areas of land. In the Bahr El Ghazal sub-basin, land is fairly flat and precipitation is spread over large areas of swamps and marches occupied by wild animals and aquatic plantations. The Equatorial lake plateau is flat as well; however, the Nile has its route that allows water to flow downstream inside a regular channel. Both Bahr El Ghazal and Equatorial Lakes sub-basins experience two rainy seasons, one of them is long (4–6 months) and the other is short (2–3 months).

Research on the Nile Basin has proved that the river's natural flow is very sensitive to precipitation which falls on the Ethiopian highlands. An increase of 20 % in precipitation may increase the Nile natural flow at Aswan by 80 %. In the meantime if precipitation is reduced by 20 %, the natural flow may fall to 20 % of the average. Natural flow is also sensitive to temperature variation but to a less extent particularly in the Equatorial Lakes and Bahr El Ghazal sub-basins. An increase of 2 °C in temperature might cause the natural flow to fall to 50 % of the average in these two sub-basins.

These facts lead to an important conclusion that Egypt and Sudan are both extremely vulnerable to increased or decreased rainfall in the Nile Basin as well as their vulnerability to increased temperature levels.

Both increased and reduced flows have negative effects on the two countries. If the natural flow is considerably increased, the storage capacity of both water systems might not be sufficient to accommodate these high flows which might cause destructive floods. Even if the storage capacity is adequate, as it might be the case in Egypt, the conveyance and distribution network of canals and drains might not be sufficient. If the opposite happens, i.e. natural flows are substantially reduced; the two countries will face droughts that might not be tolerated.

The application of Global Circulation Models on the Nile Basin Flows resulted in variable figures over a very wide range. This uncertainty confirms the fact that regional or even local circulation models are needed. Unfortunately these types of models are not available at the present time. The only attempt cited is the studies carried out by an Egyptian team of experts to use the UKMO Circulation Model to produce a regional model on the Nile Basin by downscaling using statistical and dynamic modeling. This process needs 1–2 years to complete and the results would be the highest accuracy possible with the state of the art techniques available worldwide at the present time.

14.4.3 Turkey

In an interesting study on one of the major river basins in Turkey (Seyhan), a team of Japanese scientists (Fujihara et al. 2008) explored the impact of climate change on the hydrology and water flows of the river. A dynamic downscaling method (pseudo Global Warming Method PGWM) was used to connect the outputs of two General Circulation Models (GCM's) namely: MRI – CGCM2 and CCRS/NIES/FRCGC – MIROC under the SRES A2 scenario. The downscaled data covered

10 year time steps corresponding to the base (1990) and the future (2070). The simulation results for the future were compared with those for the present. The average annual temperature change in the future relative to the present were projected to be +2.0 °C and +2.7 °C by MRI and CCRS respectively. The annual precipitation decreased by 157 mm (25 %) in MRI-Future and by 182 mm (29 %) in CCRS-Future. The annual evapotranspiration decreased by 36 mm (9 %) in MRI-Future and by 39 mm (10 %) in CCSR- Future. This is mainly because of the reduction in soil moisture.

The annual runoff decreased by 118 mm (52 %) in MRI-Future and by 139 mm (61 %) in CCSR-Future. The analysis revealed that water shortage will not occur in the future if water demand does not increase. However, if the irrigated area is expanded under the expectation of current natural flow, water shortage will occur due to the reduced supply and increased demand.

This example is alarming to both Syria and Iraq since both countries will certainly be affected by water management regimes in Turkey. Water shortages in the upstream will no doubt have a negative effect on the downstream flows of Tigris and Euphrates Rivers.

14.4.4 Arabian Peninsula

The Arabian Peninsula is marked with extremely high summer temperatures, low intensity of rainfall, declining groundwater table levels due to over pumping and obviously high evapotranspiration rates. The area has more than half of the proven world oil and natural gas reserves which enables most of its countries to adopt the state of the art international technology in desalination of sea water.

However, oil and natural gas reserves are not permanent and the region is under the threat of having climate change to add to the already high temperature and reduced rain. Groundwater in most of the countries in the region is not renewable according to many sources and, therefore, continuous abstraction increase water table depth and in some cases deteriorates water quality due to sea water intrusion.

Obviously increasing aridity reflects the influence of climate change which is felt at a lower extent in the Dead Sea area where water level fell by more than 100 m due to excessive evaporation and decreased rainfall (Jorgensen and Al Tikriti 2002). In general, the Water Exploitation Index in most of Arab Countries is in or close to the red: 83 % for Tunisia, 92 % for Egypt, 170 % for Palestine, 600 % for Libya, 50 % for Syria, 25 % for Lebanon, 20 % for Algeria and 40 % for Morocco (Acreman 2000). Results obtained from HadCM2 (a well recognized GCM) suggest that rainfall is expected to be reduced in north Africa and some parts of Egypt, Saudi Arabia, Syria, Jordan by 20–25 % annually. Temperature is expected to increase by 2–2.75 °C, and near to the coast, the expected temperature increase will be lower (1.5 °C). Winter rain (October–March) would be decreased by 10–15 % but would be increased over the Sahara by 25 %.

However, since the existing rate of rainfall above the Sahara is insignificant, the increase would be of insignificant order of magnitude (Ragab et al. 2001). Added to the decline in rainfall; vulnerability of imported water through the Nile, Tigris and Euphrates to climate change is high. What might aggravate this vulnerability is the actions taken by upstream riparian to increase their demand and/or change their water management strategy.

14.5 Mitigation

Although the Arab countries are the highest producers of fossil fuel, mainly oil, consumption by the region is lowest in the world. The reason is that industry in almost Arab countries is still juvenile and the industrial base is just emerging. Most of the regions energy is used for household consumption, mainly lighting, cooling and the operation of household appliances.

The second consumer of the Arab countries energy is the automobile sector. The contribution of the region to greenhouse gases especially carbon dioxide is very modest and does not exceed 1 % of the total world emission.

However, some of the Arab countries are observing the requirements of the international community concerning the reduction of greenhouse gases emission; some of these measures are:

- Converting petrol operating vehicles to natural gas.
- Use of solar and wind energy as a substitute to thermal and steam power plants.
- Reduction of the emission of methane gas by reducing rice cultivation and livestock manure.
- Adoption of “Clean Development Mechanism CDM” which enables developing countries to obtain technical and financial support from industrial countries and to raise the capacity of individuals to reduce greenhouse gas emissions.
- Termination of all sources of subsidy on the prices of fossil fuel.
- Application of carbon taxes on activities that result emission of green house gases using “Polluter Pay” principle.
- Arranging for national awareness campaigns on the impact of climate change, targeting school and university students, the public and house wives.

14.6 Adaptation

The Arab Countries will face not only increasing temperatures but more important also disruption of the hydrological cycle resulting in less and more erratic rainfall that will aggravate even further the already critical state of water scarcity and difficulties with water allocation among different development activities.

Most probably poor residents of rural areas will suffer more and will require a range of coping strategies to help them adapt to climate change. Strategies will include diversifying production systems into higher value and greater water use efficient options. Water use efficiency can be realized by following supplementary irrigation techniques; adopting existing water harvesting techniques; conjunctive use of surface and groundwater; upgrading irrigation practices on the farm level and on the delivery side, development of tolerant crops to salinity and heat stress. Water quality should also be maintained at higher levels by preventing contamination through sea water intrusion.

In addition to the above "general" water saving measures, a number of country specific steps have to be taken according to each country's needs and requirements. For example, the Egyptian Second National Communication, 2009 calls for:

- Adaptation for Uncertainty: including the change of operation of the High Aswan Dam by lowering the storage water level and thus, allow more space to receive higher floods and reduce evaporation from free water surface at the same time; and increase of irrigated area in the case of high floods.
- Adaptation to increased inflow by providing additional storage structures upstream of the High Aswan Dam in order to reduce the risk of flooding downstream the dam.
- Adaptation to inflow reduction by applying the strategies stated in the country's National Water Resources Plan (NWRP) which can be categorized into three main parts: optimal use of available resources, development of new resources and water quality preservation and improvement.
- Minimizing water losses.
- Change of cropping patterns.
- Increased reuse of land drainage and treated sewage and industrial effluent.
- Desalination of sea and brakish groundwater.

The Lebanese Ministry of Agriculture, as another example, adopt the following adaptation measure (Assaf 2009; Halwani 2009)

- Natural adaptation where vegetation and wildlife may acclimatize if climate change is still within their range of tolerance.
- Cultivation of drought tolerant crops.
- Reduced habitat fragmentation by means of corridors and connections between different types.
- Rationalized water and land use to protect wetlands and riparian habitats.
- Increased area and number of protectorates.
- Rational use of renewable and non-renewable water resources through the adoption of modem irrigation techniques as a substitute to the conventional systems in the irrigated areas.

The Sudanese authorities adopt the following strategies in their plans to adapt against climate change

- Capacity building of relevant stakeholders for better understanding of climate change scenarios and risk analysis.
- Public awareness on climate change issues and implications.
- Crisis management.
- Technology transfer including modern irrigation systems, water harvesting, desalination, water transport and recycling of waste water.

- Afforestation and reclamation of marginal and waste land.
- Active participation in regional and worldwide forums.
- Utilization of cost effective environment friendly energy.
- Combat desertification and land degradation.
- Sustainable and integrated water resource management.
- Construction of water storage facilities.
- Establishment of climate proof projects.

The Jamahiriya of Libya put more emphasis on the following points:

- Preparation of an inventory of activities leading to the emission of greenhouse gases including the energy, transport, industry, agriculture, health, environment, housing and utilities.
- Combine policies of climate change in the national policy and update supporting legislation.
- Education and public orientation programs.
- Data collection, exchange and analysis.
- Study of the extent of exposure of the country to climate change.

References

Acreman MC (2000) Guidelines for the sustainable management of groundwater-fed catchment, Report to European Union. Institute of Hydrology, Wallingford, United Kingdom

Assaf H (2009) Climate change: potential impact on water resources in the middle east and adaptation options. Research and policy memo #2, Research and policy forum on climate change and environment in the Arab, Issam Fares Institute for Public Policy and International Affairs, American University of Beirut (AUB), Lebanon

Dia El-Din El Quosy (2009) Investigating the climate sensitivity of different Nile sub-basins. Thirteenth international water technology conference, IWTC 13 2009, Hurgada, Personal communication

Fujihara Y, Tanaka K, Watanabe T, Nagano T, Kojiri T (2008) Assessing the impacts of climate change on the water resources of the Seyhan river basin in Turkey: use of dynamically downscaled data for hydrologic simulations. J Hydrol 353:33–48

Giorgi F (2006) Climate change hot-spots. Geophys Res Lett 33:L08707. doi:10.1029/2006GL025734

Halwani J (2009) Climate change and water resources in Lebanon. IOP Conf Ser: Earth Environ Sci 6:292011. doi:10.1088/1755-1307/6/29/292011

Jorgensen DG, Al Tikriti WY (2002) A hydrologic and archeologic study of climate change in Al Ain, UAE. Global Planet Change 35:37–49

Ragab R, Pearce G, Kim J, Nairizi S, Hamdy A (2001) Proceedings of the International workshop on the wastewater reuse management. International Commission on Irrigation and Drainage (ICID), Seoul, 19–20 Sept 2001

Chapter 15
Climate Change Adaptation and Mitigation Options for the Livestock Sector in the Near East and North Africa

Markos Tibbo and Jeannette van de Steeg

Abstract An assessment of the impacts of climate change and climate variability on livestock sector in Near East and North Africa (NENA) was undertaken to document impacts, past evidences, hotspots of climate change, projections and vulnerability of the sector, and measures to adapt to and mitigate climate change. This was done through an in depth analysis of literature, utilization of GIS tools and experiences in the region. NENA region is one of the driest regions in the world and is vulnerable to extreme climatic events such as droughts, sea level rise, floods, and storms of dust, sand and snow. Conservative predictions show that by 2050 the temperature will increase by 1–4 °C (avg. 2.4 °C) and precipitation will reduce by 8–29 % except in isolated areas of the Arabian Peninsula. Dry season will increase by 2 months in some countries and substantially reducing the length of time that the rangelands can support grazing animals. In the region the livestock sector shares 30–60 % of the agricultural output and contributes to food security and nutrition, poverty alleviation, employment and economic development, monetary saving, social security, living insurance and manure. Demand for livestock products is increasing due to the increasing population, urbanization and income growth. Nearly all countries of the region are net importers of animal and animal products. Smallholders will continue to depend on livestock for their livelihoods in the region.

M. Tibbo (✉)
Food and Agriculture Organization of the United Nations, Regional Office for the Near East, 11 Al Eslah El Zerai St., PO Box 2223, Dokki, Cairo, Egypt
e-mail: Markos.Tibbo@fao.org

J. van de Steeg
Freelance Consultant, Pythagorasstraat 3, 7323 HA Apeldoorn, The Netherlands
e-mail: javandesteeg@gmail.com

M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_15,

In 2006, FAO estimated that the livestock production systems, from feed imports to marketed animal products, generate directly and indirectly 18 % of global GHG emissions. However, the livestock systems have also great potential to climate change adaptation and mitigation. Adaptation and mitigation measures for the region's livestock sector are discussed. This paper advocates all concerned parties to take concrete actions to tackle the impacts of climate change on agriculture and food security.

Keywords GIS • Smallholders • Livestock production systems • Adaptation strategies • Mitigation strategies

15.1 Introduction

Climate change and climate variability have put the countries in the Near East and North Africa (NENA), where scarce natural resources are already under considerable pressure, at significant risk. NENA, one of the driest regions in the world, is vulnerable to extreme climatic events such as droughts, floods, sea level rise, storms of dust, sand and snow. The Intergovernmental Panel on Climate Change (IPCC 2007) predicts increases up to 4 °C over the short term and to 9 °C in the summer months in NENA by the end of the twenty-first century. A reduction in precipitation of 7–29 % is predicted, for example, in Syria, Iraq and Arabian Peninsula; and the dry season is expected to increase by 2 months (Evans 2009) hence reducing the length of time that the rangelands can support grazing animals. Sea levels rise would place coastal areas in Egypt, Kuwait, Libya, Qatar, Tunisia, and UAE at particular risk. Climate change is expected to exacerbate water stress and alter river flows. The region's vulnerability to climate change is aggravated by widespread poverty, particularly in the rural areas where 34 % of the population lives below the poverty line (IFAD 2010).

The Near East is one of the centers of domestication for several livestock species, with a high genetic diversity remaining today. Livestock contributes to food security, poverty alleviation, employment and economic development and shares 30–50 % of the agricultural output in the region. Given the aridity of the region, livestock is a prime component of rural livelihoods in the NENA. Dwindling water and feed resource base due to recurrent droughts, degradation of rangelands and desertification are major concerns.

The impacts of climate change on livestock are eminent with varying degree of vulnerability among sectors and countries. In addition to their role as source of food, transport, fiber and other useful products, these natural resources have great potential for climate change mitigation. However, they contribute about 18 % of the greenhouse gases (GHG) emissions which have to be dealt with. The aim of this paper is to describe the measures to adapt to and mitigate climate change in the region and address climate change impacts, past evidences, hotspots of climate change, projections and vulnerability of the sub-sectors, with a special focus on livestock, forestry, fisheries and aquaculture sectors.

15.2 Climate Change Impacts on Livestock Sector

Changes in temperature have been well documented in NENA. Recent studies (Zhang et al. 2005) using data from 75 weather stations of 15 countries in NENA disclosed significant increases in number of warm days and decreases in number of cold days, and revealed ample evidence of hotspots of impacts and vulnerability to climatic fluctuations in the Region (Celis et al. 2007; De Pauw 2008). The region also witnessed varying degree of extreme events such as droughts, floods, and sand and snow storms. In the north-eastern Syria, for example, herders lost almost 85 % of their livestock due to repeated droughts since 2005 (IRIN 2011).

Reduced precipitation and number of precipitation days in a year will add stress on already scarce water resources in many countries, and shift arable land into more arid rangelands, which would result in increased importation of water and feedstuffs or decreasing herd sizes. For example, a reduction in productivity of crops and shortage of water will be evident in Egypt and shortening of the length of growth period and number of freezing days would affect crops in Iran. It is expected that climate change will overall increase the interdependence of countries in respect to the access and use of genetic resources for food and agriculture (Fujisaka et al. 2011). Some of the projected changes in the region are summarized below.

Climate change impacts livestock production and health through changes in the quantity and quality of available feeds, heat stress, available water, livestock diseases and disease vectors, and genetic diversity (Thornton et al. 2009). A reduction in precipitation will result in the loss of natural pastures leading to a loss of adapted animal genetic resources. Accelerated feed shortages are likely to worsen the rangeland degradation further. A predicted loss of 25 % of animal production (Sequin 2008) relate to only reduced feeds and increased heat stress in the mixed crop-livestock system. Mapping and quantifying climatic data in combination with the spatial information on livestock production systems, livestock numbers and people was used to identify hotspots of change and vulnerability. Hotspots of vulnerability were identified where most people and livestock will be affected. Table 15.1 presents results grouped by livestock production systems, as adaption and mitigation options often will relate to these production systems.

15.3 Improving Adaption to Climate Change in Livestock Sector

Livestock producers have long been adapting to environmental and climate changes using herds of mixed animal species and breeds, widespread and seasonal pastures, splitting animals into discrete herds and mobility, and involving in other economic activities (McIntire 1991). However, increased urbanization, population growth, economic growth, consumption of animal source foods and commercialization made those existing coping mechanisms inadequate (Sidahmed et al. 2008). New approaches, technologies, and training to deal with climate change are now needed

Table 15.1 Projected changes in precipitation, temperature, vulnerable human and livestock population in the NENA

Production system	Countries	Precipitation reduces by	Temperature increases	Vulnerable rural people	Vulnerable livestock population
Agro-pastoral	MAR, TUN and ALG	11–28 %	2.2–3.3 °C	15–23 %	Sheep and goats ALG: 37 % TUN: 33 %
	EGY LIB		2.2–2.8 °C	EGY: 22 % LIB: 88 %	Sheep and goats EGY: 38 % LIB: 87 % Cattle EGY: 13 % LIB: 79 %
	Near East	Up to 20 %	2.3–3.1 °C	IRN: 29 % IRQ: 35 % JOR: 22 % SYR: 8 %	Sheep and goats IRN: 44 % IRQ, JOR and SYR: 24–38 % Cattle IRN and IRQ: 31 % JOR and SYR: 15 %
	GCC and YEM	↑7 % 24 %	2.2–2.9 °C		Sheep and goats OMN, QAT and YEM: 90 %; KWT and UAE: 50 %
Mixed extensive	MAR, TUN and ALG	ALG and TUN: 9–23 %, MAR: 8–26 % MAU: 15–29 %	ALG: 1.9–3.6 °C TUN: 1.6–2.8 °C MAR: 1.6–3.3 °C MAU: 2.3–3.2 °C	ALG: 71 % TUN: 65 % MAR: 70 % MAU: 16 %	Sheep and goats 30–59 % Cattle 41–61 %
	EGY LIB		2.2–2.8 °C	EGY: 22 % LIB: 88 %	Sheep and goats EGY: 38 % LIB: 87 % Cattle: EGY: 13 %; LIB: 79 %
	Near East	SYR: 18 % IRN and IRQ: 14 %	SYR: 1.7–2.3 °C IRN and IRQ: 2.5–3.3 °C	43–47 %	Sheep and goats SYR: ca. 50 % IRN: 35 % IRQ: 47 % Cattle SYR: ca. 50 % IRN: 39 % IRQ: 29 %

Source: Modified from Van de Steeg and Tibbo (2012)

ALG Algeria, *EGY* Egypt, *GCC* Gulf Countries Cooperation, *IRN* Iran, *IRQ* Iraq, *JOR* Jordan, *KWT* Kuwait, *LIB* Libya, *MAR* Morocco, *SYR* Syria, *TUN* Tunisia, *UAE* United Arab Emirates, *YEM* Yemen as well as better policies and stronger institutions to manage natural resources sustainably. Adaptation strategies include:

(a) *Integrating crops and livestock* which allows better use of crop residues as feed and animal manure as organic fertiliser and/or source of bioenergy for biogas, and reduces pressure on rangelands and water resources. *Supplementary feeding* of animals is also needed especially for animals reared for market as rangelands provide only a third or less of their feed needs. Introducing drought-tolerant crops and shrubs and use of appropriate tree forages (Kitalyi et al. 2008) would also help rehabilitate rangelands and increase productivity of livestock.
(b) *Herd diversity* (Hoffmann 2010) by using multi-species and multi-breed and *herd splitting* into smaller manageable groups and moving them into different areas would buffer against climatic and economic adversities, prevent over-grazing and maintain the long-term productivity of rangelands (Nyariki and Ngugi 2002). *Mobility* has also been used for centuries by livestock keepers as a strategy to adapt to spatial and temporal variations in precipitation, though it can lead to problems of overgrazing, exposure to new diseases and parasites, resource use conflicts, etc.
(c) *Production and marketing strategies* involve a range of husbandry adjustments to counteract heat stress that may suppress feed intake, production, fertility, and survival rates (Pilling and Hoffmann 2011). Livestock *insurance* scheme based on index (Barrett et al. 2008) which compensates clients for the loss of animals or reduced productivity because of drought should be introduced. The scheme is based on cumulative precipitation, cumulative temperature, area average yield, area livestock mortality and related indices. Unlike traditional insurance a payout is based on an external indicator which triggers a payment to all insured clients within a geographically defined space (Ouma et al. 2011).
(d) *Adapted local livestock breeds* produce under conditions where other breeds cannot survive, resist or tolerate diseases, drought, water scarcity, stress from strong heat and solar radiation. They are also integral parts of their environment that help sustain biodiversity, as highlighted in FAO's *Global Plan of Action for Animal Genetic Resources* (FAO 2007). Most of the adapted breeds, however, are largely uncharacterized and their loss as a result of droughts and floods, or disease epidemics related to climate change may increase. To secure against such disasters, it is necessary to characterize animal genetic resources and subsequently to build inventories, including information on the spatial distribution of breeds and valuable breeding stocks and countries should have a plan for conservation programmes. Countries need to introduce animal identification and traceability as an important livestock management tool.
(e) *Modelling and forecasting emerging infectious animal disease and early warning systems* are crucial components for preparedness. Remote sensing satellite imagery is now being used to study a variety of environmental parameters in order to evaluate their potential to predict the emergence patterns of mosquito vectors of the *Rift Valley Fever* (Gould and Higgs 2009). *Bluetongue* is another important viral disease whose distribution is affected by the changing climate. Climate and environmental changes might deeply alter the transmission pattern and disrupt the local epidemiological equilibrium, as is expected for malaria.

The demographic growth of large cities and, more generally, the increase of human populations in NENA will result in more intense livestock aggregation around market areas, the merging of populations from different origins, and increased trade from sub-Saharan Africa to these regions. With periurban growth and climate change, some devastating outbreaks could happen due to the fact that the vector *Culicoides* deposits their eggs in stagnant or slow moving waters with rich organic material or dung. *Old World Screwworm* risk prediction identified hotspots in southwest Iran, southwest Yemen, and along the south coast of Oman, and observed areas with suitable conditions in parts of Syria, Lebanon, Jordan, along the Nile Valley in Egypt, and in relatively large areas of Sudan. The FAO coordinated Global Information and Early Warning System (GIEWS) and the Famine Early Warning Systems Network (FEWS NET) of USAID were developed to manage the risk of food insecurity through the provision of timely and analytical early warning and vulnerability information (http://www.fews.net/).

(f) *Appropriate policies and institutions* for coping with climate change are needed for assisting livestock keepers, farmers and rural communities manage droughts in dry areas. Policies need to provide supportive conditions for smallholder farmers and pastoralists through guaranteeing access to grazing land and water, and facilitating the provision of appropriate services and infrastructure. Livestock keepers should be represented in national and international decision-making bodies, a voice in policy-making.

15.4 Improving Mitigation Roles of Livestock Sector to Climate Change

(a) *Adjusting livestock numbers* to available resources, increasing individual animal resource use efficiency and optimization of feed rations and feed additives or other technologies may be primarily used to reduce methane excretion in ruminants. GHG from enteric fermentation change as production systems intensify and move toward higher feed use and increased productivity. Less GHG emissions are produced, for example, in beef cattle intensive feedlot systems and dairy farms. Emissions from extensive systems can be reduced through improved genetic potential of the animals, increased feed quality and manure management. Reducing livestock numbers is probably the only effective way to reduce GHG emissions in pastoral systems. Problems to be overcome in mitigation are incentive systems, institutional linkages, policy reforms, monitoring techniques for carbon stocks, and appropriate verification protocols.

(b) *Animal waste management*: GHG emitted from manure are mainly methane and nitrous oxide (Steinfeld et al. 2006). Raising animals on pasture is an efficient way to reduce methane emission from manure. In addition to production of renewable energy, reducing storage duration of slurry, especially in hot conditions, the treatment of manure, and improved spreading techniques could reduce GHG emission (Dourmad et al. 2008).

(c) *Intensifying livestock production systems* reduce emissions through (1) improved feeding management through the use of biotechnologies and additives and high quality feeds and concentrates; (2) selective culling of unproductive animals, breed selection, improved herd health and minimizing involuntary culling; (3) keeping browsing and grazing animals together, especially when feed is in short supply, to increase complementarities and make use of forage that cannot easily be used by other species; (4) improved feed conversion efficiency through appropriate practices including genetics, nutrition, reproduction or health improvement.

Challenges or constraints to livestock sector, climate change adaptation strategies, benefits of the adaptation, and policy implications or interventions are summarized in Table 15.2.

Table 15.2 Challenges, adaptation strategies, benefits of adaptation and policy implications

Constraints/challenges	Adaptation strategies	Benefits of adaptation	Policy intervention
Feed scarcity both in quantity and quality, high cost of feeds	Improve crop-livestock integration (nutrient cycling)	Improves productivity, income, food security	Policy to optimize number of animals with resources available
Rangeland degradation, species disappearance	Herd management (herd splitting, culling, species diversification or substitution)	Prevents rural–urban migration	Rangeland management policy, PES
Expansion of croplands	Rehabilitate rangelands (water harvesting, grazing management, re-seeding)	Prevents overgrazing, land degradation and repeated crop failures	Representing livestock keepers in policy dialogue
	Use alternative feed resources (feed blocks, cactus, fodder trees)		Policies to limit inappropriate expansion
Animal health problems			
Vaccination coverage is very low	Improve vaccination coverage through improved vet capacity	Improves productivity, income, food security	Cross-border cooperation in the prevention of trans-boundary animal diseases ADs and zoonosis as per the OIE regulations
Limited capacity in disease diagnosis	Improving capacity in disease diagnosis, disease monitoring and surveillance	Prevents loss of livestock assets, zoonosis, and rural–urban migration	
Limited capacity in disease monitoring and surveillance	Creating sub-regional capacity in disease forecasting diseases and linking to CC	Prevents disease spread and loss of income due to trade restrictions	
Limited capacity in forecasting diseases and linking to CC		Improves public health and welfare	

(continued)

Table 15.2 (continued)

Constraints/challenges	Adaptation strategies	Benefits of adaptation	Policy intervention
Limited market access			
Low price of animals	Use of producers groups	Improves income of producers	Policies that encourage competitiveness of smallholders
	Create market information system	Prevents rural–urban migration	Policies that encourage local products that serve certain niche markets (branding)
	Capacity building in value addition to primary products	Contributes to conserving adapted breeds	
Inappropriate policies, regulations, land use and tenure			Improve land use and land tenure policies
Droughts, increased transhumance, increased livestock trade, TADs	Index-based livestock insurance scheme	Keeps livestock keepers job; allows to feed animals during scarcity, prevents TADs	Establishing early warning systems
	Conserve feeds, strengthen veterinary quarantine system		
Urban and periurban system			
Urban encroachment	Manure management	Reduces GHG emitted	Animal waste management policy
Animal waste management	Incentives for organic fertilizer use, nutrient cycling	Puts carbon back to soil and improves system productivity (crop yield and livestock productivity)	Education in consumption behavior helps consumers to change their diets
Contamination of soil and water	Use quality feeds	Culling mediocre ones releases feed for productive ones; reduces GHG emitted	
Human health concerns, pollution	Selective culling of unproductive animals, improved herd health		
Reducing land holding	Minimize involuntary culling		

(d) *Enhancing research into farming methods* to generate knowledge in search of better ways of managing farm inputs, characterizing local livestock breeds in terms of their resistance and tolerance to specific diseases, adaptation to poor-quality feeds or to feeding in harsh conditions, and tolerance to climatic extremes.

(e) *Improving policies* have the greatest chance of success in mitigation if they build on traditional pastoral institutions and knowledge, while providing pastoralists with food security benefits at the same time.

15.5 Enabling Conditions for Climate Change Adaptation

National politics and policies have a major effect on the livelihood of livestock keepers. Supportive policies stimulate, for example, the import of live animals in Jordan and Lebanon. Jordan relies on importing beef cattle for meat. Lebanon imports more than twice the amount of cattle and more than half the amount of sheep than that reared in the country. These import numbers are high, as local production is not supported by regulations and policies and witnessed that importing is cheaper than local production leading to further decline in local food production. The impact of climate change on the price of feeds will have direct effect on livestock production and import. In order to respond to the increasing demand for livestock products, enhancing local production should be stimulated by national policies. The import of live animals for local slaughtering ignores the GHG emission of livestock production elsewhere.

Gender disaggregation of roles in livestock production systems should be studied (Tibbo et al. 2008) to direct appropriate capacity building to improve adaptive responses to the impacts of climate change. Climate change is likely to intensify existing inequalities and have different effects on the capacity of women and of men to cope with additional stresses (IFAD 2009). In view of their role as the most significant suppliers of family labor and efficient managers of household food security, more emphasis needs to be placed on ensuring that any adaptation and mitigation strategies developed take into account these differences and the increased needs of women for building community resilience to climate change.

Regional cooperation needs enhancement in areas of the implementation of Global Plan of Action for Animal Genetic Resources (GPA-AnGR), developing regional capacity in vulnerability assessment, monitoring and adaptation measures, drought insurance scheme, early warning systems for climate risk reduction, regional trust fund for climate change adaptation and mitigation, mapping breeds against environment for exchange and conservation of genetic resources for sustainable use in the region, etc.

15.6 Conclusions and Recommendations

Climate change will have far-reaching effects on livestock sector in all the NENA countries although the impacts will vary considerably from location to location. Reduction in rainfall by up to 29 % and temperature increase by up to 4 °C will significantly reduce water available for much needed increase in food production. Degradation of rangelands will negatively impact food and feed production and biodiversity conservation. Extreme climatic events will be evident such as droughts, floods, sea level rise, sand storms and occasionally snow. Better modeling of impacts is needed to better define (at local level) and assure investment in adaptation strategies. Increasing incidences of droughts, new animal diseases and parasites, and scarcity of feed supply are issues farmers have already experienced. Disappearance of palatable rangeland species following severe degradation of grazing lands, severe water shortage and shrinkage of annual rivers, repeated crop failures due to recurrent droughts are visible phenomena. Producers have been trying to adapt to these changes but with only short-term measures and need sustainable and coordinated adaptation and mitigation measures so that they continue to produce by increasing resilience of their production systems. It is recommended that:

(a) Climate change impact assessment on livestock sector and the use of model projections should be considered as a priority.
(b) Adaptation to climate change is a top priority for livestock, crops and rangelands among others to achieve food security.
(c) Adaptation and mitigation to climate change are very much linked in natural resources sectors, including biodiversity and genetic resources for food and agriculture, and therefore attention should be paid to both aspects in view of synergies and funding opportunities.
(d) Full regional cooperation and exchange of successful experiences among countries using various networks and fora, funding for regional projects and programs should be strengthened.
(e) Enhancing coordination among relevant institutions at the local, national and regional levels, including the understanding of how farmers and herders, are coping with climate change for improving sharing of best practices. Exchange of genetic resources for food and agriculture and of their related knowledge may also be taken into consideration.
(f) Financing adaptation actions should be ensured through rural development funding mechanisms (official development assistance and other sources) as a primary funding source, with complementary specific climate change funding mechanisms or integrating adaptation priorities into rural development programmes and funding mechanisms may be relevant.
(g) Member Countries of the Region, FAO and other organizations to launch a cooperative action in order to enhance national capacities in tackling the impacts of climate change on agriculture and food security in the Region through:

- Enhancing involvement of policy and decision-makers and their recognition of climate change impacts;
- Elaborating and implementing national policies and strategies for adaptation to climate change in agriculture and food security;
- Considering the needs of proper management of genetic resources for food and agriculture in planning and implementing National Adaptation Programs of Action and Nationally Appropriate Mitigation Actions;

- Developing capacity in vulnerability assessment, monitoring and adaptation measures;
- Supporting assessment of the impact of climate change on livestock and rangelands in the region;
- Improving data-collection and information-sharing on climate change impacts and adaptation options between relevant stakeholders;
- Developing early warning systems against extreme climatic events;
- Strengthening national coordination among the multiple stakeholders and expanding involvement of stakeholders to include NGOs, civil society, universities, the private sector, etc.;
- Increasing public and private investment in climate change adaptation, improving capacity to access other available financial resources and considering the establishment of weather-based index insurance;
- Promoting the climate change agenda in the agricultural sector within national institutions systematically for fund raising;
- Enhancing integrated ecosystems approaches;
- Enhancing community-based management of livestock and rangeland resources;
- Implementing more flexible risk-management strategies through adjustments in stocking rates along with diversifying species of animals kept, and multiple production systems;
- Enhancing agricultural technologies such as the development of stress-tolerant forage varieties and the improvement of water resources development and management;
- Development partners assisting the assessment of climate change impacts should consider the formulation of projects aimed at improving the sustainable management of the scarce natural resources and safety nets and support projects to enhance the livelihoods of vulnerable groups.

References

Barrett CB, Sommarat C, Getachew G, McPeak JG, Mude AG, Vanderpuye-Orgle J, Yirbecho AT (2008) Codebook for data collected under the improving pastoral risk management on East African Rangelands (PARIMA) Project, Department of Applied Economics and Management, Cornell University, Ithaca, NY 14853-7801, USA. http://dyson.cornell.edu/special_programs/AFSNRM/Parima/projectdata.htm

Celis D, De Pauw E, Geerken R (2007) Assessment of land cover/land use in the CWANA region using AVHRR imagery and agroclimatic data. Part 2. Hot spots of land cover change and drought vulnerability. ICARDA, Aleppo, p 69

De Pauw E (2008) Hot spots of vulnerability to climate change. ICARDA Caravan 25:43–44

Dourmad J-Y, Rigolot C, van der Werf H (2008) Mission of greenhouse gas, developing management and animal farming systems to assist. In: Rowlinson P, Steele M, Nefzaoui A (eds) Livestock and global change. Proceedings of an international conference, Hammamet¸ Tunisia, 17–20 May 2008. Cambridge University Press, Cambridge, UK

Evans JP (2009) 21st century climate change in the Middle East. Clim Change 92:417–432

FAO (2007) Global plan of action for animal genetic resources and the Interlaken declaration. FAO, Rome. ftp://ftp.fao.org/docrep/fao/010/a1404e/a1404e00.pdf

Fujisaka S, Williams D, Halewood M (2011) The impact of climate change on countries' interdependence on genetic resources for food and agriculture. Commission on genetic resources for food and agriculture. Background study paper no. 48, FAO, Rome. ftp://ftp.fao.org/docrep/fao/meeting/017/ak532e.pdf

Gould EA, Higgs S (2009) Factors influencing emerging arbovirus diseases. Trans R Soc Trop Med Hyg 103:109–121

Hoffmann I (2010) Climate change & the characterization, breeding and conservation of anim. genet. resources. Anim Genet 41:32–46

IFAD (2009) Livestock and climate change. International Fund for Agricultural Development, Rome

IFAD (2010) Climate change and sustainable water resources management: IFAD's experiences in the Near East and North Africa and in Eastern and Central Europe background paper – executive summary by Avraam Louca. http://www.ifad.org/events/gc/33/roundtables/pn/bg_e.pdf

IPCC (2007) Climate change 2007: synthesis report. Contribution of working groups I, II and III to the fourth assessment report of the intergovernmental panel on climate change. In: Core Writing Team, Pachauri RK, Reisinger A (eds). IPCC, Geneva

IRIN (2011) SYRIA: drought pushing millions into poverty. http://reliefweb.int/node/367335

Kitalyi A, Rubanza C, Komwihangilo D (2008) Agroforestry and livestock: adaptation/mitigation strategies in agro-pastoral farming systems of Eastern Africa. In: Rowlinson P, Steele M, Nefzaoui A (eds) Livestock and global change. Proceedings of an international conference, Hammamet, Tunisia, 17–20 May 2008. Cambridge University Press, Cambridge, UK

McIntire J (1991) Managing risk in African pastoralism. In: Holden D, Hazel P, Pritchard A (eds) Risk in agriculture. Proceedings of the tenth agriculture sector symposium. The World Bank, Washington, DC

Nyariki DM, Ngugi RK (2002) A review of African pastoralists' production system: approaches to their understanding and development. J Hum Ecol 13:137–250

Ouma R, Mude A, van de Steeg JA (2011) Review of pastoral development in an era of escalating change: some innovations in risk management. Exp Agric 47:375–393

Pilling P, Hoffmann I (2011) Climate change and animal genetic resources for food and agriculture: state of knowledge, risks and opportunities. Background study paper no. 53, FAO, Rome

Sequin B (2008) The consequences of global warming for agriculture and food production. In: Rowlinson P, Steele M, Nefzaoui A (eds) Livestock and global change. Proceedings of an international conference, Hammamet, Tunisia, 17–20 May 2008. Cambridge University Press, Cambridge, UK

Sidahmed AE, Nefzaoui A, El-Mourid M (2008) Livestock and climate change: coping and risk management strategies for a sustainable future. In: Rowlinson P, Steele M, Nefzaoui A (eds) Livestock and global change. Proceedings of an international conference, Hammamet, Tunisia, 17–20 May 2008. Cambridge University Press, Cambridge, UK

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C (2006) Livestock's long shadow: environmental issues and options. LEAD. FAO, Rome

Thornton PK, van de Steeg J, Notenbaert A, Herrero M (2009) The impacts of climate change on livestock and livestock systems in developing countries: a review of what we know and what we need to know. Agric Syst 101:113–127

Tibbo M, Iñiguez L, Rischkowsky B (2008) Livestock research for climate change adaptation. ICARDA Caravan 25:40–42

Van de Steeg J, Tibbo M (2012) Livestock and climate change in the Near East: measures to adapt to and mitigate climate change. FAO, Regional Office for the Near East, Cairo

Zhang X et al (2005) Trends in Middle East climate extreme indices from 1950 to 2003. J Geophys Res 110:D22104, 12 pp. http://www.agu.org/pubs/crossref/2005/2005JD006181.shtml

Chapter 16
Afforestation Potential in the WANA Region to Sequester Carbon and Improve Soil Quality

Roger A. Williams

Abstract The region of West Asia and North Africa (WANA) is characterized by hot, dry climates which provide little support for vast areas of forests. This region currently contains 106.3 million ha of forests, which represents a 4 % decrease since 1990. These forests have suffered from a long history of degradation and over exploitation which has impacted soil quality and in some cases caused desertification to occur. Afforestation has benefits of sequestering C, stabilizing soil, and placing C and other elements into the soil, thus rehabilitating the soil. Many different tree species have been examined for afforestation purposes within the WANA region, and great care needs to be given to match species with site. Early successional and edaphic climax species may be candidates as they are typical of harsh environments. Based on reported species, C sequestration rates will vary from 0.3 to 3.6 tC/ha/year. Afforestation will enhance the sequestering of C in the soil, but only if the plantations exist on the site for relatively long periods. Most C is sequestered in the forest floor and the upper soil layer in the initial years after planting from the litter that begins to accumulate.

Keywords Forest cover • Tree species • Species performance • Soil Carbon • West Asia • North Africa

16.1 Introduction

The region of West Asia and North Africa (WANA) extends from Pakistan in the east to Morocco in the west and from Turkey in the north to Ethiopia and Sudan in the south. A Mediterranean climate dominates the region displaying cool to cold

R.A. Williams (✉)
School of Environment and Natural Resources, The Ohio State University,
210 Kottman Hall, 2021 Coffey Road, Columbus, OH 43210, USA
e-mail: williams.1577@osu.edu

M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_16,

Table 16.1 Total forest area (×1,000 ha), total carbon stock in forest biomass (Gt) and forest carbon stock (t/ha) in the WANA region, and compared to other world regions, 1990–2010[a]

		Year		
Region	Forest attribute	1990	2000	2010
West Asia	Total forest area (×1,000 ha)	25,588	26,226	27,498
	Total carbon stock in forest biomass (Gt)	1.1	1.2	1.3
	Mean forest carbon stock (t/ha)	43.0	43.8	47.3
North Africa	Total forest area (×1,000 ha)	85,123	79,224	78,814
	Total carbon stock in forest biomass (Gt)	1.8	1.8	1.7
	Mean forest carbon stock (t/ha)	21.1	22.7	20.9
Europe	Total forest area (×1,000 ha)	989,471	998,239	1,005,001
	Total carbon stock in forest biomass (Gt)	42.0	43.0	45.0
	Mean forest carbon stock (t/ha)	42.4	43.1	44.8
Latin America	Total forest area (×1,000 ha)	972,171	926,302	883,850
	Total carbon stock in forest biomass (Gt)	112.5	108.2	104.0
	Mean forest carbon stock (t/ha)	115.7	116.8	117.7
North America	Total forest area (×1,000 ha)	676,760	677,080	678,958
	Total carbon stock in forest biomass (Gt)	34.5	34.9	36.8
	Mean forest carbon stock (t/ha)	51.0	51.5	54.2

[a]Compiled and adapted from FAO 2011

wet winters and warm to hot dry summers (Kassam 1981). These hot, dry summer climates provide little support for vast areas of forests, and the majority of countries within this region are classified as Low Forest Cover Countries (LFCC) by FAO (FAO 2008). This region currently contains 106.3 million ha of forests (27.5 m ha in WA, 78.8 m ha NA), which represents a 4 % decrease since 1990 (FAO 2011). Overall WANA has experienced a net loss of 440,000 ha of forest land since 1990, most of which has occurred within the North Africa region (FAO 2011). The North Africa region witnessed a 7 % reduction in forest cover since 1990, while the West Asia region experienced a 7 % increase. Africa accounted for some of the world's largest forest losses since 1990, with an annual cover reduction of 937,000 ha between 1990 and 2000 (Nabuurs et al. 2007; FAO 2003).

These changes in forest cover (Table 16.1) created a 8 % decline in forest carbon (C) stocks in the North Africa region to an estimated 1.65 Gt C while the West Asia region experienced a 9 % increase in forest C stocks to its present estimate of 1.3 Gt C (FAO 2011). The C losses in the North Africa regions are attributed to the loss in forest area. On a per hectare basis, the West Asia region is comparable to other global regions, perhaps due to the most productive forests of the region that occur in Turkey and Iran. North Africa on the other hand displays a much lower C stock per hectare compared to all regions.

In view of the extremely arid conditions in the WANA region, the forest resource situation is somewhat precarious. Most countries have very limited forest cover and several have less than 1 % of their land area under forests or woodlands. Furthermore, most forest are open and of low productivity. The major portion of productive forest is located in the central and southern Sudan and has been subjected to heavy deforestation in the past 10 years. Indeed, the Sudan had one of the highest rates of deforestation in Africa, accounting for almost 18 % of Africa's forest-cover loss between 1990 and 2000 (FAO 2003). In WA region the average growing stock is estimated at 42 m^3 ha^{-1} which is far less than half of the world average of 110 m^3 ha^{-1} (FAO 2008). While Turkey has forests that contain volumes of 138 m^3 ha^{-1}, many areas that contain forests average only 10 m^3 ha^{-1} of growing stock. Turkey contains the most productive forests of the WA region with an average annual increment of 3.15 m^3 ha^{-1}, compared to an average annual increment of 0.22 m^3 ha^{-1} found throughout this region (FAO 2008).

The ecosystems within this region have undergone some of the most significant land use changes over the past centuries which have led to serious degradation of these ecosystems including desertification, soil salinization, and loss of soil organic C (SOC) (Puigdefabregas and Mendizabal 1998; Hbirkou et al. 2011; Lal 2001, 2003). Land degradation and desertification continue to be the major environmental issues in WANA, especially in countries where the agricultural sector makes a significant contribution to the national economy. The direct causes of land degradation and desertification in this region are numerous and include: (1) excessive use of irrigation water for crops, (2) overgrazing of livestock, (3) illegal and excessive fuelwood collection and charcoal production, (4) conversion of forests, rangelands and croplands for unplanned urban expansion and ecotourism development, and infrastructure development, (5) conversion of forests and rangelands to croplands, and (6) conflicts, resulting in the direct or indirect destruction or damage of forests (FAO 2003, 2008, 2011).

These dryland ecosystems are very sensitive to these forms of land use disturbances, which can easily cause some irrevocable changes (UNEP 1991; le Houerou 2000). Different methods, including reforestation and afforestation, have been examined as means to mitigate these changes and restore ecosystems. Reforestation and afforestation have the added benefits of sequestering C, stabilizing soil, and placing C and other elements into the soil, thus rehabilitating the soil (Niu and Duiker 2006; Paul et al. 2002; Vesterdal et al. 2007; Kumar et al. 2001). Many different tree species have been examined for reforestation purposes within the WANA region, including *Argania, Canocarpus, Juniperous, Acacia*, and *Pawlonia*, which have produced both successful and unsuccessful outcomes (Bhat et al. 1998; Tomar and Gupta 1985; Abido 2000; Aref and El-Juhany 2004; Padilla et al. 2009; Aladosa and El Aichb 2008). In areas of the WANA region where rainfall is more abundant productivity of forests may average 0.02–0.50 m^3 ha^{-1} $year^{-1}$, but can be as high as 2.9 m^3 ha^{-1} $year^{-1}$ in the natural *Pinus brutia* forests (Nahal 1995; GORS 1991). One study of irrigated *Eucalyptus* plantations in this region reported productivity as high as 17 m^3 ha^{-1} $year^{-1}$ (Abido 2000).

Table 16.2 Area of planted forests in WANA region from 1990 to 2010, and the relationship to the total forest area within each region and to the total area of forests planted globally (Adapted from FAO 2011)

		Region	
Year	Statistic	North Africa	West Asia
1990	Area planted (× 1,000 ha)	6,794	3,208
	% of total forest area in region	8.0	12.5
	% of total area planted globally	3.8	1.8
2000	Area planted (× 1,000 ha)	7,315	3,926
	% of total forest area in region	9.2	15.0
	% of total area planted globally	3.4	1.8
2010	Area planted (× 1,000 ha)	8,091	5,073
	% of total forest area in region	10.3	18.4
	% of total area planted globally	3.1	1.9

Over the past two decades, the amount of planted forest area has been increasing in the WANA region (Table 16.2). While the NA region contains a larger area of planted forests, the area of planted forests in the WA region has been increasing at a much faster rate (58 % increase compared to 19 % increase). Most of these plantings are for production purposes, and for the protection of soil and water (FAO 2011). When compared to the global situation, the areas of forest plantings in the WANA region have either maintained the same rate or have fallen behind.

In spite of the potential benefits afforded by reforestation efforts, relatively few projects have been initiated in the WANA region due to water supply issues, the inherent crop harvest volatility in agriculture, and the harsh environmental conditions that exist region wide (Flamos et al. 2007). It becomes evident that species selection, methods of management and matching proper species to the site are very critical in this process. This paper examines the potential species that can be used for reforestation, the proper management necessary for success, anticipated yields, and the benefits of these efforts including C sequestration and soil amelioration, and the potential problems to be encountered.

16.2 Tree Species Selection

Afforestation typically creates increased biomass and dead organic C pools, and to a lesser extent soil C pools (Paul et al. 2003). The selection of species to plant requires careful consideration of species/site requirements and planting goals. Species that are indigenous to a region are of first consideration for obvious reasons. However, those species may not demonstrate needed growth rates or fulfilment of desired soil remediation goals. While forest growth is important from the perspective of establishment and C capture, survivability is also of equal importance. Table 16.3 displays some of the most common tree species planted for reforestation and

Table 16.3 Some common tree species planted for reforestation and commercial production purposes within and around the WANA region with the reported growth rates and rotation lengths (Compiled from Del Lungo 2003)

Species	Region[a]	Mean annual increment (m^3 ha^{-1} $year^{-1}$)	Rotation (years)
Acacia auriculiformis	WA	8	10
Acacia nilotica	WA, NA	10–18	21
Dalbergia sissoo	WA	9	NA
Eucalyptus globus	WA	20	16
Eucalyptus grandis	WA, NA	16–32	6–25
Gmelina arborea	WA	13	60
Pinus halepenis	WA, NA	3–12	30–80
Pinus radiata	NA	20–30	20–38
Populus spp.	WA	12–19	15
Swietenia macrophylla	WA	7	50
Tectona grandis	WA, NA	4–12	35–65

[a]*WA* West Asia, including South Asia, *NA* North Africa, including East Sahelian Africa

production purposes within the region, based on the area planted to these species. As we might expect, there is a wide range of reported growth rates for some species, depending on the site and region where these species are planted. Since forest volume and biomass are directly related (Hahn 1984; Smith et al. 2003), we would anticipate that forests demonstrating the higher mean annual volume increment (MAI) would also demonstrate higher rates of C sequestration.

16.2.1 Considerations of C Sequestration and Survivability

The amount of C stock that a forest contains is highly dependent upon the species composition of the forest and the soil properties (Schulp et al. 2008; Bravo et al. 2008). What species to use for afforestation purposes with goals of soil rehabilitation and sequestering C should be given careful consideration. Coniferous trees tend to contain a larger amount of C per unit of tree biomass compared to broadleaved trees (Ibanez et al. 2002). Species composition will also influence the forest density, thus dictating the total standing C stock. Williams and Tao (2011) found that the total forest C stock is correlated to forest density as measured by basal area, and weakly correlated to the number of trees per area.

Afforestation strategies that seek to maximize the total forest basal area will be a more effective approach to maximize the total C stock rather than a focus on the total number of trees per area. Species composition can also influence the soil organic C by the quality and type of litterfall from trees and shrubs (Schulp et al. 2008). The rate of C sequestration through afforestation practices will vary tremendously by tree species and site, and globally ranges from 1.0 to 35.0 t CO_2 ha^{-1} $year^{-1}$ (Richards and Stokes 2004). According to the reporting countries in WANA, there is an average of 27.5 t C ha^{-1} and 40.3 t C ha^{-1} of C in living forest biomass in 2010 for West Asia and North Africa, respectively (FAO 2011).

Problems associated with afforestation in these arid climates can be very severe due to droughts, high temperatures, depleted soils, and grazing (Maestre et al. 2003). Thus it is because of these harsh environments that we need to look at the ecological adaptations of species to determine what species may best be established for afforestation purposes. Species that colonize land after severe disturbances are those that have the adaptations to acclimate to the harsh conditions created by these disturbances (Valiente-Banuet et al. 2006). Typically, severe disturbances tend to create large open areas that are characterized by exposures to high irradiance and temperatures, such as what may be found in arid climates. Early to mid-successional species therefore tend to be more drought and irradiance tolerant (Valiente-Banuet et al. 2006) and have deeper root systems (Padilla and Pugnaire 2007). Padilla et al. (2009) found higher survival rates with the use of mid-successional species in the restoration of arid shrublands.

However, some of these same desirable attributes of early successional species could likewise create longer-termed problems. This might be particularly true when afforestation is practiced in ecosystems more characteristic of grass and shrublands. The deeper rooted, fast-growing woody species can transpire large quantities of water, thus lowering the water table and potentially creating more water availability issues in areas where water is of short supply (Normile 2007; Cao et al. 2009, 2010, 2011). For example, *Eucalyptus* spp., a species that has been planted in the region, typically display relatively high growth rates where they are planted, but these species also have a high demand for water (Morris et al. 2004). Thus survival of this species in the arid climates would be questionable and could place a higher demand on already critical water sources.

Late successional species might be considered in areas where they occupy an edaphic climax, i.e., species that comprise the late successional communities because of harsh soil and climatic conditions. Species in these communities often persist due to the fact that they are adapted to and can tolerate moisture and nutrient depleted environments (Mansburg and Wentworth 1984). While species in these communities are not typically fast-growing, their ability to persist in such environments may outweigh the losses in growth rates.

16.2.2 Examples of Species Performance

Winrock International has provided information regarding additional species well-suited for planting in these arid climates. While these species, which include *Acacia seyal*, *A. saligna*, *A. tortilis*, *Albizia lebbeck*, *Prosopis cineraria*, and *Ziziphus mauritiana*, may not attain large size, they display the ability to survive the harsh arid environment and thus sequester C (Fagg 1991; Kaairia 1998; Crompton 1992; Hall 1994; Prinsen 1998; Sandison and Harris 1991). Many of these species provide additional benefits of creating fodder, edible fruits, and soil stabilization.

Table 16.4 Mean values of forest attributes and carbon stocks of different forest types in Katran Cukuru-Aladag, Adana, Turkey[a]

Forest type	Age (years)	Trees per hectare	Basal area (m^2 ha^{-1})	Carbon stock (mg C ha^{-1}) Above	Below	Total	Sequestration rate over life of stand (mg C ha^{-1} $year^{-1}$)
Pinus nigra	92	300	50.3	116	21	137	1.5
Cedrus libani	114	500	43.6	100	18	118	1.0
Mixed stand	103	900	47.4	73	13	86	0.8
Juniperus excelsa	100	625	30.3	4	4	28	0.3
Pinus brutia	100	525	51.6	102	18	120	1.2

[a]Adapted from Evrendilek et al. 2006

Average dry biomass of stems and branches in 3-year-old plantations of *Acacia saligna* has been reported to range from 65 to 80 t ha^{-1} (33–40 t C ha^{-1}) in the Riyadh region of Saudi Arabia (Hegazy and Aref 2010).

Recently Algeria has planted the largest areas in the North Africa region as part of afforestation attempts, primarily planting *Pinus* spp. and *Eucalyptus* spp. Approximately two-thirds of the Maghreb region consist of *Eucalyptus* spp., *Pinus* spp., and *Thuya* spp. (FAO 2003). Unfortunately many of these plantations have not yielded the results anticipated due to poorly adapted techniques, lack of proper maintenance, or unfavourable soil or climate conditions for the species planted.

Afforestation and reforestation practices for environmental rehabilitation have also been conducted in Western Asia, with that majority of areas planted in Iran and Turkey. In Iran approximately 2 m ha have been planted for purposes of sand dune stabilization, desertification control, and restoration of forest productivity, biodiversity and other ecological functions (FAO 2008). The primary species used in these projects include *Haloxylon persicum*, *Tamarix* spp., and *Prosopis* spp. Turkey annually regenerates approximately 25,000–30,000 ha through man-made and natural methods, and rehabilitates about 5,000 ha of degraded forests (FAO 2008). For production purposes both countries plant *Populus* spp. and Iran also plants *Eucalyptus* spp. These plantations mainly provide roundwood and energy wood, but also demonstrate potential for soil rehabilitation because of the establishment success that has been attained. Other species that have been used to develop forest plantations for a variety of purposes in the region include *Pinus brutia*, *P. pinea*, *P. halepensis*, *Acacia* spp., *Salix* spp., *Cedrus libani*, *Cupressus sempervirens*, *Quercus calliprinos*, and *Pistacia palaestina* (FAO 2008).

Evrendilek et al. (2006) reported C stock values for native forests regenerated naturally in Turkey (Table 16.4). *Pinus nigra*, *P. brutia*, and *Cedrus libani* forest contained the higher C stocks and sequestered C at rates of 1.5, 1.2, and 1.0 Mg C ha^{-1} $year^{-1}$, respectively, over the life of the stand. *Juniperus excelsa* sequestered C at a rate of only 0.3 Mg C ha^{-1} $year^{-1}$, demonstrating the variability of sequestration rates by species and site. The density of these forests, as measured by stand basal area, is strongly correlated (0.89) to the total forest C stock, but weakly correlated (0.55) with the number of trees per hectare. Turkey is considered to have the most

Table 16.5 A summary of afforestation performance indicators (low, medium, high) of ten tree and shrub species in two soil types in Khorezm, Uzbekistan. The soils were typed as gleyic solonchak soil according to FAO classification and represented a light sandy soil underlain by a loam layer and a more finely textured silt loam underlain by a loam layer (Khamzina et al. 2006)

Species	Survival	Root establishment	Aboveground biomass production	Growth	Overall potential for afforesting degraded land
Prunus armeniaca	Low	Low	Low	Low	Low
Biota orientalis	Medium	Low	Medium	Low	Low
Elaeagnus angustifolia	High	High	High	High	High
Morus alba	Medium	Medium	Medium	Medium	Medium
Populus euphratica	Low	High	Medium	Medium	Medium
Populus nigra var. *pyramidalis*	Low	Medium	Medium	Medium	Medium
Salix nigra	High	Medium	Medium	High	Medium
Tamaricx androssowii	High	High	High	Medium	High
Ulmus pumila	Medium	Medium	Medium	High	Medium

productive forests in west Asia, and the average increment of its forests is 3.15 m^3 ha^{-1}, while the average increment of other wooded land is only 0.22 m^3 ha^{-1} or less (FAO 2008).

Grunzweig et al. (2003) reported C sequestration rates and C stock in *Pinus halepensis* forests planted along the edge of the Negev desert as an afforestation project. The 35 year old plantation contained 65.0 ± 12.0 t C ha^{-1} and displayed a sequestration rate of 1.3–2.4 t C ha^{-1} $year^{-1}$. Based on these rates and the total afforestation projects within the region it is possible that these projects could sequester approximately 1 % of the anthropogenic C of the region (Koch et al. 2000) that is largely desert with a dense population.

Elaeagnus angustifolia and *Tamarix androssowii* have demonstrated superior biomass growth in afforestation plantings in Uzbekistan, producing 11.0 and 10.4 t ha^{-1} of aboveground dry matter, respectively (Khamzina et al. 2006). *E. angustifolia* further demonstrated the potential for rapid establishment based on the rate of root elongation. Within this region these two species were the top recommended species out of ten examined to use for afforestation purposes based upon their performance (Table 16.5). *Tamarix* spp. are aggressive colonizers and demonstrate abilities to capture sites quickly, characteristic of early successional species (Cleverly et al. 1997). Both species demonstrate the ability to grow on saline soils and accumulate soluble salts in their aboveground tissues; however, *Tamarix* spp. at later stages will release some of these salts back into the soil via salt glands and litterfall where salt has accumulated in its foliage (Khamzina et al. 2006).

Green shelterbelts are planted on agricultural land in most countries within Western Asia, but the information on the extent is difficult to attain. These shelterbelts are planted primarily for the purposes of protecting croplands against drying winds and wind deposition of sand. In most cases the tree species used in these operations include *Tamarix aphylla*, *Cupressus sempervirens*, *Ziziphus* spp., *Prosopis cineraria*, and *Phoenix dactylifera* (FAO 2008).

Table 16.6 A list of native and non-native species planted for all purposes within the WANA region and their commonly reported uses. Uses of tree products for food and medicinal uses are not listed

Species name	Common uses[a]	Species name	Common uses[a]
Acacia nilotica	1, 2, 3, 5, 6	*Pinus pinaster*	5, 6
Acacia seyal	1, 2	*Pistacia palaestina*	3
Acacia saligna	1, 2, 3, 4	*Populus* spp.	5, 6, 7
Acacia tortilis	2, 3, 4	*Prosopis africana*	1, 2, 3, 5, 6
Albizia lebbeck	1, 5, 6, 7	*Prosopis cineraria*	1, 2, 3, 5, 6
Argania spinosa	1, 2, 3, 5, 6	*Prosopis pallida*	1, 2, 3, 5, 6
Cedrus atlanticus	5, 6	*Quercus calliprinos*	3, 5, 6
Cedrus libani	5, 6	*Quercus faginea*	1, 2, 5, 6
Cupressus sempervirens	5, 6	*Quercus ilex*	1, 2, 4, 5, 6
Elaeagnus angustifolia	3	*Quercus suber*	3, 5, 6, cork
Eucalyptus spp.	5, 6, 7	*Salix* spp.	5, 6
Haloxylon persicum	2, 3	*Sclerocarya birrea*	5, 6, extracts
Juniperus excelsa	5, 6	*Tamarindus indica*	3, 4, 5, 6
Phoenix dactylifera	1, 5, 6	*Tamarix* spp.	3, 4
Pinus pinea	5, 6, 7	*Terminalia laxifolia*	5, 6
Pinus brutia	5, 6, 7	*Tetraclinis articulata*	5, 6, extracts
Pinus halepensis	5, 6, 7	*Thuya* spp.	5, 6
Pinus nigra	5, 6, 7	*Ziziphus mauritiana*	1, 2, 5, 6

[a]Uses include: 1 – fodder, 2 – fuel, 3 – soil stabilization/reclamation, 4 – windbreaks, 5 – timber, 6 – roundwood, 7 – pulp

16.2.3 Tree Species Selection

It is apparent that in spite of the dry arid climate characteristic of this region, there are a variety of species options available for afforestation purposes (Table 16.6). While many of these species may not exhibit rapid biomass and hence C accumulation, they display an ability to survive the harsh conditions. Yet, there is evidence to suggest that the right match of species to site can produce forests that will sequester substantial amounts of C and survive over relatively long periods. In the WANA region it is just as important for a plantation to reside on a site long enough to have a meaningful impact on soil rehabilitation.

Afforestation means that you are planting a forest on a site that previously did not have a forest due either to natural or anthropogenic reasons. In many cases there are ecological reasons why a site did not previously support a forest, which may include insufficient rainfall or soil moisture, temperature or soil texture extremes, or shallow soils. This is particularly true in these arid environments. Afforestation efforts in WANA are usually successful where the annual precipitation is 200 mm year^{-1} or greater (Le Houerou 2000). These efforts can be successful where annual precipitation is lower if the right species is selected for the site. Therefore selecting species that will be able to survive the environment is as critical as a species that can sequester C at a rapid rate. Afforestation plantations that reside longer on degraded land favour the accumulation of additional soil C (Hbirkou et al. 2011).

16.3 Potential for Improving Soil Quality

Afforestation has the potential to increase not only the aboveground C stocks but also the belowground C. Of all the terrestrial ecosystems forests contain the highest amount of C accounting for 86 % and 73 % of the world's aboveground and soil C stocks, respectively (Sedjo 1993). Afforestation can increase the total C stocks by an average of 18 % over a variable number of years (Guo and Gifford 2002) with the initial C accumulation occurring in the forest floor (Jandl et al. 2007). However the changes that occur in soil C from afforestation can be quite variable, ranging from an increase to a decrease in soil C (Guo and Gifford 2002; Vesterdal et al. 2002; Paul et al. 2003). How the soil responds will be a function of soil type, previous land use, and site conditions (Yanaia et al. 2000; Paul et al. 2003).

Soil C sequestration from afforestation may not contribute significantly to the total C budget initially, but contribute more over the long term if trees are kept in place for long periods (Vesterdal et al. 2002; Paul et al. 2002). Accordingly, this is why species selection based on survivability rather than growth rates is important. In fact, faster-growing species does not necessarily mean a faster build-up of soil C (Vesterdal et al. 2007). A complete C accounting model (GRC3) indicates that changes in soil C relative to the accumulation in tree biomass would be small following afforestation (Paul et al. 2003). Afforestation affects the C pool in the forest floor more immediately than in the mineral soil (Jandl et al. 2007). It is only after a longer period of time that this forest floor C is incorporated into the mineral soil. Until the forest floor C is incorporated into the mineral soil, it remains rather volatile.

Most soils in dryland ecosystems inherently contain low soil organic C (SOC) and low nutrient reservoirs (Lal 2002, 2004), and the process of desertification and salinization which is prevalent in many of these systems exacerbates this problem (Lal 2004). The lack of adequate water, the occurrence of drought, high temperatures and irradiance limits vegetation and lowers the net primary productivity in these systems. Consequently, the inputs to SOC from organic matter produced from plant communities, including forests, is minimal (Schulp et al. 2008; Breman and Kessler 1997; Geesing et al. 2000). Afforestation of these soils therefore has the potential to increase the SOC input that is lacking in areas where the SOC pool has been depleted as a result of land abuse and soil mismanagement. Currently the rate of soil sequestration of total soil C is generally low in these dryland systems (Lal 1999).

Practices, such as afforestation, that are used to rehabilitate soil and reduce desertification has the potential to enhance the C sequestration of these soils in the order of land use as irrigated cropland > rainfed cropland > rangeland (Lal 2002). While the response of the soils in WANA to afforestation is expected to be quite variable, the afforestation of drylands in other regions, such as Spain, Sudan, and India, has demonstrated a significant increase in SOC over periods of 8–30 years (Garg 1998; Alstad and Vetass 1994; Reucker et al. 1998).

It is anticipated that losses of SOC in the upper soil layer will occur immediately following plantation establishment. Site preparation prior to planting and accelerated decomposition of soil former labile C will account for some of these losses

(Zinn et al. 2002). In addition, the low volume of litterfall within the first few years will result in a delayed replacement of labile C. These losses of SOC in the upper layers will be greater in sandy soils compared to fine textured soils (Zinn et al. 2002). It is anticipated that the longer a plantation resides on the site, these losses will be minimized and the total soil C will increase (Hbirkou et al. 2011).

The total soil C stock in the silt loam and loamy sand soils of Uzbekistan was higher under the older plantations as a result of higher root biomass, greater litter inputs, and more developed herbaceous layers (Hbirkou et al. 2011). Shia and Cuib (2010) found that accumulation of soil C began to occur 5 years after reforestation, and 10–20 year old plantations had the highest soil C accumulation rates. Another study in semi-arid regions (Nosettoa et al. 2006) reported that after 15 years afforestation increased total C pools in the system by about 50 %. However, most of this increase resulted from tree biomass and forest litter accumulation; the SOC pools remained essentially unaffected.

Exactly how different soil types respond to afforestation is not completely understood (Vejre et al. 2003). Infertile sandy soils can lead to the formation of a thick forest litter layer (Staaf 1987; Vesterdal et al. 1995). The type of litter layer that develops in these plantations will influence the surface biota and the soil pH (Schulp et al. 2008; Berg 2000). Some report the increase in stored C in the case of fertile clayey soils as a result of the increase in aboveground and belowground litter (Liski 1995; Vogt et al. 1995). On the other hand, infertile mineral soils have been reported to store more C as a result of the slower decomposition and the complex formation between metal ions and organic compounds (Vesterdal et al. 2007). What can be garnered from many studies is that the rate of soil C sequestration is slower than what occurs in the aboveground C following afforestation (Jandl et al. 2007). What accumulates in the forest floor will do so rapidly, but is of a labile form of C and will only accumulate rapidly within the first few years following plantation establishment.

There is no doubt that there will be variability as to how the soil C will be affected by afforestation in the WANA region. However, in general it can be expected that initially there will be a decrease in the soil C, followed by an increase. Average data from 43 published and unpublished studies (Paul et al. 2002) from 204 study sites around the world indicates there is an initial decrease in soil C after afforestation, but then gradually increases to a point where after about 30 years the C within the upper 30 cm of the soil becomes greater than what existed in the previous soil. On average less C accumulated under long rotation softwood species, whereas more C accumulated under short rotation deciduous species. All these studies would suggest that eventually the soil C will become stable, but the amount and rate will depend upon the specific environment, soil type, previous soil management practices and the species planted. The sustainability of the soil C is most likely where forests reside on the site for longer periods (Hbirkou et al. 2011; Lal 2005; Paul et al. 2002).

Finally, tree species selection cannot be made independent of soil rehabilitation goals. For example, tree species that are considered to be salt tolerant typically use more groundwater and can restrict the uptake of salts. The net effect is that these salts eventually accumulate in the rooting zone thereby creating higher salinity in the upper soil layer (Cramer et al. 1999; Thorburn 1999). This was found to be the case with *E. angustifolia* (considered a salt tolerant species) plantations in Uzbekistan 4 years after planting as compared to 4-year-old *Populus euphratica* and *Ulmus pumila* plantations on the same soil (Hbirkou et al. 2011). Shallow rooted coniferous species tend to accumulate more soil organic material (SOM) in the forest floor and less in the mineral soil compared to hardwoods this affecting C stocks (Jandl et al. 2007). While there is general consensus that tree species affect soil C, it is variable and the extent of the impact is not completely understood (Binkley and Menyailo 2005).

16.4 Conclusions

Afforestation would appear to be one of the best options to increase the C stocks in the ecosystems of WANA since considering all of the terrestrial ecosystems, forests have the highest C density by comparison (Bolin et al. 2000). While there will be environmental limitations in WANA as to the total C that can be sequestered through afforestation, it will inevitably increase the C stock that currently exists. The arid and hot climates of the region present challenges to plantation establishment. It is important to carefully consider the proper species to plant, matching the species to the site conditions. A wide range of species have been planted successfully in WANA, including both native and exotic species. Since tree volume and biomass are directly related to C stocks, obviously planting fast-growing species and species that attain appreciable size will sequester and store C faster.

However, selecting species that are more likely to survive over long periods on a site needs to be considered, which may or may not be a compromise with tree growth rates and size. Plantations that reside on a site longer allow more C build-up in the soil. Losses in SOC often occurs in the upper soil layers within the first few years after afforestation, but eventually builds up and becomes resident in the mineral soil. One should consider species that are characteristic of early successional stages, or are part of an edaphic climax community. Such species typically are more resilient to harsh environmental conditions that occur after major disturbances, or are inherent in a site.

The C sequestration rates will vary widely across the region, depending on species selected and site conditions. Reported C sequestration rates have ranged on average from 0.3 t C ha^{-1} $year^{-1}$ (*Juniperous excelsia*) to 2.4 t C ha^{-1} $year^{-1}$ (*Pinus halepensis*). However, under ideal conditions, rates of 13.3 t C ha^{-1} $year^{-1}$ have been reported for *Acacia saligna* in Saudi Arabia. These compare to the reported global C sequestration rates of 1.0–35 t C ha^{-1} $year^{-1}$. Managing these afforestation plantations to maximize the basal area is more critical to maximizing the C stock rather than focusing on the number of trees per area.

Afforestation efforts in WANA are usually successful where the annual precipitation is 200 mm $year^{-1}$ or greater. There will be cases where success will be achieved when precipitation is less than this, but will be the proper matching of species with site is critical. The alternative would be to provide irrigation to supplement necessary water, but this makes afforestation projects more costly, and puts additional stress on a water supply that is critical in many areas.

Afforestation probably affects the C stock in the forest floor more than that of the mineral soil. The forest floor becomes an important C pool in afforestation projects even though it can be volatile and lost through changing site conditions. Eventually C becomes incorporated into the mineral soil and slowly builds up over time as the plantation becomes older. Therefore the residence time of trees on a site becomes important to the total C sequestration in the WANA region. Although exceptions will occur in various regions of WANA (most likely depending on species), the overall changes in soil C are likely to be small when compared to the accumulation in the tree biomass.

References

Abido M (2000) Growth performance of *Eucalyptus camaldulensis* Dehn. Under irrigated and non-irrigated conditions. Damascus J Agric Sci 16:68–81 (in Arabic)

Aladosa CL, El Aichb A (2008) Stress assessment of argan (*Argania spinosa* (L.) Skeels) in response to land uses across an aridity gradient: translational asymmetry and branch fractal dimension. J Arid Environ 72:338–349

Alstad G, Vetass OR (1994) The influence of *Acacia tortilis* stands on soil properties in arid northeastern Sudan. Acta Oecol 15:449–460

Aref IM, El-Juhany LI (2004) Planting *Juniperus procera* trees in the natural forests of Saudi Arabia: the first trial. In: The second conference of development and environment in Arab World, Assiut University, Egypt, 23–25 Mar 2004, pp 339–344

Berg B (2000) Litter decomposition and organic matter turnover in northern forest soils. For Ecol Manage 133(1–2):13–22

Bhat NR, Madouh TA, Al-Manaie H, Al-Zalzaleh M (1998) Growth performance of Paulownia clones in the arid coastal climate of Kuwait. Res Bull 78, Agric Res Center, King Saud Univ, pp 5–16

Binkley D, Menyailo O (2005) Gaining insights on the effects of trees on soils. In: Binkley D, Menyailo O (eds) Tree species effects on soils: implications for global change, NATO science series. Springer, New York, pp 1–16

Bolin B, Sukumar R, Ciais P, Cramer W, Jarvis P, Kheshgi H, Nobre C, Semonov S, Steffen W (2000) Global perspective. In: Watson R, Noble I, Bolin B, Ravindranath N, Verardo DJ, Dokken D (eds) Land use, Land-use change, and forestry. Cambridge University Press, Cambridge, pp 23–52

Bravo F, Bravo-Oviedo A, Díaz-Balteiro L (2008) Carbon sequestration in Spanish Mediterranean forests under two management alternatives: a modeling approach. Eur J For Res 27:225–234

Breeman H, Kessler JJ (1997) The potential benefits of agroforestry in the Sahel and other semi-arid regions. Eur J Agron 7:25–33

Cao S, Chen L, Yu X (2009) Impact of China's grain for green project on the landscape of vulnerable arid and semiarid agricultural regions: a case study in northern Shaanxi Province. J Appl Ecol 46:536–543

Cao S, Wang G, Chen L (2010) Questionable value of planting thirsty trees in dry regions. Nature 465:31

Cao S, Chen L, Shankman D, Wang C, Wang X, Zhang H (2011) Excessive reliance on afforestation in China's arid and semi-arid regions: lessons in ecological restoration. Earth-Sci Rev 104:240–245

Cleverly JR, Stanly DS, Sala A, Devitt DA (1997) Invasive capacity of *Tamarix ramosissima* in Mojave Desert floodplain: the role of drought. Oecologia 111:12–18

Cramer VA, Thorburn PJ, Fraser GW (1999) Transpiration and groundwater uptake from farm forest plots of *Casuarina glauca* and *Eucalyptus camaldulensis* in saline areas of southeast Queensland, Australia. Agric Water Manag 39:187–204

Crompton H (1992) Acacia saligna – for dryland fodder and soil stabilization. Fact sheet NFTA 92–03. Winrock International. http://www.winrock.org/fnrm/factnet/factpub/FACTSH/A_saligna.html. Accessed 30 Apr 2013

Del Lungo A (2003) Planted forest database: analysis of annual planting trends and silvicultural parameters for commonly planted species. In: Carle J, Varmola M (eds) Planted forests and trees working papers, forestry resources division, Food and agriculture organization of the United Nations, working paper FP/26, Rome, p 61

Evrendilek F, Berberoglu S, Taskinsu-Meydan S, Yilmaz E (2006) Quantifying carbon budgets of conifer Mediterranean forest ecosystems, Turkey. Environ Monit Assess 119:527–543

Fagg, C (1991) Acacia tortilis – a fodder tree for desert sands. Fact sheet NFTA 91–01. Winrock International. http://www.winrock.org/fnrm/factnet/factpub/FACTSH/A_tortilis.html. Accessed 30 Apr 2013

FAO (2003) Forestry outlook study for Africa: subregional report – North Africa. African Development Bank, European Commission, Food and Agriculture Organization of the United Nations, Rome, p 50

FAO (2008) The status and trends of forests and forestry in West Asia. Subregional report of the Forestry Outlook Study for West and Central Asia, Forestry policy and institutions working paper no. 20, Rome, p 84

FAO (2011) State of the world's forests 2011. Food and Agriculture Organization of the United Nations, Rome, p 164. ISBN 978-92-5-106750-5

Flamos A, Papadopoulou A, Karakosta C, Theodorou S, Psarras J (2007) CDM in MENA countries: strengths, weaknesses, and opportunities. Paper presented at the fourth Middle East and North Africa conference, Damascus, 24–27 June 2007, p 20

Garg VK (1998) Interaction of tree crops with sodic environments. Land Degrad Dev 9:81–93

Geesing D, Felker P, Bingham RL (2000) Influence of mesquite (*Prosopis glandulosa*) on soil nitrogen and carbon development: implications for global carbon sequestration. J Arid Environ 46:1–24

GORS (1991) The study of soils and forests of coastal area using remote sensing techniques (Lattakia Governorate). General Organization of Remote Sensing, Damascus (in Arabic)

Grünzweig JM, Lin T, Rotenberg E, Schwartz A, Yakir D (2003) Carbon sequestration in arid-land forest. Glob Change Biol 9:791–799

Guo LB, Gifford RM (2002) Soil carbon stocks and land use change: a meta analysis. Glob Change Biol 8:345–360

Hahn JT (1984) Tree volume and biomass equations for the Lake States. Res. Pap. NC-250. U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, St. Paul, p 10

Hall J (1994) Acacia seyal – a multipurpose tree for the Sahara desert. Fact sheet NFTA 94–07. Winrock International. http://www.winrock.org/fnrm/factnet/factpub/FACTSH/A_seyal.html. Accessed 30 Apr 2013

Hbirkou C, Martius C, Khamzina A, Lamers JPA, Welp G, Amelung W (2011) Reducing topsoil salinity and raising carbon stocks through afforestation in Khorezm, Uzbekistan. J Arid Environ 75:146–155

Hegazy SS, Aref IM (2010) Suitability of fast-growing trees and date palm fronds for particle board production. Forest Prod J 60:599–605

Ibáñez JJ, Vayreda J, Gracia C (2002) Metodología complementaria al Inventario Forestal Nacional en Catalunya. In: Bravo F, del Río M, del Peso C (eds) El Inventario Forestal Nacional. Elemento clave para la Gestión Forestal Sostenible, pp 67–77

Jandl R, Lindner M, Vesterdal L, Bauwens B, Baritz R, Hagedorn F, Johnson DW, Minkkinen K, Byrne KA (2007) How strongly can forest management influence soil carbon sequestration? Geoderma 137:253–268

Kaairia S (1998) Ziziphus mauritiana – a valuable tree for arid and semi-arid lands. Fact sheet NFTA 98–03. Winrock International. http://www.winrock.org/fnrm/factnet/factpub/FACTSH/ziziphus.htm. Accessed 30 Apr 2013

Kassam AH (1981) Climate, soil and land resources in North Africa and West Asia. Plant Soil 58:1–29

Khamzina A, Lamers JPA, Worbes M, Botman E, Vlek PLG (2006) Assessing the potential of trees for afforestation of degraded landscapes in the Aral Sea Basin of Uzbekistan. Agrofor Syst 66:129–141

Koch J, Dayan U, Mey-Marom A (2000) Inventory of emissions and removals of greenhouse gases in Israel. Water Air Soil Pollut 123:259–271

Kumar S, Datta R, Sinha S, Kojima T, Katoh S, Mohan M (2001) Carbon stock, afforestation and acide deposition: an analysis of inter-relation with reference to arid areas. Water Air Soil Pollut 130:1127–1132

Lal R (1999) Soil management and restoration for C sequestration to mitigate the accelerated greenhouse effect. J Prog Environ Sci 1:307–326

Lal R (2001) Potential of desertification control to sequester carbon and mitigate the greenhouse effect. Clim Chang 51:35–72

Lal R (2002) Carbon sequestration in dryland ecosystems of West Asia and North Africa. Land Degrad Dev 13:45–59

Lal R (2003) Global potential of soil carbon sequestration to mitigate the greenhouse effect. Crit Rev Plant Sci 22:151–184

Lal R (2004) Carbon sequestration in dryland ecosystems. Environ Manage 33:528–544

Lal R (2005) Forest soils and carbon sequestration. For Ecol Manage 220:242–258

Le Houerou HN (2000) Restoration and rehabilitation of arid and semiarid Mediterranean ecosystems in North Africa and West Asia: a review. Arid Soil Res Rehabil 14:3–14

Liski J (1995) Variation in soil organic carbon and thickness of soil horizons within a boreal forest stand—effect of trees and implications for sampling. Silva Fenn 29:255–266

Maestre FT, Cortina J, Bautista S, Bellot J, Vallejo R (2003) Small-scale environmental heterogeneity and spatiotemporal dynamics of seedling establishment in a semiarid degraded ecosystem. Ecosystems 6:630–643

Mansburg LT, Wentworth L (1984) Vegetation and soils of a serpentine barren in western North Carolina. Bull Torrey Bot Club 111:273–286

Morris J, Ningnan Z, Zengjiang Y, Collopy J, Daping X (2004) Water use by fast-growing *Eucalyptus urophylla* plantations in southern China. Tree Physiol 24:1035–1044

Nabuurs GJ, Masera O, Andrasko K, Benitez-Ponce P, Boer R, Dutschke M, Elsiddig E, Ford-Robertson J, Frumhoff P, Karjalainen T, Krankina O, Kurz WA, Matsumoto M, Oyhantcabal W, Ravindranath NH, Sanz Sanchez MJ, Zhang X (2007) Forestry. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA (eds) Climate change 2007: mitigation. Contribution of working group III to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK/New York

Nahal I (1995) Study on sustainable forest resources development in Syria. Univ Aleppo Agric Sci Ser 23:29–67

Niu X, Duiker SW (2006) Carbon sequestration potential by afforestation of marginal agricultural land in the Midwestern U.S. For Ecol Manage 223:415–427

Normile D (2007) Getting at the roots of killer dust storms. Science 317:314–316

Nosettoa MD, Jobbagy EG, Paruelo JM (2006) Carbon sequestration in semi-arid rangelands: Comparison of *Pinus ponderosa* plantations and grazing exclusion in NW Patagonia. J Arid Environ 67:142–156

Padilla FM, Pugnaire FI (2007) Rooting depth and soil moisture control Mediterranean woody seedling survival during drought. Funct Ecol 21:489–495

Padilla FM, Ortega R, Sanchez J, Pugnairea FI (2009) Rethinking species selection for restoration of arid shrublands. Basic Appl Ecol 10:640–647

Paul KI, Polglase PJ, Nyakuengama JG, Khanna PK (2002) Change in soil carbon following afforestation. For Ecol Manage 168:241–257

Paul KI, Polglase PJ, Richards GP (2003) Predicted change in soil carbon following afforestation or reforestation, and analysis of controlling factors by linking a C accounting model (CAMFor) to models of forest growth (3PG), litter decomposition (GENDEC) and soil C turnover (RothC). For Ecol Manage 177(1–3):485–501

Prinsen J (1998) Albizia lebbeck – a promising fodder tree for semi-arid regions. Fact sheet NFTA 98–03. Winrock International. http://www.winrock.org/fnrm/factnet/factpub/FACTSH/A_lebbeck.html. Accessed 30 Apr 2013

Puigdefabregas J, Mendizabal T (1998) Perspectives on desertification: Western Mediterranean. J Arid Environ 39:209–224

Richards KR, Stokes C (2004) A review of forest carbon sequestration cost studies: a dozen years of research. Clim Chang 63(1–2):1–48

Ruecker G, Sachad P, Alcubilla MM, Ferrer C (1998) Natural regeneration of degraded soils and sites: changes on abandoned agricultural terraces in Mediterranean Spain. Land Degrad Dev 9:179–188

Sandison M, Harris P (1991) Prosopis cineraria – multipurpose tree for arid areas. Fact sheet NFTA 91–04. Winrock International. http://www.winrock.org/fnrm/factnet/factpub/FACTSH/P_cineraria.html. Accessed 30 Apr 2013

Schulp CJE, Nabuurs G, Verburg PH, de Waal RW (2008) Effect of tree species on carbon stocks in forest floor and mineral soil and implications for soil carbon inventories. For Ecol Manage 256:482–490

Sedjo RA (1993) The carbon cycle and global forest ecosystem. Water Air Soil Pollut 70:297–307

Shia J, Cuib L (2010) Soil carbon change and its affecting factors following afforestation in China. Landsc Urban Plan 98:75–85

Smith JE, Heath LS, Jenkins JC (2003) Forest volume-to biomass models and estimates of mass for live and standing dead trees of U.S. forests. Gen. Tech. Rep. NE-298, U.S. Department of Agriculture, Forest Service, Northeastern Research Station, Newtown Square, p 57

Staaf H (1987) Foliage litter turnover and earthworm populations in three beech forests of contrasting soil and vegetation types. Oecologia 72:58–64

Thorburn PJ (1999) Interactions between plants and shallow, saline water tables- synopsis. Agr Water Manage 39:89–90

Tomar OS, Gupta RK (1985) Performance of some forest tree species in saline soils under shallow and saline water-table conditions. Plant Soil 87:329–335

UNEP (1991) Status of desertification and implementation of the United Nations plan of action to combat desertification: report of the Executive Director: Governing Council, third special session. United Nations Environment Programme, Nairobi, p 88

Valiente-Banuet A, VitalRumebe A, Verdu M, Callaway RM (2006) Modern quaternary plant lineages promote diversity through facilitation of ancient tertiary lineages. Proc Natl Acad Sci USA 103:16812–16817

Vejre H, Callesen I, Vesterdal L, Raulund-Rasmussen K (2003) Carbon and nitrogen in Danish forest soils – contents and distribution determined by soil order. Soil Sci Soc Am J 67:335–343

Vesterdal L, Dalsgaard M, Felby C, Raulund-Rasmussen K, Jørgensen B (1995) Effects of thinning and soil properties on accumulation of carbon, nitrogen and phosphorus in the forest floor of Norway spruce stands. For Ecol Manage 77:1–10

Vesterdal L, Ritter E, Gundersen P (2002) Change in soil organic carbon following afforestation of former arable land. For Ecol Manage 169:137–143

Vesterdal L, Rosenqvist L, Van Der Salm C, Hansen K, Groenenberg BJ, Johansson MB (2007) Carbon sequestration in soil and biomass following afforestation: experiences from oak and Norway spruce chronosequences in Denmark, Sweden and the Netherlands. In: Heil GW, Muys B, Hansen K (eds) Environmental effects of afforestation in North-Western Europe: from field observations to decision support. Springer, Dordrecht, The Netherlands, pp 19–51, 320 p

Vogt K, Vogt D, Brown S, Tilley J, Edmonds R, Silver W, Siccama T (1995) Dynamics of forest floor and soil organic matter accumulation in boreal, temperate, and tropical forests. In: Lal R, Kimble J, Levine E, Stewart B (eds) Soil management and greenhouse effect, advances in science. CRC Press, Boca Raton, pp 159–178

Williams RA, Tao Y (2011) A carbon management diagram for oak–hickory forests in southern Ohio. North J Appl For 28:161–165

Yanaia RD, Arthurb MA, Siccamac TG, Federerd CA (2000) Challenges of measuring forest floor organic matter dynamics: repeated measures from a chronosequence. For Ecol Manage 138:273–283

Zinn YL, Resck DVS, da Silva JE (2002) Soil organic carbon as affected by afforestation with *Eucalyptus* and *Pinus* in the *Cerrado* region of Brazil. For Ecol Manage 166:285–294

Part V
Policy, Financial, Institutional and Cooperation Issues

Chapter 17
Mainstreaming Adaptation to Climate Change into the Development Agenda

Nasri Haddad and Kamel Shideed

Abstract Global climate variability and change is a serious threat to the environment, natural resources, and production systems. They are also challenges to social and economic development. Recently, donor agencies, governments and non-governmental organizations have started to pay more attention to the risks and uncertainties associated with climate variability and change and to develop plans and guidelines to integrate this issue into their development planning processes. Most of the work on adaptation is focusing on how to reduce the impact of climate change per se, rather than addressing the factors that cause vulnerability to the phenomena. Mainstreaming adaptation to climate change into the national development agenda is necessary to cope with the climate change impacts, because climate change is a development issue that has economic and social dimensions and impact. ICARDA's approach to climate change adaptation is to build on technologies and research/development methods that have proved successful in the dry areas. The objective is to strengthen the adaptive capacity of communities and the resilience of farming systems, thus addressing both mitigation and adaptation. The present paper presents examples from the CWANA region where mainstreaming to climate change into the development efforts has been considered from the initiation, development and implementation of projects addressing climate change.

Keywords Central and West Asia and North Africa (CWANA) • Adaptation measures and approaches • Vulnerability reduction approach • Policy and socio-economic aspects

---

N. Haddad (✉) • K. Shideed
International Center for Agricultural Research in the Dry Areas (ICARDA),
P. O. Box 950764, 11195 Amman, Jordan
e-mail: n.haddad@cgiar.org

M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_17,

17.1 Introduction and Background

Global climate variability and change is a serious threat to the environment, natural resources, and production systems. It results in lower river flows, increased evapotranspiration, greater terminal heat stress, drier soils, and shorter growing seasons, all of which will decrease agricultural productivity. It is now evident that the effects of high temperatures, altered patterns of precipitation and possible increased frequency of extreme events, such as drought and floods, will probably combine to depress yields and increase production risks in many regions of the world, widening the gap between rich and poor countries (IPCC 2001a, b; CGIAR 2010).

According to the Intergovernmental Panel on Climate Change (IPCC) (2001a), Central and West Asia and North Africa (CWANA) is among the most vulnerable regions in the world for predicted decreases in water and food security. Changes in rainfall and temperature patterns could also affect biodiversity. Many species might not be able to adapt or migrate. However, the most likely impact on CWANA, based on various simulation models, is the adverse effect on its semi-arid zones (IAASTED 2009).

These changes are serious threats and challenges to social and economic development and achievement of the Millennium Development Goals (MDGs) for poverty reduction (Tearfund 2006; OECD 2006; UNDP 2010). Moreover, many development efforts are at risk if the effects of climate change are not taken into account at the time when development plans and programs are initiated.

Many poor countries already struggle to cope with extreme weather and variations in the climate. People in the poorest countries are the most reliant on environmental resources for their livelihoods. These resources are already under pressure and likely to be degraded further by climate change (Oates et al. 2001). A consensus has emerged that developing countries are more vulnerable to climate change than developed countries because of the predominance of agriculture in their economies, the scarcity of capital for adaptation measures, their warmer baseline climates, and their exposure to extreme events (Parry et al. 2001). Thus, climate change may have particularly serious consequences for the developing world.

Recently, donor agencies, governments and non-governmental organizations have started to pay more attention to the risks and uncertainties associated with climate variability and change (Tearfund 2006) and to develop plans and guidelines to integrate this issue into their development planning processes (UNDP 2010).

17.2 Impact of Climate Change and Adaptation Measures and Approaches

It is crucial to understand the negative impact of climate change on the agricultural sector, farming communities, and the rural poor. This understanding will help in the development of proper adaptation and mitigation measures, including proper policies that moderate, if not eliminate, such impacts. The policy measures are an important part in the process of mainstreaming adaptation into the development agenda and into government planning processes.

Even though our focus in this article is more on agricultural activities and rural communities, we need to realize that the effects of climate change on the rural poor may not necessarily be felt only through its impact on agriculture. Climate change could affect the spread of human disease, natural resource degradation and infrastructure destruction. All these will have a pronounced effect on the poor (Hertel and Rosch 2010). Climate change will require a comprehensive look at the development agenda as a whole and not only as it relates to the agricultural development agenda.

Climate change will have significant effects on agriculture. The standard circulation models show that many of the world's dry areas will be severely affected by climate change. Large parts of West Asia and North Africa (WANA) will experience at least a 20 % decrease in rainfall; it could be up to 50 % in many areas. Decreases in rainfall will directly translate into reduced production and necessitate changes in cropping patterns and agricultural production.

Climate change will also increase risk, because extreme events (drought, floods, and temperature spikes) are predicted to increase in frequency and magnitude. Greater variability will compound the problems of the dry areas where variability is already high. Developing countries will be hard hit, particularly those countries in WANA, south Asia and sub-Saharan Africa with extensive dry areas. These countries are very dependent on agriculture, not only for food security, but also for employment and economic growth. The International Food Policy Research Institute has projected that, as a result of climate change, under irrigated conditions global wheat production could be reduced by 47 %, rice by 27 %, and maize by 13 % by 2050 (Rosegrant 2011).

Climate change adaptation is defined as, "Adjustment in natural or human systems in response to actual or expected climate stimuli or their effects which moderates harm or exploits beneficial opportunities." (IPCC 2001a). It also encompasses actions reducing the adverse consequences of changes in the climate (UNDP 2010). In contrast, DFID (2006) relates adaptation to risk management and development and indicates that, "Adaptation is about reducing the risks posed by climate change to people's lives and livelihoods." Adaptation is also considered as, *"…adjustments made in response to stress…" and "…increasing climate resilience …"* (UNDP 2010)

The IPCC fourth assessment report indicated clearly that adaptation is a means of addressing the effects resulting from the warming that has already occurred as a result of past emissions (IPCC 2007). As such, it considers adaptation as a complementary strategy to mitigation. Adaptation should minimize the potentially negative effects of a variable climate, and successful adaptation enhances a system's ability to deal with uncertain future changes.

Adaptation is not a new phenomenon. "It is clear that individuals and societies have adapted to climate change over the course of human history and will continue to do so" (Adger 2003). We can learn a great deal from examining studies of the poverty impacts of historical climatic events, which highlight these events as some of the most important reasons for households falling into or remaining trapped in poverty in rural areas (Adger 2003). Therefore, adaptation to climate change becomes an immediate need (Persson 2008).

Most of the work on adaptation is focusing on how to reduce the impact of climate change per se, rather than addressing the factors that cause vulnerability to the phenomena (Schipper 2007).

Since the sub-regions in CWANA will be affected differently by global climate change, adaptation options will have to be site and situation specific. In many areas of CWANA, water is projected to become even scarcer (IPCC 2007) and, therefore, improved *water resource management* and efficient water use will be crucially important. This is particularly so for rainfed agriculture technologies, such as water harvesting, and supplemental irrigation will become particularly important (IAASTED 2009).

Diversifying production portfolios as a strategy to cope with risk might become an important option. Introducing new cropping patterns adapted to site-specific conditions will require increased use of modern technologies, such as crop simulation modeling and GIS, for long-term planning to assess and reduce the risks related to changed practices (IAASTED 2009).

Conservation agriculture can strengthen both mitigation and adaptation to climate change. It provides multiple benefits, including lower production costs, higher yields, better soil structure, reduced erosion, and better organic matter retention and thereby increased carbon sequestration (ICARDA 2010).

Crop varieties with drought tolerance, early growth vigor for rapid establishment, and phonological adaptation to changed climatic conditions are of particular importance in rainfed agriculture. Breeding crops for improved heat tolerance is an important adaptation strategy to avoid significant yield reductions because of a rise in temperatures.

At least 20 % of the world's irrigated land (more than 50 million ha) is salt-affected and/or irrigated with waters containing elevated levels of salts. This trend will likely continue. Rising sea levels are expected to accelerate saline water intrusion, highlighting the need to find ways to effectively use salt-prone waters (generated by irrigated agriculture or pumped from aquifers) for irrigation (ICARDA 2010). Similarly, salt-affected soils, which occur in at least 75 countries, will have to be used for agriculture (IAASTED 2009). This will require a comprehensive approach, focusing on amelioration of new lands, rehabilitation of salt-affected lands generated by past irrigation practices, improved productivity per unit of water used, and environmental protection.

Given the changing climatic conditions, producers will have to cope with new and exacerbated *pest, disease and weed problems*.

Feed shortage and availability will be a major concern for livestock producers because of rangeland and pasture productivity and grain prices. Whereas intensively managed livestock systems have greater potential for adaptation than crop systems, pastoral systems might need more attention since the rate of technology adoption is generally slower as changes in technology are viewed as risky (IPCC 2007).

However, all technical options to adapt to climatic changes will require an *enabling environment* that includes availability of financial resources, technology transfer, and cultural, educational, managerial, institutional, legal, and regulatory practices. Affordability of such measures is a prerequisite for their implementation, particularly for poor farmers (IAASTED 2009).

ICARDA's approach to climate change adaptation is to build on technologies and research/development methods that have proved successful in the dry areas in the CWANA region. The objective is to strengthen the adaptive capacity of communities and the resilience of farming systems, thus addressing both mitigation and adaptation.

ICARDA (2010) addresses climate change in various ways by:

- Seeking a better understanding of climate change processes, their ecological impacts, and the factors influencing them
- Taking advantage of valuable genetic diversity and local knowledge
- Undertaking vulnerability analyses and livelihood characterizations for better research and investment targeting
- Developing better adapted varieties, particularly for abiotic stresses (e.g. drought and thermo-tolerance), improved cropping systems, and more efficient use of natural resources
- Developing technology options for livelihood diversification, risk management, and income generation
- Examining international public goods. Studying local coping strategies, and drawing lessons for wider application
- Examining trade-offs. For example, will policy reform on water (in order to improve overall productivity) reduce water access for the poor?
- Identifying institutional and policy options to enhance the uptake of drought risk management technologies and other options for coping with climate change
- Following an integrated approach. Using integrated gene management or crop improvement, natural resource management, and policy options to help farmers cope with climate change.

17.3 Mainstreaming Adaptation to Climate Change into the National Development Agenda

17.3.1 Linking Adaptation to Development

Climate change is a development and cross-cutting issue that has an effect on, and links to, humanitarian and development activities. Therefore, it will have significant consequences for a country's capacity for economic growth, poverty alleviation, and the achievement of the MDGs (UNDP 2010).

Adapting to the effects of climate change is already an urgent priority for some developing countries – particularly the poorest and most vulnerable. It will soon become a priority for many more.

Adaptation is about reducing the risks posed by climate change to people's lives and livelihoods. Sustainable development would help poor countries become less vulnerable. Work on adaptation so far has addressed the impacts of climate change, rather than sufficiently addressing the underlying factors that cause vulnerability to it. Schipper (2007) suggested that successful adaptation processes and measures need to adequately address the causes of vulnerability. He concluded that, "Adaptation to climate change requires a solid development process that will ensure that factors that create vulnerability are properly addressed. These factors include; differential access to resources based on gender, age, belief systems, or other characteristics, the state of environment in which people live, and the viability of livelihoods in an existing economic system." He argued that at the end, "…*it is vulnerability reduction that should be integrated into development policy, rather than the creation of explicit adaptation strategies.*"

These two approaches both recognize a relationship between adaptation and vulnerability to climate change and development. However, they represent two different entry points, with different understandings of the types of activities that need to be undertaken to achieve a sustainable adaptation process. Schipper (2007) adapted the two approaches from McEntire (2000).

17.3.1.1 Different Approaches to Linking Adaptation and Development

Adaptation Approach

Adaptation to climate change impacts → vulnerability reduction → development.

In this approach, adaptation is carried out in response to the observed and experienced impacts of climate change on society (including ecosystems). These responses ensure that the vulnerability to the impacts is reduced. This in turn ensures that less is lost each time a climate-related hazard takes place, which means risk is reduced. With reduced risk, development can be more sustainable.

Vulnerability Reduction Approach

Development → vulnerability reduction → impact reduction → adaptation.

Whereas in this approach, development processes help reduce vulnerability to climate change. By reducing vulnerability, the impacts of climate hazards are also reduced, as there is less sensitivity and exposure to the hazards. This translates into a process of adaptation to climate change.

Climate change impacts and development processes are obviously linked in a number of ways. Developing countries, despite having contributed least to greenhouse gas emissions, are likely to be the most affected by climate change because they lack the institutional, economic, and financial capacity to cope with such outcomes. Countries which rely more on agriculture – mainly the poor developing countries – are at risk; they are also more vulnerable to coastal and water resource changes (Tearfund 2006).

Economic diversification is one of the best defenses against climate shocks. But specific actions to manage the effects of climate change are also needed. Adaptation and financing for adaptation should be part of developing countries' development plans, such as poverty reduction strategies. The G8 has agreed to develop, with the World Bank, ways of making sure that the effects of climate change are taken into account in the design of development programs (DFID 2006).

17.3.2 Mainstreaming Adaptation into the Development Agenda

In the context of climate change, mainstreaming has been described as a 'holistic' or 'development-first' approach, whereby adaptation and mitigation objectives are integrated within development agendas (Oates et al. 2001).

The UN (UNDP 2010) defines *mainstreaming climate change* as the process by which actions to address the causes and consequences of climate change are implemented as part of a broader suite of measures within existing development processes and decision cycles. The causes and consequences of climate change are often referred to collectively as *climate change considerations.*

Climate change mainstreaming implies that awareness of climate impacts and associated measures to address these impacts are integrated into the existing and future policies and plans of developing countries, as well as multilateral institutions, donor agencies, and NGOs (Tearfund 2006).

Mainstreaming adaptation to climate change into the national development agenda is necessary to cope with the climate change impacts, because climate change is a development issue that has economic and social dimensions and impact (Gotoh undated). Climate change is a cross-cutting issue facing national development efforts. For adaptation measures and strategies to be successful, they need to be integrated – 'mainstreamed' – in the development planning process (Schaar 2008).

What is particular about climate change is that adaptive processes will have to take into account the not entirely understood, but certainly extensive, impacts on

Hydrology and water resources

- Agriculture and food security
- Terrestrial and freshwater ecosystems
- Coastal zones and marine ecosystems
- Human health
- Human settlements
- Energy and industry
- Insurance and other financial services (Adger et al. 2007).

As such, a sustainable adaptation process appears to first require adjustments in policies, institutions, and attitudes that *establish enabling conditions*, and second be accompanied by eventual technical and infrastructure changes.

Mainstreaming is not a new concept, but it has become increasingly popular since the late 1990s as a means of tackling (more effectively) development issues, such as gender inequality, environmental degradation, and HIV/AIDS in the developing world. The idea was that these cross-cutting issues should influence the 'mainstream' activities of development, rather than being addressed as separate initiatives. More recently, the mainstreaming approach has been adopted in the context of climate change.

Mainstreaming or integration adaptation to climate change requires a well-planned strategy demonstrating strong technical knowledge of the impacts of climate change. Mainstreaming will requires the involvement of a broad range of stakeholders and the use of different tools to achieve the ultimate goal of the integration of climate change considerations into relevant social, economic, and environmental policies and actions (see http://ncsp.undp.org/topics/mainstreaming-climate-change).

As outlined by the UNDP 2010 guideline, mainstreaming climate change is a dynamic process, undertaken with country partners, to:

- Understand both the beneficial and detrimental linkages between climate change and development
- Use this knowledge to strengthen the national development framework and UN Development Assistance Framework (UNDAF) priorities
- Address climate change related risks and opportunities as early as possible in UN-supported programs and projects
- Track progress towards achievement of UNDAF outcomes, including their contributions to climate resilience and low-carbon development at the national level.

Mainstreaming actions must be tailored to specific country needs and capacities, as the effects of climate change, and as indicated earlier, are site and situation specific.

While mainstreaming climate change considerations occurs in the context of preparing national and sector development policies and plans, it can also take place at more local scales, such as in development planning at the district and community levels as well as in infrastructure, and other development projects.

Mainstreaming climate change may facilitate actions that use the many synergies between mitigation and adaptation, including through ecosystems management, which intersects with adaptation, mitigation, and rural livelihoods in the context of managing reservoirs of terrestrial carbon. For example, carbon finance mechanisms can be used to reduce greenhouse gas emissions, provide funding for adaptation, and deliver auxiliary benefits, such as income generation, payment for environmental services, and improved livelihoods (UNDP 2010).

17.3.3 Policy and Socio-economic Aspects as Entry Points for Mainstreaming

Depletion of the natural resource base will increase the vulnerability of agro-ecosystems to climate change. Policy and economic interventions can help prevent unsustainable use of resources; but interventions are often hard to implement because many degraded resources are open-access, i.e. common property. ICARDA's research has highlighted the requirements for creating a policy environment to enhance the uptake of natural resource management technologies in such circumstances. The results suggest that, even with promising technologies that provide significant benefits (including protection of livestock income during drought); external incentives are still needed to encourage farmers to adopt new technologies. This is because rates of return to farmers were not high enough to trigger adoption in these harsh and high risk environments. These studies have identified a range of possible institutional and policy options that could be part of the mainstreaming process:

- Links with the private sector for energy generation and ecotourism
- Building local capacity in ecosystem resilience (not agriculture per se) and risk management
- Policy analyses to assess preparedness for climate change
- Analyses of livelihood strategies in relation to climate risk management, including migration patterns, micro-credit options, remittance flows, and investments
- Social safety nets (e.g. insurance schemes) and a better understanding of existing local networks
- Decentralization of decision-making and policy formulation and greater attention to land user-policy maker linkages
- In-kind incentives to encourage farmers to invest in adaptable production systems for their lands. For example, experiences in Morocco and Tunisia, showed that provision of in-kind services during the establishment stage of shrubs was critical for the adoption of *Atriplex* and cactus alley cropping systems in marginal and low rainfall areas
- Empirically assessing and qualifying resource-use efficiency and sources of inefficiency under farmers' conditions to guide targeted interventions to increase efficiency
- Household vulnerability analysis and livelihoods assessment for targeting interventions. For example, assessing households' vulnerabilities to food insecurity, existing risk mitigation, and coping strategies for the wheat stem rust Ug99
- Policy options to optimize the use of groundwater from shallow aquifers.

17.4 Examples from Related Projects in the Region

17.4.1 The Mashreq/Maghreb Project: Developing Sustainable Livelihoods of Agro-pastoral Communities of West Asia and North Africa

The overall goal of the project was the development of productive and sustainable agro-pastoral systems that conserve the resource base and support rural livelihoods in the dry areas of the WANA region (ICARDA 1995–2007). The immediate objective is to provide technical, policy, and institutional options that empower local communities and promote sustainable livelihoods and production systems and the conservation of agro-pastoral resources. The project was funded by the International Fund for Agricultural Development (IFAD) and the Arab Fund for Economic and Social Development, and implemented by ICARDA in cooperation with four countries in the Mashreq sub-region – Iraq, Jordan, Lebanon, and Syria – and four in the Maghreb sub-region – Algeria, Libya, Morocco, and Tunisia.

The project has established a community-based participatory approach that developed packages of 'best–bet' technical, institutional, and policy options (TIPOs) for agro-pastoral communities in dry areas. These include

- On-farm feed production for alternative feed sources, with the introduction of fodder shrubs and cactus
- Feed blocks produced from agro-industrial by-products as an integral part of the feed calendar of small ruminants. The feed block technology is offering a good potential for micro-enterprise development
- New varieties of barley, oat, vetch, and triticale adapted to harsh environments
- Improved small ruminant management practices to enhance the quality of breed, fertility and lambing rates, and early weaning.

Rehabilitation of rangeland through fodder shrub and cactus plantations has been adopted on private lands. However, on communal rangelands, technology options that require high levels of investments or collective action are unlikely to be widely implemented without the development of appropriate institutional support. Property rights – tenure rights, use and access to land resources – has emerged as a critical factor in common resource management and requires further research.

By the end of the project, community members and other stakeholders agreed on '*Community Development Plans'* (CDPs) consisting of a package of 'best-bet' TIPOs for implementation at the community level. These CDPs provide investment opportunities to stakeholders in the dry areas.

As the areas addressed by the project are high risk ones, they are very negatively affected by climate change – mainly, fluctuations in and low precipitation, and frequent drought seasons. The project adopted risk management and drought mitigation strategies.

Outputs/Benefits

- A consolidated and documented community approach and identified TIPOs that can be used by development projects and programs throughout the region
- CDPs implemented in target communities
- Evaluation of the factors that hinder collective action and successful implementation of technical and institutional innovations in communal rangeland management, and recommendations for institutional and policy measures to promote communal rangeland management
- TIPOs for risk management and drought mitigation
- Identified TIPOs for diversifying production and income generation by agro-pastoral communities, including identification of market opportunities for dry land products

– Evaluation of the returns on investment in dry areas and their effects on poverty alleviation and development of communities in these areas
– Social, environmental, and economic indicators for evaluating the impacts of the approach and proposed TIPOs
– Strengthened local, national, and regional integration and human capacity.

As a result of the project it is expected that:

(i) The community approach will be institutionalized in research and extension services and in development programs and projects
(ii) TIPOs will be available to policy makers, research and extension services, rural communities, NGOs, and other stakeholders and will be included in the design of rural development strategies for the dry areas.

17.4.2 IFAD Project, 'Improving the Food Security and Climate Change Adaptability of Livestock Producers Using the Rainfed Barley-Based System in Iraq and Jordan'

The recently launched IFAD project on 'Improving the Food Security and Climate Change Adaptability of Livestock Producers using the Rainfed Barley-based System in Iraq and Jordan' in Jordan is a good example on how donors, international and national research institutions, and development projects are working together to initiate and prepare for mainstreaming climate change into the development efforts and, hopefully, into the development agenda of the country (IFAD 2011).

Global climatic trends are expected to exacerbate water scarcity and adversely affect cereal crop production in the WANA region, which suffers from the highest food deficits among all regions of the world. Global climatic projections indicate that cereal crop production in rainfed areas may drop by between 30 % and 50 % – and in some countries, by up to 80 %. Barley production will be particularly affected as it is often grown on the fringes of deserts and steppes or at higher elevations with modest amounts of, or no inputs.

One goal of the project is to improve the food security, livelihoods, and climate change adaptability for poor rural households in rainfed areas dependent on barley and livestock production. The objective is to increase the productivity and climate change resilience of farming communities in targeted areas of Jordan and Iraq.

Research initiatives and methodological instruments have been implemented by ICARDA and its partners to tackle the inter-related challenges to rural communities posed by climate change. The proposed project will capitalize on the results of these initiatives and ensure that they are more easily and quickly accessible to resource poor farmers and livestock producers. The proposed project will improve awareness of climate change at the policy and community levels, as well as support technology delivery frameworks that rely on farmer participation (in identifying technical needs and options, demonstration trials, and adaptive research). In this way it is possible to, facilitate the farmers' access to technologies that can strengthen the resilience of systems and livelihoods to climate change.

The project will work with, and augment, ongoing activities related to livestock improvement and natural resource conservation in the Agricultural Resource Management Project – Phase II (ARMP-II) and complement its Global Environment Fund component; both projects operate in the target area in Jordan. This will insure buy-in for the results by the development agencies and will establish an entry point to integrate the climate change adaptation measures into the development efforts.

The project will be assessing the technology in terms of its suitability and resilience to climate change, and the measurable improvements in livelihood outcomes for targeted rural communities. It will promote technologies that can withstand weather variability and, thereby, facilitate their continuous adoption and their sustainable impact on livelihoods.

This project is oriented towards water scarcity conditions that will be exacerbated by climate change; previous projects did not assess the implications of climate change on livelihood systems as a whole. This project will downscale the climate change impact for the community livelihood and production systems resources. This bottom up approach will result in a better understanding of the climate change impact and the vulnerability causes that affect communities and their resource capacities to adapt to climate change. It will also suggest policy and institutional tools and options that reduce the risks of climate change effects. This is coupled with community awareness and readiness to apply appropriate measures to cope with the climate change impact. In parallel, climate change proofing technologies are being tested, with community participation, to evaluate their adaptation capabilities. Also the community memory of how to cope with climate change is being addressed. Since policy/decision makers are part of the whole process, they will, at the same time, be able to integrate and mainstream the findings into the development agenda of the country.

17.5 Conclusions and Future Perspectives

According to the IPCC (2001a), CWANA is among the most vulnerable regions in the world for the predicted decreases in water and food security. Changes in rainfall and temperature patterns could also affect biodiversity; many species might not be able to adapt or migrate. However, the most likely impact on CWANA, based on various simulation models, is the adverse effects on its semi-arid zones (IAASTED 2009).

These changes present serious threats and challenges to social and economic development and achievement of the MDGs for poverty reduction (Tearfund 2006; OECD 2006; UNDP 2010).

Recently, donor agencies, governments, and non-governmental organizations have started to pay more attention to the risks and uncertainties associated with climate variability and change (Tearfund 2006). They have started to develop plans and guidelines to integrate this issue into their development planning process (UNDP 2010).

Since the sub-regions in CWANA will be affected differently by global climate change, adaptation options will have to be site and situation specific.

ICARDA's approach to climate change adaptation builds on technologies and research/development methods that have proved successful in dry areas in the CWANA region. The objectives are to strengthen the adaptive capacity of communities and the resilience of farming systems, thus addressing both mitigation and adaptation.

The effects of climate change and the development processes are obviously linked in a number of ways. Developing countries, despite having contributed least to greenhouse gas emissions, are likely to be the most affected by climate change because they lack the institutional, economic, and financial capacity to cope with such effects. Countries which rely more on agriculture – mainly poor developing countries – are at risk. They are also more vulnerable to coastal and water resource changes (Tearfund 2006).

Mainstreaming adaptation to climate change into the national development agenda is necessary to cope with climate change impacts; climate change is a development issue that has economic and social dimensions and impacts (Gotoh undated). Climate change is a cross-cutting issue that confronts national development efforts. For adaptation measures and strategies to be successful they need to be integrated – 'mainstreamed' – into the development planning process (Schaar 2008).

Mainstreaming or integrating adaptation to climate change requires a well-planned strategy demonstrating strong technical knowledge of the consequences of climate change. Mainstreaming will requires the involvement of a broad range of stakeholders and the use of different tools to achieve the ultimate goal of the integration of climate change considerations into relevant social, economic, and environmental policies and actions (see http://ncsp.undp.org/topics/mainstreaming-climate-change).

Research agendas that improve our understanding of people's potential to adapt to climate change require both appropriate frameworks for analysis and empirical data to question how adaptation occurs. These requirements can be met if the research embodies tools for climate data analysis – in order to identify the details of the changes in climate parameters – and methods for identifying and then exploring people's livelihood responses to the relevant climate factors. In this paper we have attempted to show how these requirements can be met, through an analysis of responses to scientifically identified climate dynamics (Thomas et al. 2007).

ICARDA's research is thus contributing directly to climate change mitigation/adaptation. Work on the conservation and use of biodiversity and the development of crop varieties resistant to salinity, drought, heat, etc., will contribute to food security under a changing climate. Work on conservation agriculture is producing more robust production systems that are more efficient in water and nutrient use and also sequester more carbon in soils. Agro-ecological characterization is helping to anticipate future trends and identify the most vulnerable regions. Crucially, ICARDA's integrated multi-disciplinary approach leaves it well placed to respond to the scientific challenges posed by climate change.

Building on the results, research could be extended into new areas in the future: These research areas could include:

- Carbon trading/offset schemes (the clean development mechanism, voluntary markets, mitigation-adaptation offsets)
- Payment for environmental services and valuation of natural resources, linked to carbon trading.

Managing risk and vulnerability becomes a fundamental tool in building resilient and sustainable dryland systems, but it has many dimensions. System shocks, often influenced significantly by climate change, resulting in a single failed crop or grazing season, livestock disease epidemics, or a shift in market structure can have major consequences for vulnerable communities. Building adaptive capacity is, therefore, an integral part of reducing poverty and ensuring food security. ICARDA is leading a global program on 'integrated agricultural production systems for the poor and vulnerable in dry areas'. Within the framework of this program, there is a clear focus on reducing vulnerability and managing risk, leading to resilient dryland agro-ecosystems with less vulnerable and improved livelihoods for rural communities. Specific outputs on this dimension include:

– Developing technical, institutional, and policy options for reducing vulnerability
– Scaling up tested and proven options for reducing vulnerability and mitigating risk
– Analyzing trade-offs between options for reducing vulnerability and mitigating risk.

Partnerships and capacity development are integral components of the integrated agricultural systems for better managing the vulnerability and risks associated with climate change.

References

Adger WN (2003) Social capital, collective action, and adaptation to climate change. Econ Geogr 79:387–404

Adger WN, Agrawala S, Mirza MMQ et al (2007) Assessment of adaptation practices, options, constraints and capacity. In: Parry ML, Canziani OF, Pal JP et al (eds) Climate change 2007: impacts, adaptation and vulnerability. Cambridge University Press, Cambridge

Consultative Group on International Agricultural Research (CGIAR) (2010) CGIAR research program on dryland cereals. Food security, better health and economic growth for the world's most vulnerable poor. International Crops Research Institute for the Semi-Arid Tropics, Hyderabad

Department for International Development (DFID) (2006) Eliminating world poverty: making governance work for the poor. White paper on institutional development. DFID, London

Gotoh J (Undated) Mainstreaming adaptation into development agenda. United Nations ESCAP. http://www.wamis.org/agm/meetings/rsama08/S601-Gotoh-UNESCAP.pdf. Accessed 2 Oct 2011

Hertel TW, Rosch SD (2010) Climate change, agriculture, and poverty. Appl Econ Perspect Pol 32:355–385

Intergovernmental Panel on Climate Change (IPCC) (2001a) Climate change 2001: the scientific basis. Contribution of working group I to the third assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

Intergovernmental Panel on Climate Change (IPCC) (2001b) Climate change 2001: impacts, adaptation, and vulnerability. Contribution of working group II to the third assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

IPCC (2007) Climate change 2007: synthesis report. Contribution of working groups I, II and III to the fourth assessment report of the intergovernmental panel on climate change. In: Core Writing Team, Pachauri RK, Reisinger A (eds). IPCC, Geneva

International Assessment of Agricultural Science and Technology for Development (IAASTED) (2009) Agriculture at a crossroads, Vol. I: the global report. IAASTED, Washington, DC

International Center for Agricultural Research in the Dry Areas (ICARDA) (1995–2007) Mashreq and Maghreb Project 1995–2007. Adaptive research for crop/livestock in low rainfall areas of WANA, Several documents and reports. ICARDA, Aleppo

International Center for Agricultural Research in the Dry Areas (ICARDA) (2010) ICARDA and climate change. Draft working paper for discussion. ICARDA, Aleppo

International Fund for Agricultural Development (IFAD) (2011) Improving the food security and climate change adaptability of livestock producers using the rainfed barley-based system in Iraq and Jordan. IFAD, Rome

McEntire D (2000) Sustainability or invulnerable development? Proposals for the current shift in paradigms. Aust J Emerg Manage 15:58–61

Oates N, Conway D, Calow R (2001) The ‘mainstreaming’ approach to climate change adaptation: insights from Ethiopia’s water sector. ODI background note. Overseas Development Institute, London

Organization for Economic Co-Operation and Development (OEOD) (2006) Putting climate change adaptation in the development mainstream. Policy brief, OECD, Paris. http://www.oecd.org/dataoecd/57/55/36324726.pdf. Accessed 2 Oct 2011

Parry M, Arnell N, McMichael T et al (2001) Millions at risk: defining critical climate threats and targets. Global Environ Change 11:181–183

Persson Å (2008) Mainstreaming climate change adaptation into official development assistance: a case of international policy integration. EPIGOV paper No. 36. Ecologic Institute for International and European Environmental Policy, Berlin

Rosegrant MW (2011) Impacts of climate change on food security and livelihoods. In: Solh M, Saxena MC (eds) Proceedings of an international conference on food security and climate change in dry areas. ICARDA, Aleppo

Schaar J (2008) Overview of adaptation mainstreaming initiatives. Commission on Climate Change and Development, Stockholm. http://www.ccdcommission.org/Filer/pdf/pb_overview_mainstreaming_initiatives.pdf. Accessed 2 Oct 2011

Schipper ELF (2007) Climate change adaptation and development: exploring the linkages. Tyndall Centre for Climate Change Research working paper 107, School of Environmental Sciences. University of East Anglia, Norwich and South East Asia START Regional Centre, Bangkok

Tearfund (2006) Overcoming the barriers: mainstreaming climate change adaptation in developing countries. Tearfund climate change briefing paper 1. Institute of Development Studies. Tearfund, Teddington

Thomas DSG, Twyman C, Osbahr H et al (2007) Adaptation to climate change and variability: farmer responses to intra-seasonal precipitation trends in South Africa. Clim Change 83:301–322

UNDP (2010) Integrating climate consideration in the country analysis and UNDAF. A guidance note for United Nations country teams. United Nations Development Group, New York

Chapter 18
Possible Financial Innovations and Market Mechanisms at the National Level to Cope with Climate Change in WANA Region

S.V.R.K. Prabhakar

Abstract The West Asia and North African (WANA) region is characterized by developmental diversity with high climate change vulnerability. Despite decades of developmental efforts, many countries in the region continue to suffer from a combination of issues such as lack of political stability and peace, poor agricultural production, malnutrition, poor access to health and sanitation facilities, and impacts from repetitive climatic vagaries such as droughts and floods. With the growing evidence of possible impacts of climate change in the region, enhancing efforts for climate change adaptation is necessary for safeguarding development achieved thus far in the region. Due to chronic poverty and developmental deficit, many countries in the region are not in a position to fund and initiate climate change adaptation programs necessitating an international support. These reasons make financing climate change adaption a priority for the region. With this background in view, this chapter looks at the funding needs for adaptation in the WANA countries, gaps in available funding and means to bridge those gaps through national level actions. From the chapter it is evident that there is a significant potential for taking benefit from financial innovations such as risk insurance, microfinance, conditional cash transfer programs, and targeted subsidies by scaling up these initiatives through policy and community level initiatives. Greater capacity for taking benefit of GHG mitigation schemes by WANA countries could generate more funds those could benefit the development and coping with climate change in the region. Better governance in all spheres of development is the only means for the region to cope with climate change. There is a need for strengthening community based organizations and community managed participation in climate change adaptation and for regional cooperation linking institutions in the developed and developing countries.

Keywords WANA region • Risk financing • Climate resilience • Insurance • Microfinance • Development governance

S.V.R.K. Prabhakar (✉)
Institute for Global Environmental Strategies, Hayama, Japan
e-mail: prabhakar@iges.or.jp

M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_18,

18.1 Introduction

The West Asia and North African (WANA) region is characterized by developmental diversity with high climate change vulnerability calling for an urgent intervention for climate change risk reduction in these countries (Cruz et al. 2007). Though WANA appears to be a rich region from the average figures of economic development, some WANA countries have poor socio-economic development and poor political stability that affect their capacity to fund and implement climate change adaptation agenda. More specifically, financing adaptation is a priority for countries and regions such as Chad, Georgia, Niger, Palestine, South Sudan, Sudan, Syria, Western Sahara, and Yemen which are the low income economies with high proportion of population in agriculture and allied sectors living in climatically challenged regions. Due to poor socio-economic development, political and institutional mechanisms in some of these countries, the progress in funding for adaptation is hampered.

Financing plays an important role in improving the social resilience to a variety of man-made and natural stresses that societies face (Benson et al. 2012). Realizing this fact, globally, several financial innovations have emerged that can help building social resilience. However, countries in the West Asia and North African (WANA) seem to lag in taking the advantage of these innovations happening around the globe. This lag can be very crucial for the WANA region as countries in the region are projected to undergo a range of climate change impacts that can put even greater pressure on the already over utilized water and land resources in the region calling for an urgent intervention for climate change risk reduction in these countries.

Keeping the above background in view, this chapter looks at the funding needs for adaptation in the WANA region, performance of WANA countries in the clean development mechanism (CDM) under the Kyoto Protocol, gaps in available funding and means to bridge those gaps through national level actions, and proposes way forward for promoting climate resilience agenda in the region.

18.2 Developmental State of the WANA Region

18.2.1 Agricultural Performance in the Region

Agriculture contributes significantly to national gross domestic product (GDP) of most countries in the region, with double digit contribution in Afghanistan, Eritrea, Ethiopia, Mauritania, Pakistan, Sudan, and Syria, and it provides significant amounts of employment in most countries in the region with 79 % of total population depending on agriculture in Ethiopia (Table 18.1). Except few countries (Cyprus, Lebanon, and United Arab Emirates), income from agriculture continue to show positive growth rates during the recent past (World Bank 2012). This indicates the importance of agriculture to the wellbeing of major population in the WANA region. The WANA region is also characterized by diversity in climate, soil and land

Table 18.1 Major economic, financial and agriculture indicators of WANA countries (Average for 2005–2009)

Country	GDP per capita, PPP (current interna-tional $)	FDI, net inflows (% GDP)	Net ODA received (% of GNI)	Central government debt, total (% of GDP)	Poverty headcount ratio at $2 a day (PPP) (% of population)	R&D expenditure (% of GDP)	Researchers in R&D (per million people)	Agriculture, value added (% of GDP) [Annual growth (%)]	Agriculture water use (% of total water use)	Employment in agriculture (% of total employment)
Afghanistan	921	2.7	44.2	–	–	–	–	33.2 [8.9]	98.8	–
Algeria	7,718	1.5	0.3	–	–	0.1	170.1	7.6 [1.8]	64.0	–
Bahrain	27,123	9.0	–	21.4	–	–	–	–	44.5	–
Cyprus	28,949	9.2	–	150.5	–	0.4	725.2	2.4 [–4.5]	77.7	4.3
Egypt	5,244	6.7	0.9	85.8	16.9	0.2	500.2	14.0 [3.3]	86.4	31.4
Eritrea	572	0.0	14.6	–	–	–	–	21.5 [8.0]	94.5	–
Ethiopia	797	1.6	13.3	–	77.6	0.2	21.2	47.1 [9.6]	93.6	79.3
Iran	10,598	0.9	0.0	–	8.0	0.7	733.4	10.3 [6.7]	92.2	23.0
Iraq	3,303	1.7	26.8	–	21.4	–	49.5	–	78.8	22.7
Jordan	5,083	15.1	3.7	66.0	2.8	0.4	–	2.8 [6.4]	65.0	3.0
Kuwait	50,819	0.3	–	–	–	0.1	167.8	–	53.9	2.7
Lebanon	11,075	13.1	2.7	–	–	–	–	6.7 [-0.5]	59.5	–
Libya	15,733	3.8	0.1	–	–	–	–	2.1	82.9	–
Mauritania	2,273	10.6	10.2	–	47.7	–	–	23.6 [5.3]	93.7	–
Morocco	4,056	3.0	1.5	51.3	14.0	0.6	651.8	15.3 [7.3]	87.4	42.9
Pakistan	2,409	2.8	1.5	–	60.5	0.5	134.0	20.8 [4.4]	94.0	43.7
Saudi Arabia	21,512	6.7	0.0	–	–	0.1	–	2.8 [0.9]	88.0	4.2
Sudan	1,949	6.2	5.5	–	44.1	0.3	–	29.2 [3.5]	97.1	–
Syria	4,659	2.9	0.2	–	–	–	–	19.3	87.5	17.7
Tunisia	8,293	5.0	1.1	46.6	8.1	1.1	1,681.9	9.4 [1.2]	76.0	–
Turkey	13,577	2.7	0.1	47.9	5.3	0.7	690.1	9.4 [1.9]	73.8	25.4
UAE	59,904	4.6	–	–	–	–	–	1.1 [-5.2]	82.8	4.5
Yemen	2,378	2.9	1.8	–	46.6	–	–	10.0 [3.6]	90.7	–

Source: World Bank (2012). Blanks indicate non-availability of data resources (Kassam 1981). Most countries in the WANA region fall under arid and semi-arid tropics characterized by water scarcity and known for its historical vulnerability to recurring droughts due to low and erratic rainfall, limited arable land and water resources (El-Beltagy 1997).

In terms of agriculture performance, the WANA region lags behind that of South Asia, East Asia and global averages. During 2010, the cereal yields recorded in West Asia and North Africa were 2.3 and 1.9 t per hectare respectively (FAO 2012) (the agriculture sector has used 81 % of total freshwater withdrawals in the region during 2005–2009, Table 18.1). In comparison, the cereal yields in East and Southern Asia were 5.5 and 2.7 t per hectare respectively as compared to a global average of 3.7 t per hectare during the same period (the average freshwater use by agriculture sector in East Asia and South Asia were 74 % and 90 % of total freshwater withdrawals respectively during 2005–2009). The poor performance of agriculture in the WANA region can be partly attributed to the geographical and climatic limitations that WANA region suffers and the economic deprivation that has hindered the region from advancing research and development in agriculture sector. Though agriculture consumes an estimated 81 % of total freshwater withdrawals in the WANA region, it only irrigates 37 % of the cultivated area in the region. As a result, significant amount of agriculture in the WANA region is rainfed and is prone to seasonal rainfall vagaries and related crop losses (FAO 2012).

The vulnerability of the WANA region to natural climatic events like droughts deserves a mention here. A total of 31 climatic hazards such as droughts, extreme temperatures and wild fires were reported in the WANA region affecting 9.35 million people with an estimated economic loss of 1.3 billion USD during 2000–2011 (FAO 2012). Armenia, Georgia, Jordan, Morocco, Sudan and Syrian Arab Republic are particularly vulnerable to droughts. Crop losses due to erratic and undependable rainfall and dry spells, insect pests and poor agriculture support systems are common in the region. In addition, though disaggregated data for agriculture sector is not available, the low values of indicators like research and development (R&D) expenditure (as percentage of GDP) and researchers for R&D (per million) also explains partly the poor performance of agriculture in the region (Table 18.1).

The International Food Policy Research Institute (IFPRI) classifies Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and United Arab Emirates at low risk of food insecurity; Iran, Libya, Tunisia, and Turkey at moderate risk of food insecurity, and Marutania, Sudan, Yemen, and Somalia at serious, alarming, or extremely alarming levels of food insecurity risks in the Middle East and North Africa (Breisinger et al. 2012). Breisinger et al. (2012) reported that the North Africa region will continue to face the problems of risk to agriculture production, malnourishment, and poverty and greater possibility for absolute increase in malnourished children in Africa towards 2025 under business as usual scenario and could even worsen under pessimistic scenario of climate change (Rosegrant et al. 2005). In another research, Ringler et al. (2010) have concluded that climate change could even worsen the food security situation in Africa.

18.2.2 Development and Its Financing in the Region

The WANA region is comprised of countries with varied developmental levels (Table 18.1). The wide range of average per capita income in these countries, USD 571 in Eritrea to USD 59,904 in the United Arab Emirates (UAE), explains the economic and developmental diversity of countries in the region. In addition to the developmental differences between countries, there is a wide socio-economic disparity within some of the WANA countries that doesn't fit into the picture of a region that boasts some of the richest people in the world. The average economic wealth figures reported from the region often mask out this extreme poverty prevalent in the region (El-Beltagy 1997). As a consequence, the region does not attract needed attention and hence is an important policy planning issue for the entire WANA region. As is evident from Table 18.1, countries such as Ethiopia, Iraq, Mauritania, Pakistan, Sudan, and Yemen have alarming rates of poverty and most countries in the region rank poorly in terms of Gini Coefficient (World Bank 2012) and Millennium Development Goals (United Nations 2011).

Countries such as Cyprus, Egypt and Jordan have accumulated considerable national debt over the years and Afghanistan, Eritrea, Ethiopia, Iraq, Mauritania and Sudan receive significant amount of overseas development assistance (ODA, Table 18.1). These are also the countries that attract least foreign direct investment (FDI) with an exception of Mauritania and Sudan that receive more FDI than ODA. Many other countries in the WANA region enjoy a significant amount of FDI with figures several times higher than those of South Asia on percentage GDP basis (South Asia has received FDI to the tune of 2 % of its total GDP in 2009). Preliminary statistical analysis carried by the author didn't reveal a strong correlation between FDI and crop yields (correlation coefficient $r = 0.07$), investment in research and development and cereal yields ($r = -0.29$) and ODA and crop yields ($r = -0.2$). This suggests that either these investments have not been routed to improving agriculture sector or that these have not been able to help countries to overcome the limitations faced by the agriculture sector. This argument is supported by the observations made by Habbab (2012) who reported that significant amount of agriculture investment in the WANA region is characterized by investments in irrigation infrastructure that has largely deprived the research systems of needed resources for improved research and development in agriculture. Except Tunisia, the investment in overall research and development in most WANA countries is less than 1 % of their national GDP which falls short of global average of 2 %.

The above discussion conveys three important messages: there is tremendous potential for improving agriculture performance in the region, agriculture research and development investment in most WANA countries is insufficient and the agriculture systems in the region are most vulnerable to climatic vagaries. This has implications that the region needs to invest more for development in general and agriculture in specific and more so in a changing climate.

18.3 Adaptation Costs and Available Finances

18.3.1 Adaptation Costs

In addition to the existing limitations with the fiscal and agriculture situation in the WANA region, the climate change is projected to bring additional burden to the region and financing adaptation assumes greater importance. The available adaptation cost estimates suggest a global adaptation costs in the range of USD 44–164 b depending on how the estimates are made (Table 18.2). There are no specific adaptation cost estimates available in the published research literature for the WANA region. For the purpose of this chapter, adaptation costs reported by national governments in their National Adaptation Plan of Action (NAPA) have been referred to and reported in Table 18.3. The adaptation costs in the WANA region are significant to the tune of 872 million USD in the short term. This cost relates to only priority sectors and projects identified by national governments and don't constitute full cost of adaptation in medium and short term which could be several times more than this figure.

18.3.2 Adaptation Financing

Though there has been considerable progress in characterizing the nature of adaptation finance under the United Nations Framework Convention on Climate Change (UNFCCC), much needs to be done on the lines of making available necessary

Table 18.2 Various assessments of adaptation costs

Region	Sector	Assessment (b USD)	Sources
46 NAPA countries	All NAPA sectors	2.1	UNFCCC (2011)
Africa	Urban water infrastructure	2–5	Muller (2007)
Developing	–	3–37 per year (WB)	Stern (2007)
Developing	–	50 per year	Oxfam (2007)
Global	Agriculture and fisheries	14	McCarl (2007)
Global	Water sector	531	Kirshen (2007)
Global	Agrl., water, health and infrastructure	49–130	Smith (2007)
Global	Few sectors	44–164 (27–66 for developing countries)	UNFCCC (2008)

Table 18.3 Adaptation costs for WANA region based on costs submitted in NAPAs[a]

Country	Sector	Required (m USD)	Source
Ethiopia	All NAPA sectors	769	UNFCCC (2011)
Sudan	All NAPA sectors	15	
WANA region	All NAPA sectors	872[a]	

[a]Six countries have submitted NAPAs out of 27 WANA countries

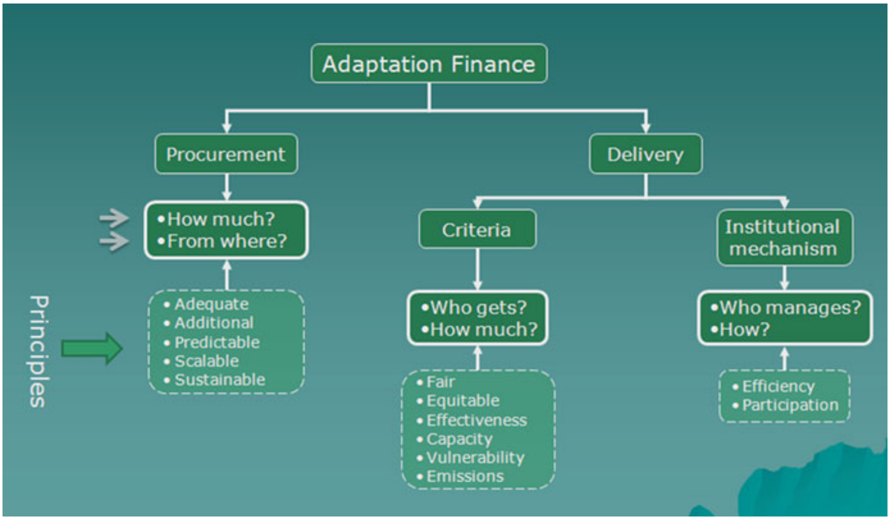


Fig. 18.1 Multiple dimensions of adaptation financing (Source: Prabhakar 2008)

adaptation finances, putting in place governance mechanisms, and mainstreaming climate change adaptation in planning at all levels. Adaptation financing has multiple facets to it from procurement to ultimate disbursement and use for the intended purpose. Any financing proposal for climate change adaptation should be able to satisfy a set of principles that most developing countries adhere under the UNFCCC (Fig. 18.1). Any finances proposed for adaptation should meet the principles set by the Bali Action Plan (BAP) i.e. funding should be adequate, predictable, sustainable, new and additional (as outlined in e (i) of Bali Action Plan). In terms of procurement, the adaptation financing must be adequate, additional, predictable, scalable and sustainable. The delivery of adaptation finances also need to satisfy a set of principles which include fairness, equitable, effective, in line with the capacity of the recipient, vulnerability, and GHG emissions.

The current financial sources, as shown in Fig. 18.2, indicates several overlaps and most importantly the fragmented nature of it (modified from Bouwer and Aerts 2006). Currently available finances for adaptation are put at USD 581–801 million (Table 18.4). Potential finances with not so much clear allocation for adaptation actions amounts to near about USD 5.7 billion and are not sufficient. Hence, bridging the gap is an important issue being dealt in the ongoing negotiations under UNFCCC.

Several proposals have already been put forward both under UNFCCC negotiations and outside UNFCCC negotiations. Some of these proposals are listed below. These sources can provide finances in the range of USD 54–122 b.

- Continuation of CDM beyond 2012 could generate USD 100–500 m (low carbon credit demand) to USD 1–5 b (high carbon credit demand) in 2030
- Extending 2 % levy on joint implementation and international emissions trading (USD 10–50 m by 2010, Oxfam)

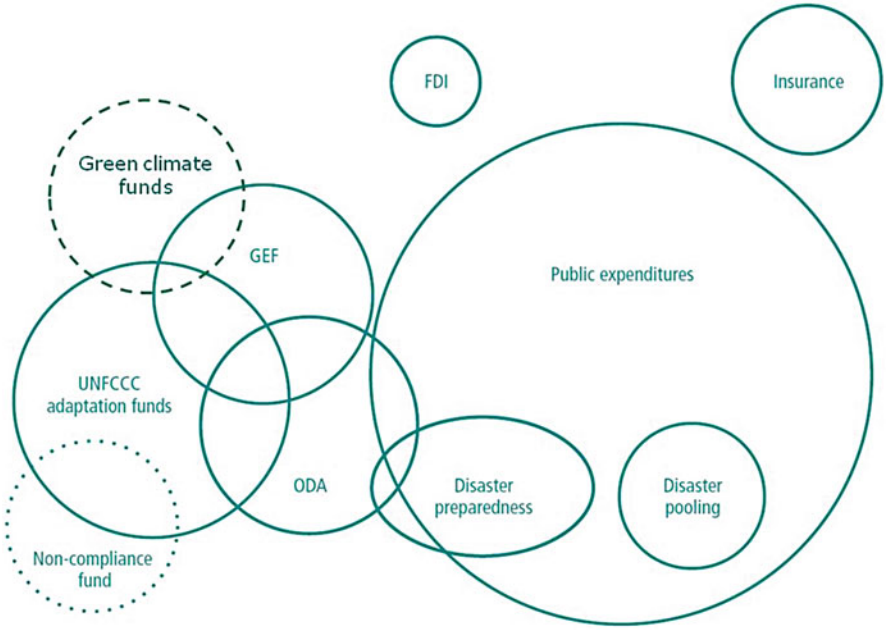


Fig. 18.2 Financial sources: global picture (Source: Modified from Bouwer and Aerts 2006)

Table 18.4 Existing and potential finances until 2012 for funding adaptation actions

Fund	Disbursements (b USD)	Total[a] (b USD)	Notes
Kyoto Protocol Adaptation Fund	0.241	0.372	Until 2012
World Bank Climate Investment Funds			
Forest Investment Program	0.007	0.577	Pledges so far
Pilot Program for Climate Resilience	0.027	0.987	Pledges so far
DFID International Climate Fund	1.4	6	Pledged until 2014/2015
Global Environment Facility (Trust fund, Least developed countries fund, special climate change fund)	0.023 + 0.104 + 0.08	NA + 0.324 + 0.18	–
Japan Fast Start Finance	–	15	Until 2012, 50 % for adaptation in LDC and Africa through GEF and CIF
EU Global CC Alliance	0.113	0.226	Until 2010
Indonesia CCTF	0.005	0.019	Adaptation: 1.2 mn total
International Climate Initiative (Germany)	0.077[a]	0.680	[a]Adaptation only (14 % of total)
Millennium Development Goals Fund (Spain)	0.053[a]	0.089	[a]59 % of total approved so far

Source: Climate Funds (2011)
[a]With uncertain amounts allocated to adaptation

Table 18.5 Some stakeholder perspectives and proposals on adaptation funding

Developed countries	Developing countries
USA and EU emphasized the role of private sector	G77/China emphasized for funds from Annex I public finance, additional to ODA and sees limited role of private sector (unfair burden on poor)
Japan emphasized the multi- and bi-lateral cooperation	
Switzerland proposed the multi-lateral adaptation fund with prevention and insurance, National CC Fund, (Carbon tax based on per capita emissions. Adaptation as exclusive funding purpose)	Mexico proposed the world climate change funds for adaptation and mitigation with participation of all parties
	Cook Islands (AOSIS) proposed the climate adaptation funds
Norway proposed auction of assigned amount units	Philippines highlighted the importance of domestic financing for small scale local adaptation actions
Australia emphasized the need to differentiate among SIDS (e.g. Singapore)	

Source: Prabhakar and Srinivasan (2009) and UNFCCC (2008)

- International air travel levy (USD 8–15 b)
- Auction of allowances for international maritime and aviation (USD 22–40 b year^{-1})
- Reducing Emissions from Deforestation and Forest Degradation (REDD) up to USD 12 b year^{-1} by 2030 with an uncertain amount to contribute to adaptation (UNFCCC 2007)
- Soil carbon sequestration: 0.9 F 0.3 Pg C year^{-1} (×3 USD per ton)
- Green climate fund: Characteristics not yet clearly defined
- US Climate change legislation: 20 % of proceeds from the auction of GHG emission permits for Adaptation Fund would provide USD 1 b during initial years and to increase continuously till 2030.

Many developing countries argue that Adaptation Fund is not additional (2 % proceeds from CDM) and not sustainable (lasts only until the ending period of Kyoto Protocol). The developing countries have been objecting to putting levy on CDM proceeds since they are neither additional nor sustained for long time. Complains have also been made regarding the GEF requirement of co-financing to seek support from Adaptation Fund. Though the exact nature of Green Climate Fund, proposed in COP 16, is not yet known, imbalance in allocation of finances between mitigation and adaptation components and lack of direct access (similar to Adaptation Fund) appears to be major issues with the Green Climate Fund. Public finances from Annex I Countries do not have much public and political acceptance either. With the ongoing global economic recession, the effectiveness of many available financial options to pay for adaptation is even more doubtful. The current funding available are neither additional nor sustainable (most of the funding is limited to 2012).

There are diverse perspectives on adaptation financing among parties to the Convention. The Table 18.5 provides some perspectives. While there is an overwhelming consensus on the need for adaptation funding, there is lack of agreement on details of funding such as sources of funds, how to manage them and fund distribution among developing countries. While developed countries such as USA and EU emphasize on market mechanism, developing countries fear that these mechanisms may unduly impact the poor and argue for public funding.

18.4 Assessing Current Risk Financing Innovations

While sourcing additional finances is absolute necessary to bridge the gap between supply and demand, it is also important that the available finances are used efficiently. This section discusses various finance related initiatives in the WANA region that improves resilience to climatic vagaries (e.g. risk insurance, micro finance) or that helps improving the efficiency in the use of existing finances (e.g. conditional cash transfer programs and targeted subsidies). The section helps us to understand the current state of use of these instruments on the ground and help in drawing way forward.

18.4.1 Risk Insurance

Risk insurance is an ex-ante risk management strategy that would not only reduce the financial risks emanating from natural disasters to the insured but can also reduce financial burden on national governments and bring additional finance to the risk management pool from the financial contributions of the people subscribing the insurance. Risk insurance has become an important solution for mitigating various climatic and non-climatic risks across the globe and it can play an important role in the WANA region for the fact that the region faces several climatic hazards.

There is dearth of information on risk insurance initiatives in the WANA region which could be an indication of primitive development of risk insurance sector in the region. This is despite the fact that many WANA countries suffer from natural calamities. Most governments are heavily dependent on traditional risk management options such as investing in irrigation infrastructure and expansion of area under high yielding varieties, ex-post risk management options such as relief management, and very few are dependent on ex-ante risk management options such as risk insurance.

The risk insurance initiatives observed in the WANA region vary from small scale insurance products offered by local non-governmental organizations to the large schemes run by multi-stakeholder networks (e.g. Horn of Africa Risk Transfer for Adaptation program offered by International Research Institute for Climate and Society (IRI), Oxfam, Swiss Re through local institutions, see Table 18.6). In addition to these formal risk insurance initiatives, one can also find several non-formal risk management options practiced by farmers which involves precautionary savings, informal insurance such as kin sharing risk, and informal credit mechanisms that come to help (McIntyre et al. 2009). Risk insurance systems in the region are well

Table 18.6 Some significant examples of risk insurance initiatives in the WANA region

S No	Country	Case	Hazard	Insurance type	Agencies involved	References
1	Ethiopia	Horn of Africa Risk Transfer for Adaptation	Drought	Weather index	IRI, Oxfam, WFP, Swiss Re, Nyala Insurance Co. and Debit Credit and Savings Institution	Oxfam (2012)
2	Iran	Agriculture Insurance Fund	Multi-peril	Traditional indemnity based	National Government through Agricultural Insurance Fund	Agricultural Insurance Fund (2012), Mahul and Stutley (2010)
3	Pakistan	Crop and livestock insurance	Multi-peril	Traditional indemnity based	Public-private partnerships for agriculture and private market based insurance for livestock, mostly in pilot stages with limited geographical and population coverage	FAO (2011), United Insurance Company of Pakistan Ltd. (2012)
4	Morocco	Crop insurance	Drought	Traditional indemnity based	Managed by *Mutuelle Agricole Marocaine d'Assurances* (MAMDA, Agricultural Mutual Insurance Company)	Mahul and Stutley (2010), Stoppa and Hess (2003)
5	Algeria	National agricultural insurance fund	Multi-peril	Traditional indemnity based yield insurance	Managed under National agricultural insurance fund	Making Finance Work for Africa (2011)

integrated into the bank credit systems where it is mandatory for the farmer to enroll into crop insurance schemes to be eligible for a bank loan.

Except Horn of Africa Risk Transfer for Adaptation (HARITA), most risk insurance programs in the region still follows traditional indemnity based insurance. Probably only Iran has a comprehensive agriculture insurance program in the entire WANA region. Unlike many countries in the WANA region, Iran has Agriculture Products Insurance Law, 1983 and an Agricultural Products Insurance Fund. The insurance is managed and implemented by the Agricultural Bank in association with various other ministries and private insurance companies (Agricultural Insurance Fund 2012). The agricultural insurance in Iran covers a wide variety of perils and crops and the agriculture insurance is primarily managed through the Agriculture Insurance Fund established by the national government. The other kinds of insurance (that include health, motor, fire, accident and life insurance) are mainly offered by the government owned Central Insurance of Iran (Bimeh Markazi Iran) and by several private companies governed by the Iran Insurance Act (Bimeh Markazi 2012).

In Pakistan, a multi-peril crop insurance scheme, Mandatory Crop Loan Insurance Scheme, with subsidy on premium was launched as a public-private partnership between government and private sector insurance agencies in 2008 and crop insurance is compulsory for farmers to access bank credit facilities (FAO 2011). In North Africa, Morocco has crop insurance program under the state sponsored drought program (*Programme Secheresse*) which was initially a yield insurance program (Stoppa and Hess 2003) and subsequently the emphasis has changed to weather index based insurance due to high costs to the government and moral hazard and adverse selection problems (Skees et al. 2001). New agriculture insurance scheme, on the lines of traditional yield insurance, has been launched in Algeria to cover potato farmers and is expected to start from 2012 (Making Finance Work for Africa 2011).

18.4.2 Microfinance

Microfinance is a tool for increasing access to finance for the rural poor. It has similar objectives of conditional cash transfer programs (CCT) i.e. cash transfer is only an incentive for promoting a particular cause. In the case of microfinance, the ultimate objective is to enhance financial resilience of rural poor by providing them with the seed money that helps rural poor in starting small income generating activities which leads to substantial reduction in material poverty and physical deprivation of goods and services. Microfinance has been receiving tremendous attention in the past decade for its ability to bring rural poor out of poverty and for its ability to produce rural entrepreneurship especially in South Asia and in the WANA region.

Africa, as against Asia, suffers from lack of private savings and heavy reliance on public savings (OSCAL 2000). The United Nations Office of the Special Coordinator for Africa and the Least Developed Countries (UN-OSCAL) has put together an elaborate compilation of microfinance experiences from Africa region entitled 'Microfinance and Poverty Eradication: Strengthening Africa's Microfinance Institutions' explains the presence of microfinance experiences in Egypt and Morocco (OSCAL 2000) and this report offers a wide range of solutions for promoting microfinance in the region. There is a great demand for microfinance in Algeria and Libya (CGAP 2006). Among countries in East Asia, microfinance has humble beginnings in Pakistan (IFC and KFW 2008), Afghanistan (World Bank 2009), and Iran (Bakhtiari 2009). No considerable presence of microfinance has been reported in Iraq until 2007 (USAID and IZDIHAR 2007). The Islamic microfinance is gaining much popularity in Afghanistan and Iran.

18.4.3 Conditional Cash Transfer Programs

Conditional cash transfer (CCT) programs have become an important public policy tool for poverty reduction (Adato and Hoddinott 2007) and as an important safety net strategy in number of countries with poor financial resources and public safety net programs. Though CCT programs by themselves do not ensure making available additional finances for developmental and climate change adaptation purposes, they ensure efficient use of existing financial resources as they demand certain action or criteria to be met on the part of the beneficiaries. There is very limited experience of implementing CCTs in the WANA region when compared to regions such as Asia and South American countries. The DFID CCT in Egypt claims to be first of its kind in the WANA region (DFID 2010). The program involves transfer of certain amount of cash to selected families that chose to participate in the program upon satisfying criteria such as visits to clinics, child school attendance, and attendance in awareness sessions on related matters.

In Morocco, World Bank has conducted CCT program on experimental basis to address the issue of poor school enrolment in rural areas (World Bank 2010). There has not been systematic research on why the CCTs have failed to penetrate in the WANA region as a policy tool. However, from the understanding of the CCT, it can be deduced that these programs demand substantial attention both by the implementing agencies and beneficiaries and require elaborate institutional arrangements and capacity for these programs to succeed. Another possible reason for lack of CCT penetration could be the presence of "unconditional cash transfer" policies implemented by many countries in the WANA region that suffer from 'resource curse' (refer to the Center for Global Development Working Paper 237 by Moss 2011).

18.4.4 Targeted Subsidies

Discussion on subsidies is valid in this chapter for the following reasons: (a) Subsidies have been major public policy interventions by governments to tackle drought in the WANA region and have played an important role in providing relief to the drought affected population. Major part of subsidies has been directed to providing feed for cattle during drought years (Hazell 2000). (b) Subsidies for drought are an ex-post measure and are often disincentive for farmers to invest on drought mitigation measures. (c) There are both best practices of providing subsidies in a targeted manner and blanket subsidies that have attracted criticism as being ineffective means of supporting the needy.

The International Monitory Fund has called for improving subsidy regime in the Middle East (Hay and Grebler 2011) indicating great potential for improvement in subsidies in the WANA region. However, there exist few best examples of subsidies in the WANA region that deserves special attention though not particularly in drought management. For example, economic status-based targeted subsiding of education has helped many school children in Ethiopia to reach higher education (Tekleselassie and Johnstone 2004). The voucher system, a means of targeting beneficiaries, which is successful elsewhere in Africa (Minot and Benson 2009) has not yet spread in other parts of the WANA region.

18.5 Market Mechanisms

Market mechanisms constitute provisions available under the Kyoto Protocol for Annex B countries to 'offshore' greenhouse gas (GHG) emission reduction activities in a developing country (clean development mechanism, CDM) where emission reduction can be achieved at more economic way, to purchase emission reductions achieved by another Annex B country (emission trading through carbon markets) or to implement emission reduction projects in another Annex B country (joint implementation, JI). WANA region consists of countries that are at diverse economic and carbon emission levels (Table 18.7) and GHG emission levels of some countries are comparable to many other Annex I countries of UNFCCC. Among all WANA countries, only Turkey, with a total GHG emission level of 287 Tg CO_2 eq (UNFCCC 2012b), is in the Annex-I list of UNFCCC and no country from the WANA region are in Annex B list of the Kyoto Protocol which means that the region as a whole has no obligation to reduce GHG emissions under Kyoto Protocol.

Total emissions from countries in WANA region are negligible when compared to most countries in the world and many countries in Africa are already at the lowest level of total and per capita emissions. Very few countries in the WANA region (Bahrain, Iran, Saudi Arabia and United Arab Emirates) have comparable per capita emissions as that of major Annex I countries. While these countries are in a position to take up voluntary GHG mitigation commitments, some of them have voluntarily refrained from participating in related negotiations under UNFCCC and others have shown little interest due to the position taken by the Arab League (Hmaidan 2008).

Though CDM has received considerable criticism for not being able to deliver developmental benefits in the developing countries, CDM continues to be an important mechanism in the first commitment period of the Kyoto Protocol that ends in

Table 18.7 GHG emission levels with LULUCF of selected countries in WANA region and other developed countries listed under Annex I of UNFCCC

Country	Total GHG emissions (Tg CO_2 eq)	Per Capita GHG emissions (t CO_2 eq)
WANA countries		
Bahrain	20	36
Egypt, Arab Rep.	193	3
Ethiopia	38	0.7
Iran, Islamic Rep.	493	8
Saudi Arabia	282	14
Sudan	72	2
Turkey	287	4
United Arab Emirates	120	40
Yemen, Rep.	8	0.5
UNFCCC Annex-I countries		
Australia	600	27
Canada	680	20
Germany	937	11
Japan	114	9
United States	5,618	18

GHG data: UNFCCC (2012a); Population data: World Bank (2012)

2012. The lack of willingness and capacity for using available opportunities under global climate architecture is a cause of concern for the WANA region. This is evident from the poor performance of WANA region in attracting CDM projects. It is apparent that the Africa region and Middle East are able to attract only a fraction of overall CDM projects (4 % of all CDM projects) in the region (UNEP RISO 2012). As a result, the region could generate a very small amount of certified emission reductions, 5.4 % of all certified emission reductions (CERs). This is a missed developmental opportunity for many countries in the region.

CDM is an important source of funds for Adaptation Fund being managed under the Convention in the form of 2 % levy on proceeds of CERs. Though disbursement of Adaptation Funds to the vulnerable countries is not related to their contribution to the Adaptation Fund (i.e. share of proceeds from CERs generated in the developing countries of WANA region), the poor performance of WANA region in attracting CDM projects is a cause of concern and reflects its willingness and ability to participate in global climate architecture. Greater capacity for participating in GHG mitigation schemes could generate more adaptation funds those could benefit the region. Though Africa has not been a target place for CDM projects due to its already low carbon foot print, the same cannot be said in the case of most oil producing countries in the WANA region. The poor performance of Africa has to do with the limited capacity of many countries to prepare and submit proposals to the CDM Board, internal security situation and lack of political will (Hagbrink 2010) and political will in oil exporting countries.

18.6 Better Governance for Financing Resilience

From previous sections, it is apparent that there is considerable room for improvement in risk financing in the WANA region and most of it has to come from better governance of existing finances by scaling up the innovative financing options discussed in the Sect. 18.4 and some part of these finances could potentially come from market mechanisms implemented within the WANA region.

Effective governance of adaptation is important even if sufficient finances are made available since there is a lack of capacity and experience to govern adaptation at the scale that is necessary. Adaptation governance encompasses how adaptation actions are identified, prioritized, funded and implemented along the 'continuum of adaptation'. The continuum here starts from UNFCCC to the 'Action Platform' where adaptation actions are implemented in various climate vulnerable countries. The stakes are very high in adaptation governance now than ever since large amount of funds would have to be invested.

The concern for adaptation governance has several reasons. Primarily, the concern is due to lack of sufficient progress on development under various international initiatives. Noteworthy to mention are Johannesburg Plan of Action and Millennium Development Goals (MDG). Both these are excellent initiatives in terms of what they aim to achieve. However, they fall short of various critical aspects which made them less than successful. For example, neither of them is binding, no sufficient financial support and incentives for courtiers to implement, limited understanding on what sustainable development constitutes and how to put the concept of sustainable development to design on-the-ground actions, and overtly ambitious for some countries (e.g. several countries in Africa) while inadequate for others (e.g. India).

The Aid Effectiveness work under the Paris Declaration provides us some more insights into the state of affairs of what made the ODA funds be less successful. The survey of more than 50 developing countries which depend on ODA indicated that majority of the aid recipient countries lack operational strategy to utilize ODA, poor country public finance management systems, and poor country procurement systems (Third High Level Forum on Aid Effectiveness 2008) which holds good for most countries in the WANA region as well. Since adaptation funds would have to be channeled through the same institutional and governance systems, it is essential that these systems be rectified with priority. In this section, the necessary governance improvements are discussed at national and international levels.

18.6.1 Governance Framework at National Level

Better governance at the national level requires that the capacities of countries be enhanced to identify, prioritize, and implement wide variety of adaptation actions, policies and programs. The Nairobi Work Program (NWP) has identified some priority areas for countries to improve their understanding and assessment of climate change impacts, vulnerability, and adaptation so as to make informed decision on practical adaptation actions and measures in response to and in anticipation of climate change. The implementation of NWP is not free from challenges. Issues such as limited finances and limited capacity to implement the ambitious program need to be addressed (Okereke et al. 2007).

At national level, financing climate resilience could be facilitated through establishing a national focal body for adaptation (could be called as National Coordinating Committee or National Adaptation Body) that works with close technical cooperation from a national level institute, either newly established or designation of existing ones, for implementing national level adaptation actions. A National Level Adaptation Program of Action (APA), to be agreed under UNFCCC would ideally drive the national level adaptation actions designed by taking into consideration the national circumstances, vulnerabilities and capacities. Some countries, depending on their national circumstances, may put additional efforts in generating national level finances pooled as National Climate Change Funds in general or National Climate Change Adaptation Funds. These funds could be generated through multiple mechanisms being discussed under UNFCCC.

18.6.2 Governance at Regional and International Levels

Adaptation governance could be considerably improved if adaptation actions could be measured, reported and verified. Currently, the Bali Action Plan interprets the measuring, reporting and verification (MRV) only for mitigation actions. However, considering the importance of better monitoring and evaluation of investments made in resilient development, the author suggests that the MRVs be applied to adaptation actions too in order to enhance the accountability. MRV require that the climate risks are quantified, an index be developed to rate the effectiveness of adaptation actions, quantify the incremental progress in adaptive capacity of societies, institutions, natural ecosystems etc and be compared against a base line year or average of years. Though MRVs can be applied both at national and international levels, it is more relevant at international level since most adaptation funds would come from international sources.

However, there is a long way to go for implementing the MRVs for adaptation actions since measuring adaptation is largely a neglected area of work. Challenges include identifying a set of metrics that are applicable to wide range of geographical and time scales. This could also mean that establishing new institutional capacities at national and international levels that enable efficient monitoring of adaptation actions taken at the ground level. These actions and their effectiveness should ideally be reported to UNFCCC or some permanent body, to be established under UNFCCC, to oversee adaptation at international level.

The international framework of adaptation in the future climate regime depends on how the adaptation is governed under UNFCCC. There would be a permanent body under UNFCCC overlooking adaptation actions at the international level. By looking at various proposals made by different Parties to the Convention, this body would manage Adaptation Fund, play a decisive role in deciding financial allocations, monitoring adaptation actions, developing guidelines for accessing funds and for reporting procedures etc.

Managing finances is another important aspect. Creating a permanent body under the UNFCCC to manage the funds with major participation from the developing countries could be an option. The Adaptation Fund Board created to manage Adaptation Fund under Kyoto Protocol could set an example in this regard. Regarding the role of multi-lateral bodies, though institutions such as World Bank and Global Environmental Facility (GEF) play an important role in helping the UNFCCC, they should not dominate the decision making process on how funds are distributed to various parties. The future climate regime should make sure that the funds are not fragmented since multiple funds with multiple procurement guidelines could increase the bureaucratic hurdles.

Sourcing and disbursement of funds is an important issue of negotiations under UNFCCC. In various stakeholder consultations conducted by the Institute for Global Environmental Strategy, Japan the participants representing developing countries have argued that the historical responsibility should be considered as an important principle for financing adaptation in developing countries (Prabhakar and Srinivasan 2009). In addition to the historical responsibility, some have also suggested that the developed countries have additional incentives to support adaptation actions since a stronger global South means sustained supply of goods and services to the global North. This has reference to the fact that the countries are increasingly polarized in terms of producers and consumers of goods and services. Long-term benefits to developing countries are a clear incentive for developing countries to act on adaptation. Differentiation among developing countries can be a feasible proposition. Climatic vulnerability of developing countries could be used as a means of differentiation with the most vulnerable countries getting the highest funding in proportion to their vulnerability. This requires that the climatic vulnerability of different countries be quantified and developed in the form of an index such that fund disbursement could effectively be made. Increasing the efficiency of national financial mechanisms, better coordination among different ministries and avoiding replication of efforts could further enhance the finances at the national level.

Since adaptation costs are huge, no single mechanism will be sufficient to raise finances for adaptation rather it is necessary to have multiple sourcing mechanisms to fund for adaptation. A combination of market mechanisms and public financing could be an option. Involvement of private sector could also bring additional finances. With regard to the private sector involvement, it can be suggested that the corporate social responsibility of multinational and big corporate bodies should be made mandatory with possible adaptation targets, on the lines of carbon mitigation targets, with incentives such as tax exemptions, allowance for higher FDIs etc. National governments should encourage multinational companies to pursue enhanced investment in adaptation in their country since such investments would largely secure the investments made in vulnerable countries.

Within the WANA region, countries could benefit greatly by enhanced cooperation among themselves for initiating climate mitigation and adaptation actions.

Major oil exporting Arab countries could have positive impact either by initiating voluntary GHG mitigation activities or by contributing certain portion of oil revenues to the climate change adaptation funds created within the region through bi- and multi-lateral means. For this, there is a need for a change in the political will which can only happen by agreeing to the basic principles agreed under UNFCCC.

18.7 Conclusions

From this chapter, it is evident that the West Asia and North Africa region (WANA) is facing several developmental and climate related challenges overcoming which requires considerable finances. The available finances under the global climate architecture are going to fall short of requirements. For improved financing of climate resilient development in the WANA region, it is important that the region focuses on important issues such as security, political stability, strengthening institutions, and providing strong policy support at the national level that undermine the effectiveness of using available finances. There is a greater need for strengthening institutional mechanisms and capacity to design and implement policies and programs that enhance climate resilience. The widely different developmental and capacity levels of countries in the WANA region provide an important opportunity for the countries to collaborate for mutual development before looking outside for help. In order to achieve this, there is a need that all countries agree on principles of responsibility and needs of the most vulnerable with a room for further differentiation among the vulnerable developing and least developed countries that would further enhance the efficiency of resources employed for climate resilience.

For international finances, there is a room to increase the efficiency in delivering and managing developmental funds; plug leakages (including corruption, red tape), avoiding project delays, avoiding duplication including in institutions, and tapping monetization of ecosystem services. However, national level finances are crucial and there is a considerable room for tighter fiscal management in many WANA countries that could make available additional financial resources that could be directed to the neediest in the region. Promoting corporate social responsibility and public private partnerships for strengthening risk insurance and microfinance facilities is the main area for the region. Some other options include mainstreaming and focus on no-regret options; cutting down on public spending and overheads, introduction of domestic carbon taxes, realigning available finances including direct MDBs to increase the focus on non-infrastructural aspects of adaptation and finance those projects and programs that have clear micro level targets and operational mechanisms.

Some radical suggestions could include setting climate change adaptation targets for industry as a part of corporate social responsibility activities (self-imposed by developing countries). For this, developing and operationalizing adaptation metrics is a prerequisite. While a strategy that links the developed and developing countries in the region through options such as regional carbon trading is a possibility, there is even more need to look at opportunities available within individual countries in the region. Mechanism such as CDM needs to be modified to benefit the poor in the region and for that the oil exporting countries from the WANA region should actively engage in processes under UNFCCC and share the burden of climate change according to the principles set under the Convention.

Acknowledgements This chapter has benefitted from the discussions carried in the proceedings of the International Conference on Adaptation to Climate Change and Food Security in West Asia and North Africa, Kuwait, 13–16 November.

References

Adato M, Hoddinott J (2007) Conditional cash transfer programs: a “magic bullet” for reducing poverty? 2020 focus brief on the world’s poor and hungry people. International Food Policy Research Institute, Washington, DC

Agricultural Insurance Fund (2012) History of crop insurance in Iran. Agricultural Insurance Fund, Tehran. http://www.aiiri.gov.ir/HomePage.aspx?TabID=1&Site=aiiriPortal&Lang=en-US. Accessed 8 May 2012

Bakhtiari S (2009) Islamic microfinance, providing credit to the poor: a case study of Iran. Int Econ Studies 34:99–107

Benson C, Arnold M, Fuente A, Mearns R (2012) Financial innovations for social and climate resilience: establishing an evidence base, Framework Paper. The World Bank, Washington, DC

Bimeh M (2012) Central insurance of Iran http://www.centinsur.ir/Index.aspx?tempname=englishtemp&lang=2&sub=0#tab1. Accessed 7 May 2012

Bouwer LM, Aerts JCJH (2006) Financing climate change adaptation. Disasters 30:49–63

Breisinger C, Kcker O, Al-Riffai P, Yu B (2012) Beyond the Arab awakening: policies and investments for poverty reduction and food security, Food Policy Report. International Food Policy Research Institute, Washington, DC

CGAP (2006) Microfinance in Algeria: opportunities and challenges. Joint CGAP and AFD mission under the auspices of the Ministry of Deputy Minister for Financial Reform. CGAP, World Bank, Washington, DC

Climate Funds (2011) Climate funds and profiles. Climate Funds, Heinrich Böll Stiftung and the Overseas Development Institute. http://www.climatefundsupdate.org. Accessed 10 Nov 2011

Cruz RV, Harasawa H, Lal M, Wu S, Anokhin Y, Punsalmaa B, Honda Y, Jafari M, Li C, Ninh NH (2007) Asia. Climate change 2007: impacts, adaptation and vulnerability. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Contribution of working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp 469–506

DFID (2010) Conditional cash transfer pilot in Ain es-Sira. DFID, UK. http://www.dfid.gov.uk/What-we-do/Research-and-evidence/case-studies/research-case-studies/2010/Conditional-Cash-Transfers/. Accessed 9 May 2012

El-Beltagy A (1997) West Asia and North Africa: a regional vision. CGIAR News 4(2). http://www.worldbank.org/html/cgiar/newsletter/april97/8beltagy.html. Accessed 15 Apr 2012

FAO (2011) Agricultural insurance in Asia and Pacific, RAP Publication 2011/12. Food and Agriculture Organization, Rome

FAO (2012). FAOSTAT. Food and Agriculture Organization, Rome. http://faostat.fao.org. Accessed 10 May 2012

Habbab S (2012) Tracking investments in agricultural research for development–the WANA region. In Stakeholder Workshop on Tracking Investments in Agricultural Research for Development. Berlin, 20 Jan 2012. http://www.agrifeeds.org/node/72616. Accessed 15 Apr 2012

Hagbrink I (2010). Why so few carbon projects in Africa? Development in a changing climate blog, The World Bank, Washington, DC. http://blogs.worldbank.org/climatechange/why-so-few-carbon-projects-africa. Accessed 9 May 2012

Hay A, Grebler D (2011) Reuters: IMF urges targeted subsidies in Middle East. Reuters, Washington, DC. http://www.reuters.com/article/2011/02/17/us-imf-mideast-idUSTRE71F5HY20110217. Accessed 9 May 2012

Hazell P (2000) Public policy and drought management in agropastoral systems. In: McCarthy N, Swallow B, Kirk M, Hazell P (eds) Property rights, risk, and livestock development in Africa. ILRI/IFPRI, Nairobi/Washington, DC

Hmaidan W (2008). World Environment Magazine: The Arab World in the Post-Kyoto Regime, May 2008. The Arab Climate Alliance, Lebanon. http://www.arabclimate.org/alliance_news/wem05_08.html. Accessed 2 May 2012

IFC, KFW (2008) Pakistan: microfinance and financial sector diagnostic study. IFC, KFW and MIFA, Washington, DC

Kassam AH (1981) Climate, soil, and land resources in North Africa and West Asia. Plant Soil 58:1–29

Kirshen P (2007) Adaptation options and cost in water supply. Report to the UNFCCC Secretariat Financial and Technical Support Division. http://unfccc.int/cooperation_and_support/financial_mechanism/financial_mechanism_gef/items/4054.php. Accessed 15 Aug 2012

Mahul O, Stutlley CJ (2010). Government support to agricultural insurance: challenges and options for developing countries. Annex E: international experiences with agricultural insurance: findings from a World Bank Survey of 65 Countries. The World Bank, Washington, DC. http://databank.worldbank.org. Accessed 15 Apr 2012

Making Finance Work for Africa (2011). Algeria: new insurance product launched for potato producers. News Dated 12.12.2011, Making finance work for Africa. http://www.mfw4a.org/news/news-details/2/algeria-new-insurance-product-launched-for-potato-producers.html. Accessed 7 May 2012

McCarl B (2007) Adaptation options for agriculture, forestry and fisheries, a concept to the UNFCCC secretariat financial and technical support division. UNFCCC, Bonn

McIntyre BD, Herren HR, Wakhungu J, Watson RT (2009) International assessment of agricultural knowledge, science and technology for development (IAASTD): Central and West Asia and North Africa (CWANA) report. Island Press, Washington, DC

Minot N, Benson T (2009) Fertilizer subsidies in Africa. Are vouchers the answer? IFPRI Issue Brief 60. International Food Policy Research Institute, Washington, DC

Moss T (2011) Oil to cash: fighting the resource curse through cash transfers, Working Paper 237. Center for Global Development, Washington, DC

Muller M (2007) Adapting to climate change: water management for urban resilience. Environ Urban 19:99–112

Okereke C, Mann P, Osbahr H, Muller B, Ebeling J (2007) Assessment of key negotiating issues at Nairobi climate COP/MOP and what it means for the future of the climate regime, Working Paper 106. Tyndall Center for Climate Change Research, Norwich

OSCAL (2000) Microfinance in Africa: combining the best practices of traditional and modern microfinance approaches towards poverty eradication. Office of the Special Coordinator for Africa and the Least Developed Countries (OSCAL), United Nations. http://www.un.org/esa/africa/microfinanceinafrica.pdf. Accessed 9 May 2012

Oxfam (2012) Horn of Africa risk transfer for adaptation: HARITA quarterly report: October 2011-December 2011. Oxfam America, Boston. http://www.oxfamamerica.org. Accessed 15 June 2012

Oxfam (2007) Oxfam applauds adaptation funding in US legislation, urges concrete action in Bali. Oxfam press release. http://www.oxfamamerica.org/press/pressreleases/oxfam-applauds-adaptation-funding-in-us-legislation-urges-concrete-action-in-bali. Accessed 15 June 2012

Prabhakar SVRK (2008) Financing and governing adaptation in a future climate regime: Issues, perspectives and way forward. In IGES-NIES-UN ESCAP Policy Forum on Towards a Copenhagen Consensus: Opportunities and Challenges, Kyoto, 9–10 Oct 2008

Prabhakar SVRK, Srinivasan A (2009) Financing and governing adaptation and promoting disaster risk reduction, IGES briefing notes on the post-2012 climate regime. Institute for Global Environmental Strategies, Hayama

Ringler C, Zhu T, Cai X, Koo J, Wang D (2010) Climate change impacts on food security in Sub-Saharan Africa: insights from comprehensive climate change scenarios, IFPRI Discussion Paper 01042. International Food Policy Research Institute, Washington, DC

Rosegrant MW, Cline SA, Li W, Sulser TB, Valmonte-Santos RA (2005) Looking ahead: Long-term prospects for Africa's agricultural development and food security, 2020 discussion paper 41. International Food Policy Research Institute, Washington, DC

Skees J, Gober S, Varangis P, Lester R, Kalavakonda V (2001) Developing rainfall-based index insurance in Morocco, World Bank Policy Research Working Paper 2577. The World Bank, Washington, DC

Smith JB (2007) Preliminary estimates of additional investment and financial flows needed for adaptation in 2030. Paper presented at the dialogue on long-term cooperative action, Vienna, 28 Aug 2007

Stern N (2007) The economics of climate change: the stern review. Cambridge University Press, Cambridge

Stoppa A, Hess U (2003) Design and use of weather derivatives in agricultural policies: the case of rainfall index insurance in Morocco. In: International conference on agriculture policy reform and the WTO: where are we heading? Capri, 23–26 June 2003

Tekleselassie AA, Johnstone DB (2004) Means testing: the dilemma of targeting subsidies in African higher education. JHEA/RESA 2:135–58

Third High Level Forum on Aid Effectiveness (2008) 2008 Survey on monitoring the Paris declaration effective aid by 2010? What it will take? vol 1 overview, 3rd high level forum on aid effectiveness, Accra, Ghana, 2–4 Sept 2008

UNEP RESO (2012) CDM Projects by host region. UNEP RESO Center, Denmark. http://www.cdmpipeline.org/cdm-projects-region.htm. Accessed 9 May 2012

UNFCCC (2007) Investment and financial flows to address climate change. http://unfccc.int/resource/docs/publications/financial_flows.pdf. Accessed 20 Nov 2008

UNFCCC (2008) Submissions from Parties to the COP and CMP. UNFCCC, Bonn. http://unfccc.int/documentation/submissions_from_parties. Accessed 8 Nov 2008

UNFCCC (2011) NAPA database. United Nations Framework Convention on Climate Change, Bonn. http://unfccc.int/cooperation_support/least_developed_countries_portal/napa_priorities_database/items/4583.php. Accessed 10 Apr 2012

UNFCCC (2012a) GHG data: time series – annex I. United Nations Framework Convention on Climate Change, Bonn. http://unfccc.int/ghg_data/ghg_data_unfccc/time_series_annex_i/items/3814.php. Accessed 6 May 2012

UNFCCC (2012b) Greenhouse gas inventory data – detailed data by party. United Nations Framework Convention on Climate Change, Bonn. http://unfccc.int/di/DetailedByParty.do. Accessed 10 Apr 2012

United Insurance Company of Pakistan Ltd. (2012) Crop insurance. http://www.theunitedinsurance.com/. Accessed 15 June 2012

United Nations (2011) The millennium development goals report 2011. United Nations, New York

USAID, IZDIHAR (2007) Iraq private sector growth and employment generation: the Iraq microfinance strategy. USAID, Washington, DC

World Bank (2009) Building a vibrant microfinance sector in Afghanistan. The World Bank, Washington, DC. http://www.misfa.org.af/. Accessed 7 May 2012

World Bank (2010) Morocco: conditional cash transfers and education. World Bank, Washington, DC. http://go.worldbank.org/QAP8FOBY90. Accessed 9 May 2012

World Bank (2012) World DataBank: world development indicators and global development finance. The World Bank, Washington, DC. http://databank.worldbank.org. Accessed 10 Apr 2012

Chapter 19
Economic Impacts of Climate Change in the Arab World: A Summary of Case Studies from Syria, Tunisia and Yemen

Clemens Breisinger, Perrihan Al-Riffai, and Manfred Wiebelt

Abstract This paper synthesizes pioneering work based on a comprehensive modeling suite that combines biophysical, sub-national and global economic models to assess the global and local effects of a changing climate on growth and household incomes in three countries in the Middle East and North Africa: Syria, Tunisia and Yemen. This cross country comparison is important given these countries' location in a region that is consistently projected to be amongst the hardest hit by climate change. Results show that even under perfect climate change mitigation, the world market prices for food are projected to increase affecting the three economies differently. Higher global prices for food negatively affect most sectors of the economy in Syria, except for agriculture, which benefits from the higher prices. However, Syrian real household incomes decline, particularly those of poor rural nonfarm households. In Tunisia, higher food prices pose challenges to its poor and in Yemen, results from the DCGE model suggest that higher global prices for food will lower Yemen's overall GDP growth, raise agricultural GDP, and decrease real household incomes. Effects on agricultural GDP vary by agroecological zone depending on the production structure in place. Local climate change impacts alone will lead to lower crop yields for all of the countries. In Syria, the agricultural sector suffers as a result of long-term declines in yields, and different agroecological zones will be affected differently. In Tunisia, local climate change shocks operate on the sector and on households through reduced crop yields. Results from the Tunisian DCGE model shows that local climate change is welfare reducing for all household groups under both GCM scenarios, however, farm households are most adversely affected by

C. Breisinger (✉) • P. Al-Riffai
International Food Policy Research Institute (IFPRI), 2033 K Street, N.W., Washington, DC 20006, USA
e-mail: c.breisinger@cgiar.org

M. Wiebelt
Kiel Institute for the World Economy, Hindenburgufer 66, D-24105 Kiel, Federal Republic of Germany

M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_19,

these yield reductions. Finally for Yemen, the local impacts of climate change are different under the two climate scenarios considered where under the MIROC scenario, agricultural GDP is somewhat higher compared to the baseline. Rural incomes are expected to rise due to the higher yields and the lower prices for sorghum and millet, whereas the urban households are largely unaffected because they hardly consume those commodities. Under the CSIRO scenario, positive and negative yield changes cancel each other out so agricultural GDP and incomes for all three household groups hardly change over the period of analysis compared to the baseline. Over the long-term, the adverse effects of both global and local climate change impacts are felt throughout the three countries. In Syria, combining local and global climate change effects slows GDP growth in all sectors. Rural households (both farm and nonfarm households) suffer the most from climate change, but urban households are also worse off when compared with the perfect mitigation scenario. Across Tunisia, the combined climate change effects lead to negative effects on the overall economy, the agricultural sector, and a total reduction of household incomes and in Yemen, the long-term implications of climate change (local and global) lead to a reduction in household welfare under both the MIROC and the CSIRO scenarios. Those reductions in welfare accumulate over time and rural households suffer more from climate change than urban households. However, under the MIROC scenario, farm households benefit from the increasing yields but rural nonfarm households do not and suffer both in relative and absolute terms under the MIROC and CSIRO scenarios. Given the strong global *and* local impacts of climate change, a diverse set of policy actions at different levels will be required to mitigate the negative socioeconomic effects. Moreover, global price increases, declining crop yields, and droughts affect different sectors and households differently, which underscores the necessity to consider a variety of mitigation and adaptation tools including global and national action plans, investments in agriculture, social protection, and disaster risk management.

Keywords Climate change • Arab world • Syria • Tunisia • Yemen • Agriculture • Poverty • Development

19.1 Introduction

All Global Climate Models (GCMs) consistently predict increasing temperatures, and many anticipate a reduction in rainfall throughout the Arab world. While most experts agree on these climatic trends, it is less clear what the socioeconomic impacts of such a changing climate will be. Assessing these impacts is challenged by the generally complex relationship between meteorological, biophysical and economic interactions, the expected diversity of impacts by country and subnational levels, and the relatively long time horizon of the analysis. In general, climate change affects countries' economies and households through a variety of channels. Rising temperatures and changes in rainfall patterns affect agricultural yields of both rainfed and irrigated crops, and thus global and local food markets (Nelson et al. 2009, 2010). Countries that depend on rainfed agriculture, such as many in sub-Saharan Africa, are more vulnerable to an increase in climate change, leading to projected large losses in their national output (Thurlow et al. 2009). Countries with large delta regions, such as Bangladesh and Vietnam, are projected to be hardest hit by rising sea levels that may lead to loss of land, landscape, and infrastructure, with strong implications for food security and the rural poor (Yu et al. 2010a, b). Countries that are already experiencing water stress, especially those in the Arab World, are likely to experience additional declines in agricultural yields, resulting in negative effects on rural incomes and food security (Breisinger et al. 2010). A higher frequency of reduced precipitation will change hydropower production, and an increase in floods can significantly increase the need for public investment in physical infrastructure (Stern 2006; World Bank 2007; Garnaut 2008; Yu et al. 2010a, b).

This paper summarizes the major findings from a modeling suite that addresses these analytical challenges by linking the downscaling of selected GCMs, crop modeling, global economic modeling, and subnational-level computable general equilibrium with microsimulation modeling.[1] While much of the work on economic impacts of climate change has focused on either the global or national economic impacts of climate change, this paper synthesizes pioneering work based on a comprehensive modeling suite that combines biophysical, sub-national and global economic models to assess the global and local effects of a changing climate on growth and household incomes. We feed the downscaling of the GCM scenarios (Jones et al. 2009) into the Decision Support System for Agro Technology Transfer (DSSAT) (Jones et al. 2003) which assesses the changes in yields for selective crops and agro ecological zones for our three countries of study: Syria, Tunisia and Yemen. Output from DSSAT informs the International Food Policy Research Institute's (IFPRI's) International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model (Rosegrant et al. 2008) and serves as a direct input into the country specific dynamic computable general equilibrium (DCGE) models. Changes in world food prices derived from IMPACT, along with alternative global energy price futures, also flow into the DCGE models to assess the global impacts of climate change on the respective economies.

This cross country comparison is important given these countries' location in a region that is consistently projected to be amongst the hardest hit by climate change. In addition, both global and local impacts matter for their future development, given their status as net food- and energy-importing country for many of the commodities. Syria, now a net importer of oil, is also a net importer of major food items such as rice, maize, barley, soybeans, fish, and poultry (Breisinger et al. 2011). Tunisia, also a net importer of food, imports between 50 % and 88 % of cereals and many other food items resulting in a moderate risk of food insecurity (Breisinger et al. 2012a). Yemen, the largest net importer of cereals and food of the three focus countries,

[1]More details about these models can be found in Breisinger et al. (2011, 2012b) and Wiebelt et al. (2011).

imports between 70 % and 90 % of cereals and is a net importer of many other food items (Ecker et al. 2010). Yemen, in addition to being heavily import dependent, is also the poorest country in the Arab world, with an estimated 43 % of its people living in poverty, and is amongst the most food-insecure countries in the world, with 32 % of the population hungry, that is, without access to enough food (Breisinger et al. 2010; Ecker et al. 2010). It is against this background that this paper assesses how far climate change is likely to affect these three countries and stresses the necessity of it to be considered in future development strategies.

19.2 Economic Impacts of Climate Change

At the time of the analysis, Syria, Tunisia and Yemen had taken significant strides towards transition and towards substantial economic reform in order to accelerate growth and transform their economy, specifically, in the fields of trade, taxes, subsidies, foreign direct investment, and the development of non-oil industries. And yet, climate change may threaten any progress in development and pose a significant burden on economic growth and household incomes, especially of the poor, if it is neither mitigated nor incorporated into national planning. The major channels through which these economies are likely to be affected most are through changing global commodity prices and local impacts on agricultural production from either climate change or from droughts or floods. Important determinants of future water availability are likely to include more than climate change. Particularly, there is uncertainty about the levels of future water allocation and river flows, which will ultimately be dependent upon a comprehensive water strategy that addresses not only national water sources and uses but also regional water-sharing agreements with neighboring countries. Across all the three countries, agriculture's use of water resources reaches up to 90 % of all water use.[2] That, in addition to the severe water constraints in Tunisia, the droughts in the case of Syria and the floods in Yemen necessitates the importance of developing a comprehensive water strategy that goes beyond the scope of this paper.

19.2.1 Global Climate Change Impacts

World food prices are projected to increase as a result of demographic and income effects, and are expected to be augmented by climate change. Figure 19.1 reports the effects of the climate change scenarios on world food prices (CSIRO A1B and MIROC A1B). It also reports the price effects with no climate change (NoCC; perfect mitigation). With no climate change, world prices for the most important

[2] Syria uses 47 % of water used for agriculture as surface water that Syria shares with its neighbors, mainly from the Tigris, Euphrates, and Orontes Rivers (World Bank 2010).

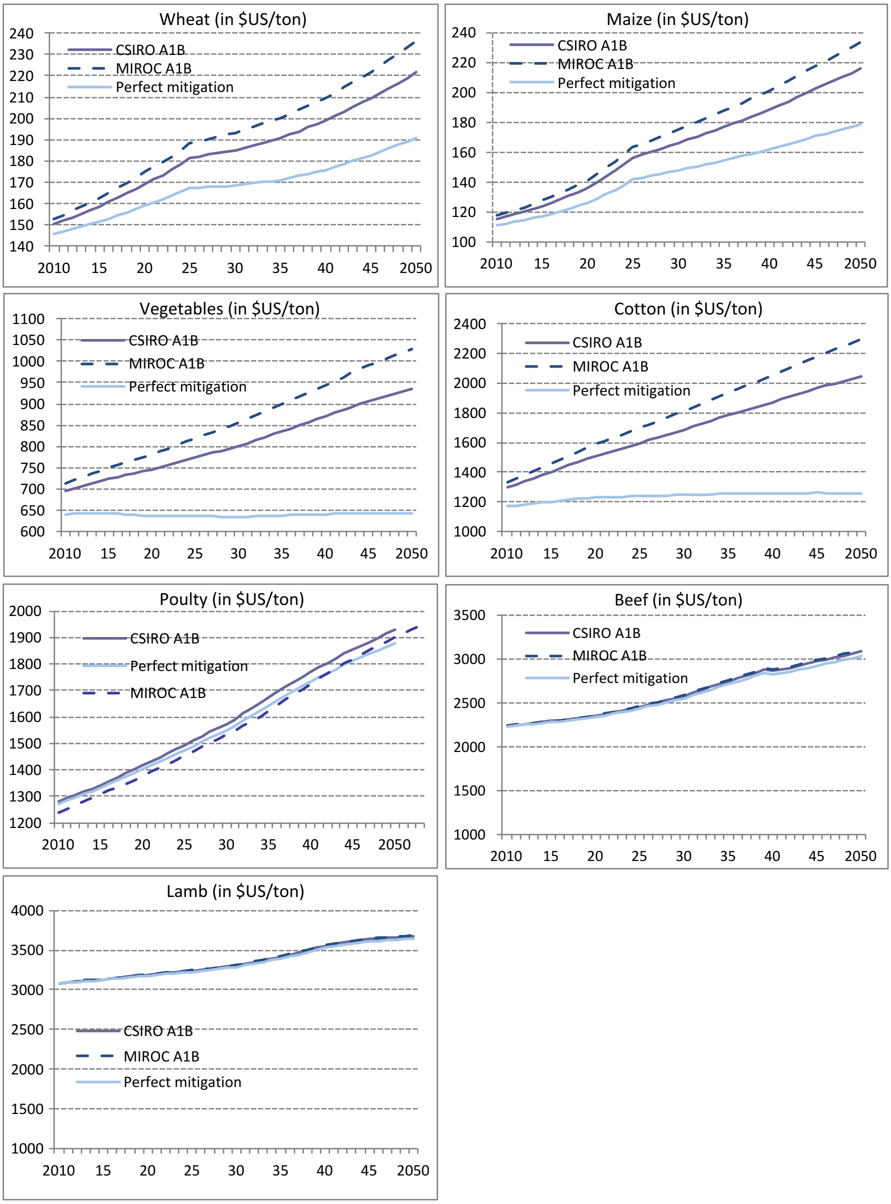


Fig. 19.1 Global food price scenarios, 2010–2050 (Source: IFPRI IMPACT model, Rosegrant et al. 2008)

agricultural crops – rice, wheat, maize, and soybeans – will increase between 2000 and 2050, driven by population and income growth and biofuels demand. Even with no climate change, the price of rice would rise by 62 %, maize by 63 %, soybeans by 72 %, and wheat by 39 %. Climate change would result in additional price increases of 32–37 % for rice, 52–55 % for maize, 11–14 % for soybeans, and 94–111 % for wheat (Nelson 2009).[3] One of the assumptions of IMPACT is that the second-generation (cellulosic) biofuels will phase in from 2025 on and replace food feedstock-based biofuels. The reduction in demand for food crops shows the slower price increase after 2025. Livestock are not directly affected by climate change in the IMPACT model; however, the effects of higher feed prices caused by climate change pass through to livestock, resulting in higher meat prices. It is from this background that we move forward with the country case studies covered in this chapter. Each of the individual country details are modeled (together with these global assumptions) to present a more detailed and comprehensive picture of how both these global impositions as well as their local effects will interact to impact their economies and social conditions.

19.2.1.1 Country Case Studies

Syria

Syria has become a net importer of oil and petroleum products and many food commodities in recent years, making the country vulnerable to global commodity price changes. Oil has played an important part in the Syrian economy since the 1990s and still accounts for about 40 % of the government revenues, 25 % of exports, and about 15 % of GDP (IMF 2009; Breisinger et al. 2011). However, Syria has become a net importer of oil. The International Monetary Fund (IMF) projects that oil output will decline during the next few years, indicating that other sectors in the economy will have to increasingly contribute to growth (IMF 2009). Syria is also a net importer of major food items, including rice, maize, barley, soybeans, fish, and poultry. Syria remains a net exporter of olives, fruits, and vegetables (Breisinger et al. 2011).

Agricultural and related processing contributes about 19 % to GDP, about half of which is produced in agroecological zone 1.[4] Livestock alone makes up close to 6 % of GDP, dominated by sheep production (3.1 %). Cereals and fruits contribute 3.3 % and 3.0 % to GDP, respectively, followed by vegetables, with 2.5 % (Breisinger et al. 2011). Nonirrigated cereals production is mostly concentrated in agroecological zones 1 and 2, as are water-intensive crops such as fruits and vegetables.

[3] In addition to various GCMs, Nelson et al. (2009) also include low, medium, and high assumptions on population and GDP percent growth. For this study, we use the medium-level assumptions.

[4] The model for Syria differentiates between five agroecological zones that are mainly defined according to rainfall quantities. See Sect. 2 in Breisinger et al. (2011) on the characteristics of these agroecological zones.

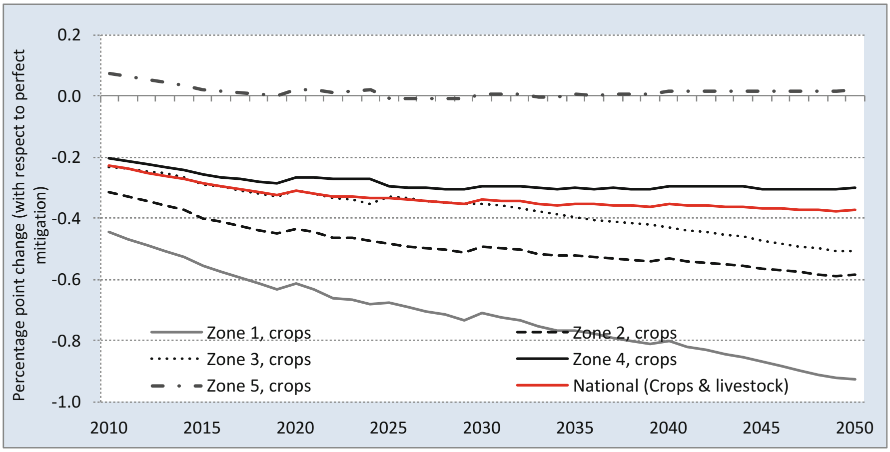


Fig. 19.2 Syria: Impact of combined local and global climate changes on agricultural GDP by agroecological zone, 2010–2050 (Source: IFPRI Syria DCGE Model results)

In terms of contributions to GDP, zone 2 is the second largest contributor, followed by zones 5, 3, and 4 (Breisinger et al. 2011).

Food- and agriculture-related processing makes up about 50 % of household consumption expenditure. Within this category, food processing constitutes the largest share of consumption, followed by meat, fruits, vegetables, and cereals. Energy and water constitute 4.8 % of total private consumption expenditures; however, potentially rising energy prices are likely to affect household consumption. For example, higher world oil prices would raise domestic prices for fuel, which increases transport cost. Since transport is an important input in the production of many goods and services, overall price levels are expected to rise, causing real household incomes to fall.

Considering the global and local effects of climate change jointly shows that the two compound each other. Economic growth is on average 0.05 percentage points lower each year compared with perfect mitigation between 2010 and 2030. However, as in the case of local climate change only, the economy adapts to climate change over time but never reaches the levels of the perfect mitigation scenario. Climate change speeds up structural change in the economy, where the share of agriculture declines to 8.3 % in 2050, compared with 9.5 % under perfect mitigation (Breisinger et al. 2011). Consequently, the industrial and services sectors gain in relative importance, moving from 45 % to 37 % of GDP, respectively, to 47 % and 46 %, respectively, by the end of the period.

Agricultural output declines under the combined climate change scenario with increasing speed over time (Fig. 19.2). The impact of global climate change in isolation has positive implications on agricultural production. However, when the negative impacts on agricultural GDP from local climate change are factored in, over time, the agricultural growth rate is between 0.2 and 0.4 percentage points lower than under perfect mitigation. The overall reduction in yields due to the local impacts of climate change translates into higher domestic agricultural prices and increasing imports. Higher domestic prices reduce competiveness on the world market and thus also affect Syria's exports of agricultural crops. However, this latter effect is reduced when global climate change is factored in and globally higher crop prices provide a boost to the agricultural sector and improve agricultural export performance, leading to faster growth of the agricultural sector (compared with perfect mitigation). Given these two opposite impacts, under combined climate effects, agricultural GDP declines from 0.2 % to 0.4 % points below perfect mitigation outcomes over the entire period (Fig. 19.2). The decline accelerates over time, indicating that if no climate change mitigation action is taken, agriculture is likely to continue to suffer after 2050.

The combined effect of global and local climate change has detrimental effects on agricultural GDP across all zones, with the largest declines occurring in zones 1 and 2, which together account for three-quarters of agricultural production in Syria (Fig. 19.2). Despite the positive impacts that global climate change may provide to the Syrian agricultural sector due to the increased price of agricultural produce, the reduced local agricultural yields hurts output across all zones. In zones 1–4, growth rates of agricultural GDP growth are between 0.2 to 0.9 percentage points lower over the baseline, with the sharpest declines occurring in zones 1 and 2. Zone 5 is the least affected in terms of reduction in crop output, largely because of the absence of rainfed agriculture. However, if we factor in potential impacts on livestock (which was not possible in this report), zone 5 is likely to suffer losses in agricultural output, too.

Taking the global and local impacts of climate change together leads to sharp declines in household welfare. The magnitude of these combined losses is far greater than when climate change was confined to the local area. Mainly two effects account for this result: an income effect and a price effect on household expenditure. For the former, despite the fact that under a global climate change scenario farmers benefit from the higher agricultural prices, when local yields decline due to local climate change, farmers are unable to increase their production and thus fail to benefit from this income potential. Additionally, agricultural prices are higher and households have to increase their consumption of imported goods, and therefore households end up paying more for their food basket than they did when climate change impacts were only local. Real income of rural farmers decreases by up to 3.2 % compared with perfect mitigation (Fig. 19.3). As for rural nonfarm households, their real income falls by up to 3.2 % over the baseline by 2050 as a result of being net food consumers who have to contend with their rising expenditure on food. Again, the welfare reductions, compared with perfect mitigation, are far greater than when climate change was local.

Overall, the poorest segments of the population are hardest hit under both local and global climate change (Fig. 19.3 above). It is important to note the differences between the different household groups (not shown in Fig. 19.3), most notably the poorest quintiles within these groups. Among rural and urban groups, the 20 % lowest income groups lose most in relative terms, while the negative effect declines the

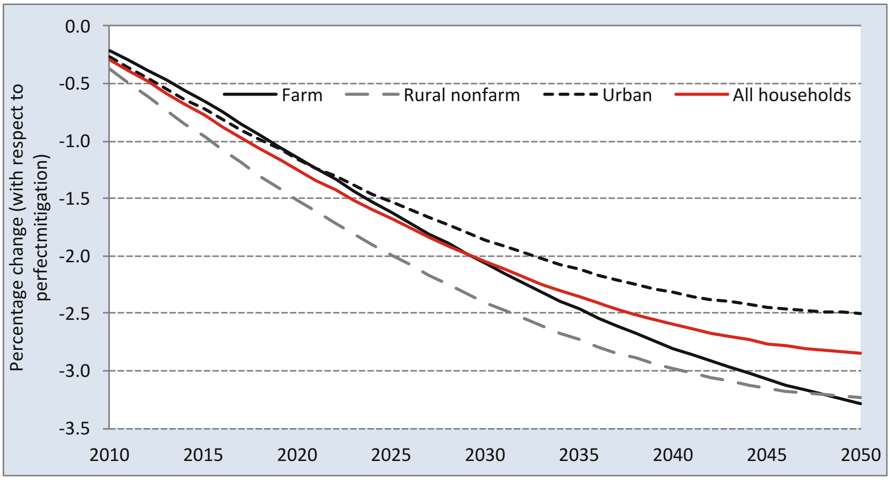


Fig. 19.3 Syria: Impact of combined local and global climate changes on household income, 2010–2050 (Source: IFPRI Syria DCGE Model results)

wealthier the people become. The poorest 20 % of rural nonfarm households are the hardest hit of any group when local and global impacts of climate change are combined, with an average annual decrease in income of 2.8 % over the baseline. The poorest suffer most mainly due the joint effect of being net food buyers who spend a high share of their income on food and of earning incomes from factors of production most affected by climate change, namely, land and unskilled labor.

Tunisia

Agriculture is an important part of the Tunisian economy, accounting for 12–16 % of the GDP, depending on the size of the harvest (Breisinger et al. 2012b). The sector provided jobs for 22 % of the country's labor force in 1998. The two most important export crops are cereals and olive oil, with almost half of all the cultivated land used for cereals production and another third planted with olive trees. Tunisia is one of the world's biggest producers and exporters of olive oil, and it also exports dates and citrus fruits. Tunisia remains one of the few Arab countries that produces most of its dairy products, vegetables, and fruit and red meat consumed domestically. Since the 1980s, agricultural output has increased by about 40 %, and exports of food have risen considerably.

Tunisia's labor-intensive agricultural sector uses very low levels of fertilizers and pesticides. Most of the land is split into small farms making production much less efficient. Some 80 % of farms are smaller than 20 ha, and only 3 % are larger than 50 ha. Severe droughts, like the one experienced in 2000, have proven to be enormously costly. Tunisia belongs to the hydraulic poor countries. Rainfall is characterized by its scarcity and spatial and temporal variability (Mougou et al. 2002).

Variability and scarcity of water resources and high temperature affect negatively the production in rainfed agriculture, especially cereals that are mainly produced under rainfed conditions (the large majority of total cereal area is rainfed).

Tunisia is also a net importer of major food items, including cereals, forage crops, and processed food. Overall agriculture's trade orientation is very low and uneven, with imports accounting for more than 15 % of total domestic consumption and exports accounting for less than 5 % of domestic production. Agriculture and related processing contribute about 17 % to GDP. Food and agriculture-related processing makes up about 30 % of household consumption expenditures. Within this category, food processing constitutes the largest share of consumption, followed by fruits and vegetables (Breisinger et al. 2012b).

Combining the local and global effects shows that the slightly positive effects of higher world market prices on agriculture do not cushion the large negative effects of lower yields enough. The overall effect of climate change on agriculture is negative (Fig. 19.4), where despite the losses being slightly less than the losses to the sector under local climate change impacts alone, agricultural GDP still falls between 0.1 % and 1 % points annually by 2030 for the CSIRO and MIROC scenarios, respectively. The overall impact on agricultural GDP due to global climate change impacts does not differ amongst the two GCM scenarios. The difference appears when considering the local impact of climate change on the agricultural sector. The negative effects are amplified under that scenario mainly due to the reduced yields for crops.

As for the households, the impact of lower yields as a result of local climate change, however, is different (Fig. 19.5). Local climate change is welfare reducing for all household groups under both GCM scenarios, however, it is more so when we consider the MIROC scenario and when we also consider farm households. Households are affected through two major channels: farm households see their incomes fall due to lower agricultural activity. In addition, lower yield raises domestic food prices thus negatively affecting real incomes of all households.

The long-term (local and global combined) implications of climate change in Tunisia will lead to a total reduction of household incomes due to the stronger impact on household welfare through the local climate change impacts (Fig. 19.5). These welfare reductions accumulate over time. In 2030, all household incomes are projected to be 1–2 % lower compared to a perfect mitigation scenario. Farmers are hardest hit. The negative effects under the MIROC scenario reduce farmer incomes by close to 13 % over a scenario of perfect mitigation by the end of the period. However, under the CSIRO scenario, farmer welfare losses are less, reaching a modest but still significant 4 % reduction over perfect mitigation. Thus, the farmers suffer the most from climate change in Tunisia, followed by their rural nonfarm and urban equivalents (respectively).

Yemen

In Yemen, oil and agriculture are the two mainstays of the Yemeni economy, however, both are under threat, thus increasing the country's vulnerability to global

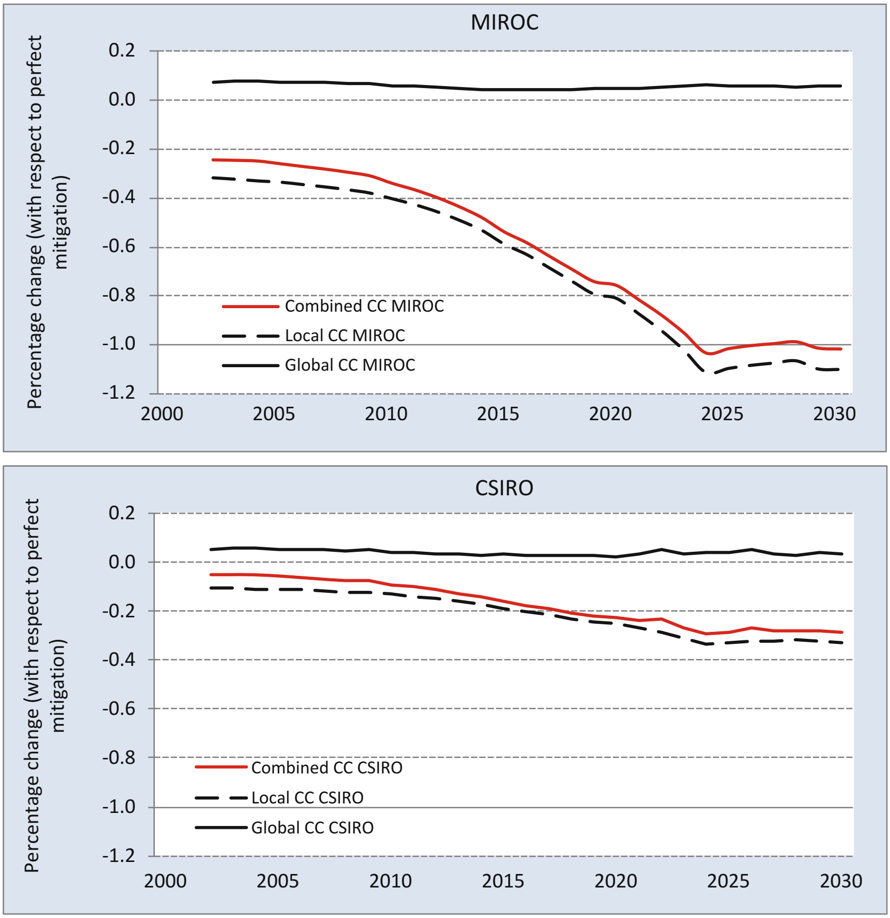


Fig. 19.4 Tunisia: Climate change impacts on agricultural GDP, 2000–2030 (Source: IFPRI Tunisia DCGE Model results)

commodity price changes. Oil reserves are set to run out by the beginning of the next decade, and aquifers, used for irrigated agriculture, have been seriously depleted in recent years. Although oil is still the dominant sector, oil production is on a declining trend, indicating that other sectors in the economy will have to contribute increasingly to growth. In the absence of new oil discoveries, it is estimated that Yemen may become a net importer of oil as soon as 2016. This will have a significant impact on the economy given that oil revenues account for 60 % of government receipts and almost 90 % of exports (IMF 2009; Wiebelt et al. 2011). Yemen is also a net importer of major food items, including maize, wheat, other grains, livestock, fish, and processed food. Agriculture's trade orientation is uneven, with imports accounting for more than a third of total domestic consumption and exports accounting for less than 5 % of domestic production.

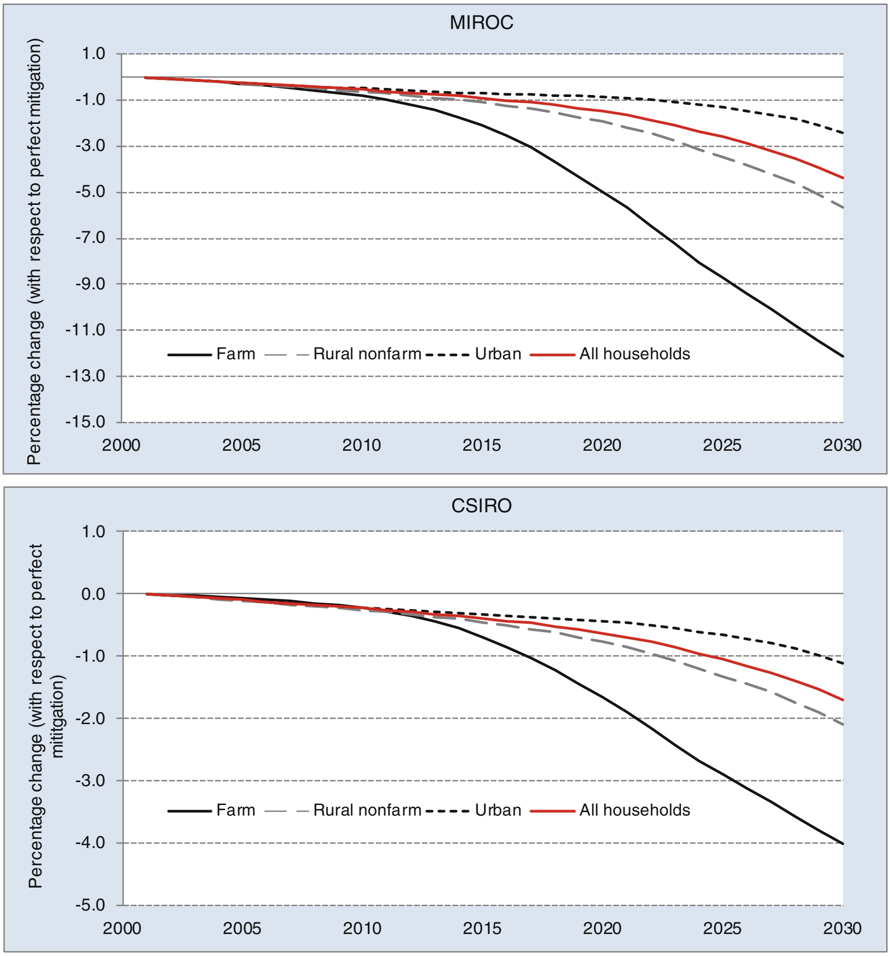


Fig. 19.5 Tunisia: Impact of combined climate changes on household incomes, 2000–2030 (Source: IFPRI Tunisia DCGE Model results)

Agriculture and related processing contribute about 13 % to GDP, about three-quarters of which is produced in the highly populated agroecological zones1 and 2 (the Upper and Lower Highlands, with 30 and 40 % of the total population living in these zones). Qat accounts for more than one-third of agricultural GDP and about 40 % of total water resource use. Vegetables and fruits make up another one-third of agricultural GDP. Livestock and cereals contribute about 20 % and 10 % to agricultural GDP, respectively (Wiebelt et al. 2011). Qat is almost exclusively concentrated in zones 1 and 2, whereas other water-intensive crops such as fruits and vegetables are also grown in zone 3 (the Red Sea and Tihama Plain Zone). Zones 1 and 2 are the two main contributors to agricultural and overall GDP, followed by zones 3, 5 (Internal Plateau), 4 (Arabian Sea Coast), and 6 (Desert). The latter three zones

Table 19.1 Yemen: Structural change under climate change scenarios (% of GDP)

		MIROC		CSIRO	
	Initial	2030	2050	2030	2050
Combined					
Agriculture	8.4	6.3	5.4	6.1	4.8
Industry	38.5	39.2	38.9	39.3	39.2
Services	53.1	54.5	55.8	54.6	56.0

Source: IFPRI Yemen DCGE Model results

together account for only 8 % of agricultural GDP. Zones 5 and 6 are the major producers of sesame and camel, however. Food and agriculture-related processing makes up about 50 % of household consumption expenditures. Within this category, food processing constitutes the largest share of consumption, followed by cereals, qat, vegetables, and fruits (Wiebelt et al. 2011).

Considering the global and local effects of climate change jointly shows that the effects cancel each other out at the macro level. Economic growth does not on average differ from the case of perfect mitigation. Whereas the share of agriculture in the economy falls as part of the general economic transformation process (Table 19.1), that pattern of structural change is even slightly reversed due to the global effects of climate change, which render the production of various agricultural commodities more profitable.

Results for the agricultural sector differ noticeably between the MIROC and CSIRO scenarios. Agricultural output rises under the combined MIROC climate change scenario with increasing speed over time. The impacts of both local and global climate change in isolation have positive implications for agricultural production. The agricultural growth rate in the combined scenario is between 0.2 % and 1.0 % higher each year than under perfect mitigation (Fig. 19.6). The overall rise in yields due to the local impacts of climate change translates into lower domestic agricultural prices and also a fall in imports. Lower domestic prices enhance competiveness on the world market and thus also affect Yemen's exports of agricultural crops. This latter effect is amplified when global climate change is factored in and globally higher crop prices provide a boost to the agricultural sector and improve agricultural export performance, thus leading to faster growth of the agricultural sector (versus perfect mitigation). In contrast, due to less optimistic yield predictions, agricultural growth in the CSIRO scenario is only slightly higher than with perfect mitigation when both local and global climate change effects are taken into account.

The combined effects of global and local climate change turn out to be favorable for agricultural production in all economically important zones (Fig. 19.7), but again much less so under the CSIRO scenario than under the MIROC scenario. In zone 3, the positive impacts of local and global climate change in the form of rising agricultural yields and rising world food prices add up to agricultural growth that in the year 2050 is between 0.5 % (CSIRO scenario) and 2.4 % (MIROC scenario) higher compared with perfect mitigation. For the two biggest regions in terms of agricultural value-added, zones 1 and 2, effects are more modest, with a rise in

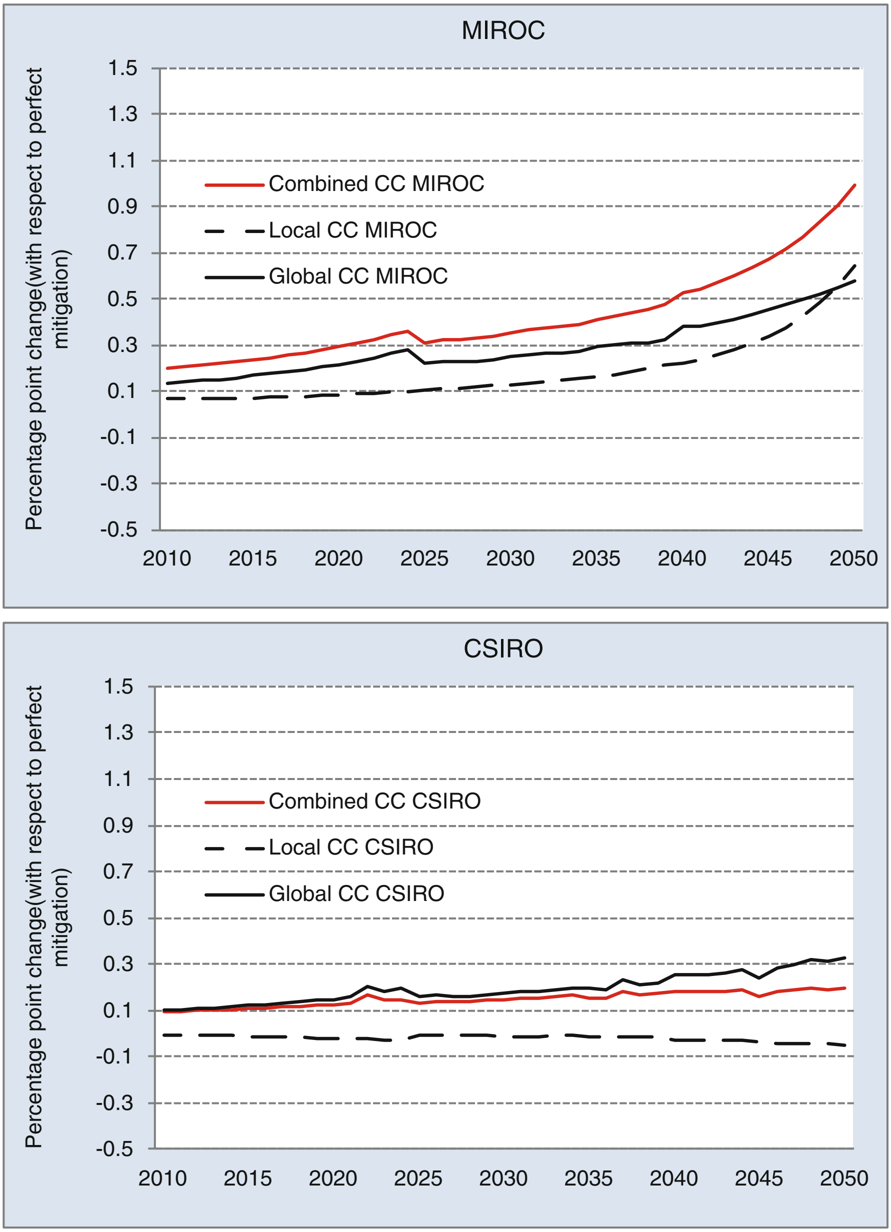


Fig. 19.6 Yemen: Impacts of local, global, and combined changes on agricultural GDP, 2010–2050 (Source: IFPRI Yemen DCGE Model results)

production by up to 0.4 % in the CSIRO scenario and 0.6 % in the MIROC scenario. Only in zones 4 and 6, which together account for not more than 3 % of total agricultural value-added, agricultural GDP is hardly affected by the combined effects of climate change.

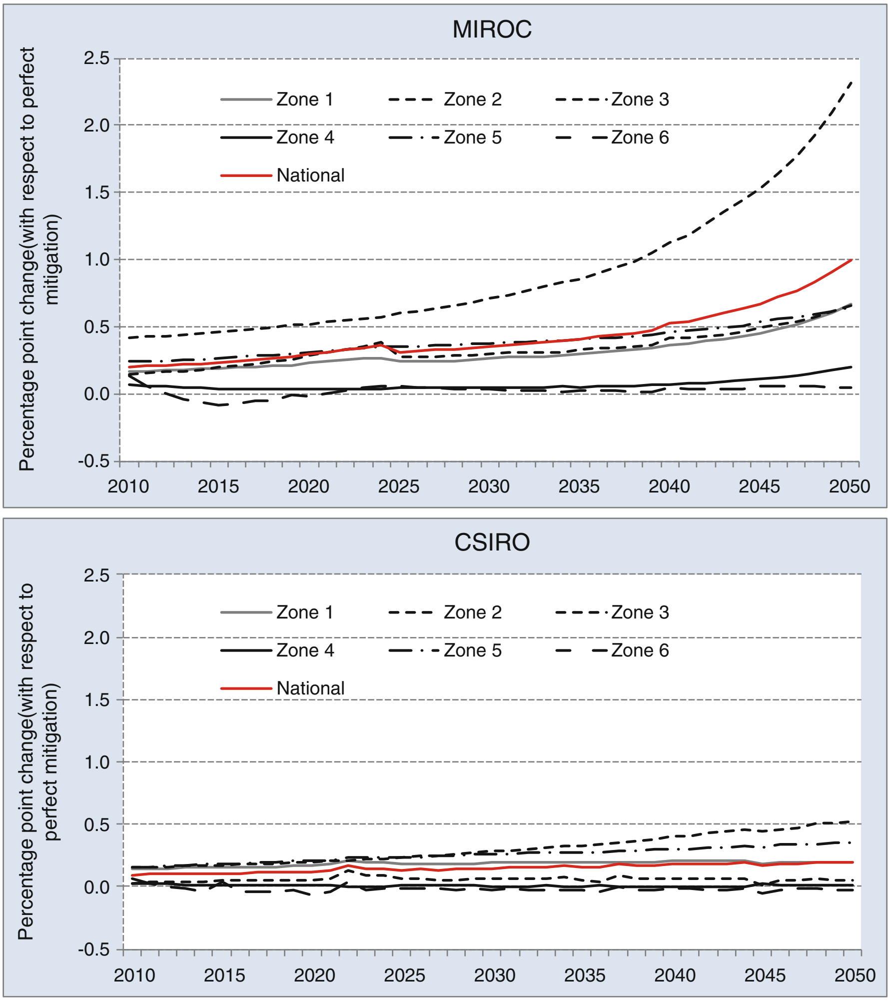


Fig. 19.7 Yemen: Impacts of combined local and global climate changes on agroecological zones, 2010–2050 (Source: IFPRI Yemen DCGE Model results)

Taking the global and local impacts of climate change together in general results in a reduction of household welfare under both scenarios. Only farm households may benefit under MIROC predictions, but incomes for rural nonfarm households and urban households fall (Fig. 19.8). Even though as net consumers farm households end up paying more for their food basket when world food prices rise, they on balance realize income gains because of the substantial yield increases for sorghum and millet. Rural nonfarm households and urban households, in contrast, are hit harder by the price effects of global climate change and benefit only indirectly – via falling prices – from the yield effects of local climate change. As a consequence, their real income falls by up to 0.8 % and 0.7 %, respectively. Under the CSIRO scenario, the gains of farm households turn into losses, and rural nonfarm

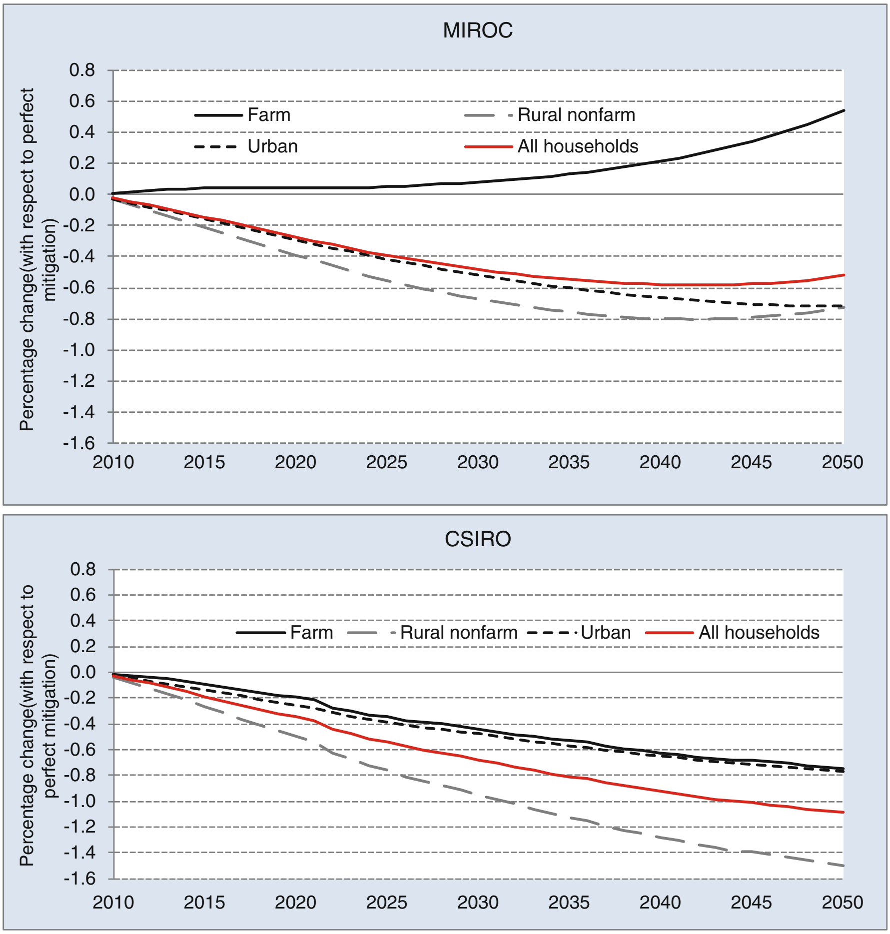


Fig. 19.8 Yemen: Impact of combined local and global climate changes on household incomes, 2010–2050 (Source: IFPRI Yemen DCGE Model results)

households see much stronger reductions in real household income as they no longer benefit from lower prices induced by higher yields.

Changes in real incomes not only differ between household groups but also exhibit considerable variation across regions. With the exception of rural farm households in zone 3 (and in zone 2 under the MIROC scenario), all households suffer real income losses as a result of the combined local and global impacts of climate change (Table 19.2). Although the effects of climate change do not reveal a clear distributional pattern, some of the poorest sections of Yemeni society are among the hardest hit. Most notably, farm households in the Desert zone have the lowest initial per capita income and are expected to experience the biggest income losses. They suffer most mainly due to the joint effect of being net food buyers, spending a high share of income on food, and specializing in agricultural activities that do not benefit from higher prices and increasing yields. Nonfarm households in zones 4 and 6 are other examples of poor groups incurring considerable losses.

Table 19.2 Yemen: Distributional impacts, local and global climate change, 2010–2050

Household group	Population	Per capita income (1,000 Yemeni rials) 2009	Average annual change, 2010–2050 (%) Combined climate change[a]
Urban			
1	2,669,219.1	242	–0.4
2	1,203,688	161	–0.5
3	774,200	177	–0.3 to –0.4
4	1,157,983	170	–0.5
5	302,989	159	–0.8
6	41,809	137	–0.7 to –0.6
Rural nonfarm			
1	1,946,108.60	152	−1.1 to −1.0
2	5,836,100.10	118	–0.3 to –0.9
3	1,616,577.60	133	–0.3 to –0.8
4	320,780.39	100	–0.8
5	999,507.30	127	−1.1 to −1.0
6	174,556.80	105	−1.0 to −0.9
Rural farm			
1	1,601,351.00	147	–0.5
2	2,544,788.70	90	0.6 to –0.3
3	737,258.54	108	1.6 to 0.1
4	134,267.62	111	–0.7
5	208,785.15	105	–0.4 to –0.5
6	189,341.65	87	−1.2 to −1.0

Source: IFPRI Yemen DCGE Model results
[a]The first number in the cell indicates the MIROC result; the second number indicates the CSIRO result

The long-term implications of climate change (local and global) leads to a total reduction of household welfare of 1,161.2 or 1,873.6 billion Yemeni rials (YER) (US$5.7 or US$9.2 billion[5]) by 2050 under MIROC or CSIRO conditions, respectively (Fig. 19.9). These reductions in welfare accumulate over time. In 2020, household incomes are projected to be 63.8 or 82.0 billion YER ($314.4 or $404.2 million) lower versus a perfect mitigation scenario, whereas those losses increase to 269.6 or 366.8 billion YER ($1.3 or $1.8 billion) by 2030. Rural households suffer more from climate change than urban households. Rural households' incomes by 2050 are 630.1 or 1,353.7 billion YER($3.1 or $6.7 billion) lower compared with urban households with lower incomes of 531.1 or 519.9 billion YER ($2.6 billion or $2.5 billion). Whereas farm households benefit from increasing yields that result from local climate change in the MIROC scenario, rural nonfarm households suffer both in relative and absolute terms in the MIROC and CSIRO scenarios. This household group is projected to lose an accumulated 711.0 or 1,147.7 billion YER ($3.5 or $5.7 billion) as a consequence of climate change by 2050.

[5]All dollars are U.S. dollars.

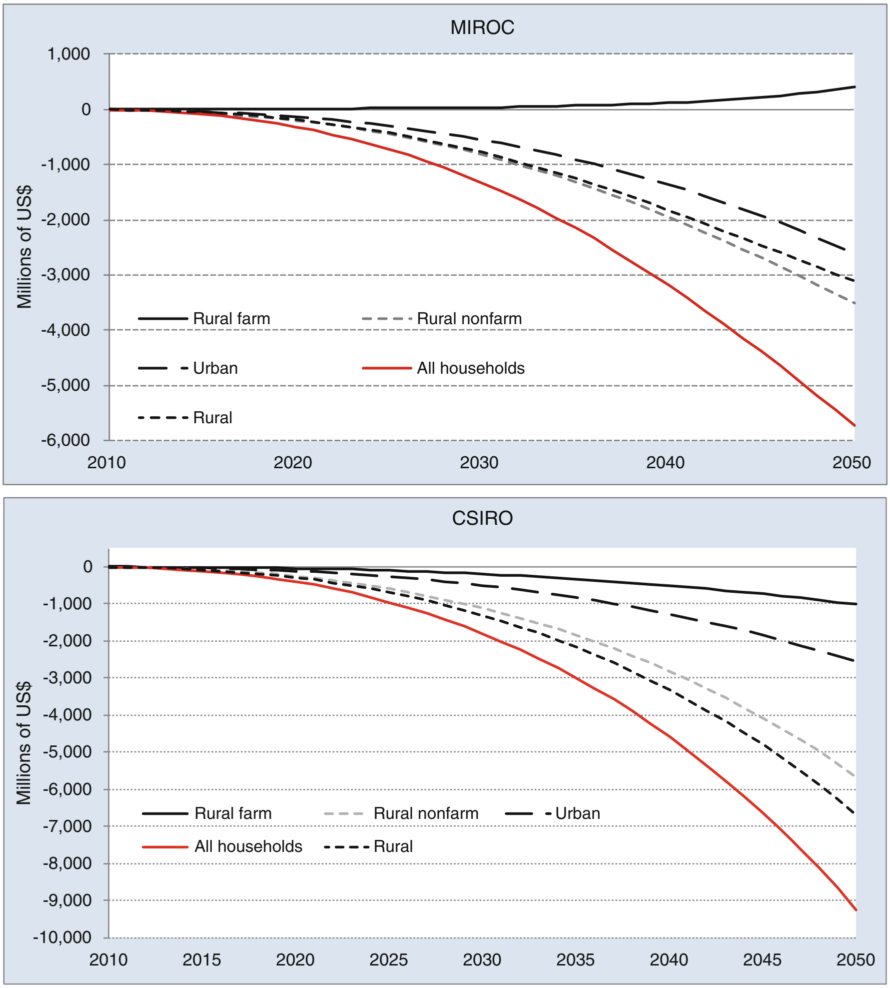


Fig. 19.9 Yemen: Impact of combined local and global climate changes on household incomes, 2010–2050 (Source: IFPRI Yemen DCGE Model Results)

Rural households are harder hit than urban households, and among the rural households the nonfarm households suffer most (Table 19.2). The negative effect on rural nonfarm households is explained through two major channels. Unlike farm households, rural nonfarm households do not benefit from higher prices for agricultural goods. At the same time, they spend the highest share of their income on food of all household groups, which makes them particularly vulnerable to food price changes. Urban households in contrast spend a lesser share of their income on food and derive most of their income from sectors that are largely unaffected by climate change.

19.3 Conclusions and Proposed Actions for Adaptation

This book has taken a global as well as a local perspective in assessing the impacts of climate change on the economy, agricultural sector, and households in three of the MENA countries; Syria, Tunisia and Yemen. The major channels of impact for global climate change are through changing world food (and energy) prices, especially since all the countries under analysis are or have become net importers of oil and petroleum products and many food commodities in recent years. The impacts of local climate change decrease crop yields in the longer run and through them, productivity in the agricultural sector and all the implications this may have on both, the livelihoods of those dependent on the sector as well as the rest of the economy. The analysis also covered what happens when both global and local climate changes work simultaneously for each country. Results have shown that across the three countries the effects are negative, GDP falls and livelihoods suffer. Furthermore, the prevalence of extreme variations in climate such as the droughts affecting Syria and the floods impacting Yemen, draws attention to the potentially significant drawbacks that are likely to not only affect any strides towards economic growth and development, but may also reverse such strides if appropriate policies are not in place to weather this storm.

Results show that even under perfect climate change mitigation, the world market prices for food are projected to increase. The price of rice is projected to rise by 62 %, that of maize by 63 %, soybeans by 72 %, and wheat by 39 %, posing real food security challenges, especially for net food importing countries and poor households. Climate change will lead to additional increases in world market prices: 32–37 % for rice, 52–55 % for maize, 94–111 % for wheat, and 11–14 % for soybeans. Energy prices may also rise as a consequence of climate change, yet estimates vary widely, and factors other than climate change are likely to play a major role too. The results suggest that higher global prices for food negatively affects most sectors of the economy in Syria, except for agriculture, which benefits from the higher prices. However, Syrian real household incomes decline, particularly those of poor rural nonfarm households. In Tunisia, higher food prices pose challenges to its poor and in Yemen, results from the DCGE model suggest that higher global prices for food will lower Yemen's overall GDP growth, raise agricultural GDP, and decrease real household incomes. Effects on agricultural GDP vary by agroecological zone depending on the production structure in place.

Local climate change impacts alone will lead to lower crop yields for all of the countries. In Syria, the agricultural sector suffers as a result of long-term declines in yields, and different agroecological zones will be affected differently. In Tunisia, local climate change shocks operate on the sector and on households through reduced crop yields. Results from the Tunisian DCGE model shows that local climate change is welfare reducing for all household groups under both GCM scenarios, however, farm households are most adversely affected by these yield reductions. Those households suffer income losses due to lower agricultural yields thus reducing their livelihoods. Finally for Yemen, the local impacts of climate change are different under the two climate scenarios where under the MIROC scenario, agricultural GDP is somewhat higher compared to the baseline. Rural incomes are expected to rise due to the higher yields and the lower prices for sorghum and millet, whereas the urban households are largely unaffected because they hardly consume those commodities. Under the CSIRO scenario, positive and negative yield changes cancel each other out. As a result, agricultural GDP and incomes for all three household groups hardly change over the period of analysis compared to the baseline.

Over the long-term, the adverse effects of both global and local climate change impacts are felt throughout the three countries. In Syria, combining local and global climate change effects slows GDP growth in all sectors. Rural households (both farm and nonfarm households) suffer the most from climate change, but urban households are also worse off when compared with the perfect mitigation scenario. Across Tunisia, the combined climate change effects lead to negative effects on the overall economy, the agricultural sector, and a total reduction of household incomes and in Yemen, the long-term implications of climate change (local and global) lead to a reduction in household welfare under both the MIROC and the CSIRO scenarios. Those reductions in welfare accumulate over time and rural households suffer more from climate change than urban households. However, under the MIROC scenario, farm households benefit from the increasing yields but rural nonfarm households do not and suffer both in relative and absolute terms under the MIROC and CSIRO scenarios.

Given the strong global *and* local impacts of climate change a diverse set of policy actions at different levels will be required to mitigate the negative socioeconomic effects. Moreover, global price increases, declining crop yields, and droughts affect different sectors and households differently, which underscores the necessity to consider a variety of mitigation and adaptation tools including global and national action plans, investments in agriculture, social protection, and disaster risk management. These adaptation measures are explained in more detail below.

19.3.1 Advancing a Global Action Plan

Richer and more developed nations have contributed the most to greenhouse gas (GHG) emissions which are causing climate change. In addition, more developed countries are less vulnerable to climate change than developing nations. Hence, the former bear a responsibility to support the latter in finding ways to adapt, whether through finance, technical expertise, or a combination of both. Thus, globally and locally, some measure of redistribution may become inevitable in the near future.

The international community, including individual countries, needs to increase investment in international research and development in the agricultural sector. Research and development should not only emphasize productivity of crops and livestock but also support modified crop varieties and livestock dietary varieties in a climatically changing world. In general, a greater emphasis should be placed on increasing the knowledge pool at the global level.[6] This enhanced international effort should create global public goods and knowledge to help all countries increase agricultural productivity in a changing climate.

Low carbon growth should become an objective for all countries. Syria, Tunisia and Yemen may each make a contribution towards reducing global GHG emissions by following a more fuel-conscious policy, adopting various mitigation measures such as revising their fuel subsidy policy, limiting carbon dioxide, capturing and storing CO_2 from the atmosphere, and possibly encouraging and developing alternative fuel possibilities as appropriate (Hainoun 2008a). The agricultural sector is typically the largest contributor to GHG emissions; however, this sector is also a potential mitigator to these emissions and to overall global warming if it is part of a comprehensive national development plan. International organizations and partner countries should support these efforts.

Reform of the global food system should become a priority in order to make it more resilient to climate change and other shocks and to make trade freer and better. With the inevitability of increased climate variability, trade is a crucial mitigation and adaptation channel that would allow "…regions of the world with fewer negative effects to supply those with more negative effects" (Nelson et al. 2010). The heterogeneity with which climate change will impact countries, and regions within countries, necessitates that Syria, Tunisia and Yemen, rely increasingly on healthy and open trade relationships to fulfill the increasing demand for food. The result may provide the additional channels necessary to face imminent climate variability.

19.3.2 Including Climate Change in National Strategies, Policies, and Investment Plans

Acknowledging and incorporating global climate change and variability and their appropriate mitigation and adaptation measures into national development targets and policies is crucial for successful adaptation and mitigation. In general, wealthier countries and households are likely to find it easier to adapt to new challenges. Therefore, general policies and investments that foster sustainable growth will also broaden the options for adaptation for governments and citizens. In the case of food security, for example, this book has shown that prices of global food commodities are likely to rise due to general global population and income growth, to be compounded even further by climate change. Improved food security can be achieved through broad-based development, specifically by increasing and diversifying nonfood exports and increasing household incomes. Nonfood exports generate much-needed foreign exchange to purchase food commodities on international

[6] An example of research that is currently inconclusive in its application to the inevitable increase in GHG emissions is carbon dioxide (CO_2) fertilization. Further tests may shed light on how crops may fare in a world with rising CO_2 (The Economist 2010).

markets and accelerating growth that is export oriented and that benefits all household groups should therefore also be a primary objective to Syria, Tunisia and Yemen to further develop in a changing climate.

19.3.3 Agricultural and Rural Development Policies

Crop yields are hit especially hard by the long-term impacts of climate change. Agricultural research and development and scientific advancement in breeding more drought-resistant varieties will therefore be crucial in the future of rainfed agriculture and the region's increasing water scarcity challenge. Investing in the development of drought-resistant seeds and encouraging farmers to adopt these seeds may mitigate adverse consequences to rainfed agriculture and safeguard farmers from drought-induced yield losses. Farmers also have different on-farm management techniques to offset the impacts of climate change. On-farm management practices may include shifting the planting date, switching crop varieties or crops, expanding the area of production, and increasing irrigation coverage (Burke and Lobell 2010).

Irrigation efficiency must be improved where economically viable to get "more crop per drop." Irrigated crops are less affected by droughts; however, expanding irrigation is possible only to a limited extent, especially in our three target countries indeed, even across other countries in the MENA region, which have severely constrained water resources. Therefore, increasing irrigation efficiency becomes necessary for the future of irrigated agriculture in Syria, Tunisia and Yemen. In addition, a system that conserves rainfall and efficiently distributes water in other zones should also be a part of the national plan to further investment in water, an increasingly scarce resource. However, it is important to note that increasing irrigation efficency often increases yields but translates only partly into water savings.

In addition to developing heat and drought-resistant cultivars to weather the expected decrease in water availability and increase in temperature, an important part of investment, research, and development in agriculture would also include changes in crop practices. That includes re-evaluating optimum sowing dates, the choice of cultivars, planned plant density (Hainoun 2008b), reevaluation and redesign of irrigation, and water-harvesting practices to sustain a healthy agricultural sector.

In addressing climate variability such as drought and floods in Syria and Yemen, respectively, it is essential to distinguish between short-term measures and long-term measures. The former improve the resiliency of the agricultural sector, and the latter introduce structural changes that affect the sector's profile for the longer term (Easterling 1996). Some examples of short-term mitigation practices may include varying the planting season from year to year as necessary. For instance, some farmers in some parts of Africa and Asia vary the planting season by one or two months from year to year (Burke and Lobell 2010). Longer-term mitigation measures may also vary, for instance; depending on the expected type of climate variability (changes in precipitation or temperature), measures may be taken to change the crop varieties farmers use for planting to adapt to the changing climate (Burke and Lobell 2010). If Syria, or the region as a whole, is expecting a decrease in precipitation, then using faster-maturing seeds varieties would reduce the time the plant has to withstand lower moisture availability and vice versa for expected floods in Yemen. If precipitation levels are not expected to change but temperatures are expected to increase, then longer-maturing seed varieties may be an appropriate alternative (Burke and Lobell 2010).

Structuring and legislating the livestock sector to highlight its income-generating prominence in the Syrian and Yemeni economies will significantly contribute to different mitigation and adaptation measures. With the expected continuation of climate variability and increased drought occurrences, the livestock sector is one that requires extensive adaptation policies and methodologies to continue its contribution to rural livelihoods. Adaptation methods may be categorized generally under climate variability adaptation and more specifically under livestock sector adaptation. The former includes various targets, from collecting and structuring information and data, to conducting the necessary research, to disseminating the findings, and finally to monitoring the impacts. Adaptation methods for the sector may be broadly classified under the following focuses: improve grazing management, improve animal biocapacity, enhance rural livelihoods, improve market access, and increase the studies on climate change and its impact on the Syrian and Yemeni economies (Batima 2006).

Grazing management techniques and practices need to have the conservation of the country's ecosystems as a prime objective. Land used for grazing should be used for one season, after which the herd should be moved to another piece of land and the previously grazed land restored for its next cycle of grazing. Furthermore, grazing times may be modified to avoid hours of extreme weather conditions for the well-being of the animal. Other grazing management techniques include increasing the reliance on cultivated pasture lands, improving pasture yields, and increasing the conservation of pasture water supply. It will be necessary to adopt legislation that will organize the possession of land for pasture to heighten a sense of ownership and thus encourage pasture land development (Batima 2006).

Another mitigation and adaptation measure will be to improve animal biocapacity to withstand climate change adversity and maintain good health and productivity. This may be done by increasing supplementary nutrient feeding of animals, improving veterinary services, and introducing high-productivity breeds to withstand the expected and unexpected changes in weather (McDermott et al. 2010).

To adapt the rural space to a changing climate, the physical, financial, social, and risk-management infrastructure will need improvements in order to enhance rural livelihoods. These may be achieved by promoting a strong education for rural households and increasing nonfarm income opportunities and relationships through improving market access to the major cities in their vicinity. Consequently, these developed and sustainable channels are fundamental to develop and disseminate new technologies, information, and support to herders. One way to help mitigate risks may be to erect an *index based livestock insurance* (IBLI) (Ayantunde et al. 2010) to provide the herders with the necessary coverage to maintain their livelihoods (see details on index-based insurance, below). Overall, any financial support scheme must not propagate moral hazard or passivity among herders but instead must increase independence and proactiveness as individuals and as herder communities (Seo and Mendelsohn 2008). All the above methods may help in rural income diversification to mitigate the risks associated with climate variability and its impact on livestock sector productivity, especially for countries heavily reliant on livestock activities such as Syria and Yemen.

19.3.4 Social Protection Policies

Even if the severity and frequency of climate variability remains constant, the vulnerable are likely to suffer increasingly negative socioeconomic impacts as a result of higher population and livestock density coupled with increasing groundwater depletion and flooding. Herders in Syria and Yemen in particular are hit increasingly hard, mainly because of the sharp spike in livestock density and the competition for pasture land. In addition to policies and investments in agriculture and rural areas, social safety nets are essential to provide the necessary channels of outreach and mitigation to the poor and vulnerable, both in times of crisis and under the more benign conditions of product, information, and technical support dissemination.

The poorest of the poor are hardest hit by climate change and variability; thus, improving the targeting of existing safety nets and building new ones is critical to protect the poor. Relying on already existing channels and improving or extending them cuts down on new outreach costs as well as helps integrate national and sectoral policy into an overall objective of poverty mitigation and adaptation and livelihood sustainability. In all of the three countries, improving and expanding social safety nets is crucial. In this process, it is important to know who the vulnerable are, where they are, what they need, how to reach them, and how to receive feedback from them.

Drought management and flood mitigation should be combined with social safety nets and long-term development goals. Both should become part of the overall economic development planning framework by recognizing the role of social transfers in building economic resilience among communities vulnerable to disasters, and it should be implemented by the relevant national authorities, international agencies, and donors. Such initiatives include direct transfers, cash-for-work programs, community asset building through public works, assistance in undertaking microenterprises, other productive activities, and nutrition and health programs. These initiatives would work at the field level and play a key role in providing immediate relief after disasters as well as assist in recovery and rehabilitation activities. The effectiveness of their roles in past droughts should be evaluated to estimate present and future needs for capacity building, funding, and the possible expansion of their role in disaster management.

19.3.5 Disaster Risk Management Strategies

It is crucial to build a rich and functioning network for risk mitigation of the social and extension services that link farmers and herders to agricultural research as well as the vulnerable population to markets and policymakers. A network of extension services is crucial in outreach to farmers and the agricultural community as a whole in disseminating relevant information, techniques, and cultivars; and such a network guarantees that national policies are implemented down to the individual unit: the farmer. A network also provides a strong link between farmers, scientists, and policymakers to collect information relevant to technological advancements and policymaking. Furthermore, relying on an already existing, strong social safety net allows for outreach and dissemination to the vulnerable in the event of a national disaster, such as an all-encompassing drought.

Index-based weather insurance schemes can be a powerful tool to mitigate the risk to small farmers' livelihoods due to weather variability and consequent crop loss. The most conventional method followed is single insurance policies that cover a single crop for a specific weather failure (Robles 2010; Hill 2010a). However, farmer uptake has been quite low and basis risk has been high. Reasons for low uptake in many countries are that the crop models for these schemes operate under generic assumptions or characteristics that simulate typical cropping practices within favorable environments; as such, they may not be applicable to practices on small farms in developing countries, especially if they face several input constraints and shortages not accounted for in the models (Robles 2010). Furthermore, these weather insurance policies are usually too complex for the average, poorly educated, liquidity-constrained farmer to be comfortable with. To address these challenges, innovative methods of weather insurance schemes have been introduced in some countries (Hill 2010a, b) and could be introduced in Syria, Tunisia and Yemen as well.[7] One tool is to introduce simple weather securities designed to insure against different weather events for different months or different phases of the crop cycle. The securities are set up against a relevant weather index, such as rainfall, and a range of weather occurrences is chosen. If the weather event falls within that range, then the farmer receives a fixed payment, which the farmer decides upon. The amount paid to the farmer will depend on how severe the weather event occurrence is, based on the weather index. The farmer decides how much to insure for and pays a percentage of that amount for the weather insurance *ticket*. The larger the range of weather incidence chosen, the larger the percentage of the insured amount paid for the ticket (Robles 2010). The impact on farmer welfare may then be measured from their resulting consumption and production decisions.

[7] For more information, see Using Simple Weather Securities to Insure Rain-Dependent Farmers in Ethiopia and Smallholder Access to Weather Securities: Demand and Impact on Consumption and Production Decisions at www.ifpri.org/book-744/node/7125 and www.ifpri.org/book-744/node/7124, respectively.

The advantages of these simple weather security schemes are several. The insurance would be provided through groups to reduce the transaction costs for the insurance company (Martins-Filho et al. 2010), and the company increases coverage on weather variability to small farmers, which translates to less livelihood disturbances and risk. The additional benefit would be to eventually eliminate the need to provide the sometimes distorted subsidies extended to farmers as a risk and income-loss mitigation tool (Robles 2010). These schemes would eventually provide a means to correctly quantify the benefits and drawbacks of weather variability and the accompanying insurance markets for future advancements (Robles 2010). However, there may also be some drawbacks to these schemes. In order to successfully operate, there has to be in place a relevant weather index against which the insurance schemes may be tied to, in order to sustainably provide timely and accurate information. Also, given the reliance on the group insurance structure for these schemes, there needs to be in place, or under construction, strong farmer extension channels for product and information dissemination.

It is imperative that climate change and variability and all their implications be made part of the vision and objectives for each of the three countries. Comprehensive and integrative policies to mitigate and adapt to this reality are crucial to each country's growth and development path and to ensuring healthy livelihoods to their people.

References

Ayantunde A, Herrero M, Thornton P (2010) Climate change adaptation in relation to livestock and livelihood in West Africa. International Livestock Research Institute. www.wamis.org/agm/meetings/iwacc09/S4-Ayantunde.pdf

Batima P (2006) Climate change vulnerability and adaptation in the livestock sector of Mongolia. A final report submitted to Assessments of Impacts and Adaptations to Climate Change (AIACC), Project no. AS 06. The International START Secretariat, Washington, DC. www.ifad.org/operations/gef/climate/19_1.pdf

Breisinger C, van Rheenen T, Ringler C, Pratt AN, Minot N, Aragon C, Yu B, Ecker O, Zhu T (2010) Food security and economic development in the Middle East and North Africa: current state and future perspectives, IFPRI discussion paper 00985. International Food Policy Research Institute, Washington, DC

Breisinger C, Zhu T, Al Riffai P, Nelson G, Richardson R, Funes J, Verner D (2011) Global and local economic impacts of climate change in the Syrian Arab republic and options for adaptation, IFPRI discussion paper 01091. International Food Policy Research Institute (IFPRI), Washington, DC

Breisinger C, Ecker O, Al-Riffai P, Yu B (2012a) Beyond the Arab awakening: policies and investments for poverty reduction and food security, IFPRI food policy report 25. International Food Policy Research Institute, Washington, DC

Breisinger C, Wiebelt M, Al-Riffai P, Robertson R (2012b) Economic impacts of climate change in Tunisia. Mimeo, International Food Policy Research Institute (IFPRI), Washington, DC

Burke M, Lobell D (2010) Food security and adaptation to climate change: what do we know? In: Lobell D, Burke M (eds) Climate change and food security. Springer Science + Business Media B.V., Dordrecht, pp 133–153

Easterling W (1996) Adapting North American agriculture to climate change in review. Agric For Meteorol 80:1–53

Ecker O, Breisinger C, McCool C, Diao X, Funes J, You L, Yu B (2010) Food security in Yemen: an innovative integrated, cross-sector, and multi-level approach, IFPRI discussion paper 982. International Food Policy Research Institute, Washington, DC

Garnaut R (2008) The Garnaut climate change review: final report. www.garnautreview.org.au/index.htm

Hainoun A (2008a) Vulnerability assessment and possible adaptation measures of energy. United Nations Development Programme. Unpublished report

Hainoun A (2008b) Vulnerability assessment and possible adaptation measures of agricultural sector. United Nations Development Programme. Unpublished report

Hill RV (2010a) Using simple weather securities to insure rain-dependent farmers in Ethiopia. IFPRI project brochure. International Food Policy Research Institute, Washington, DC. www.ifpri.org/sites/default/files/usingweathersecurities.pdf

Hill RV (2010b) Smallholder access to weather securities: demand and impact on consumption and production decisions. IFPRI project brochure. International Food Policy Research Institute, Washington, DC. www.ifpri.org/sites/default/files/SmallholderAccessWeatherSecurities.pdf

IMF (2009) Syrian Arab Republic: 2008 article IV consultation—staff report; staff statement; public information notice on the Executive Board discussion; and statement by the Executive Director for the Syrian Arab Republic, IMF country report no. 09/55. International Monetary Fund, Washington, DC

Jones JW, Hoogenboom G, Porter CH, Boote KJ, Batchelor L, Hunt A, Wilkens PW et al (2003) The DSSAT cropping system model. Eur J Agron 18:235–265

Jones PG, Thornton PK, Heinke J (2009) Generating characteristic daily weather sata using downscaled climate model data from the IPCC's fourth assessment. Unpublished project report

Martins-Filho C, Taffesse AS, Dercon S, Hill RV (2010) Insuring against the weather: integrating generic weather index products with group-based savings and loans. Seed project selected. United States Agency for International Development, Washington, DC. http://www.agriskmanagementforum.org/sites/agriskmanagementforum.org/files/Documents/Martins-Filho%20proposal%20short.pdf

McDermott JJ, Staal SJ, Freeman HA, Herrero M, Van de Steeg JA (2010) Sustaining intensification of smallholder livestock systems in the tropics, Livestock Science, 130(1–3):95–109, ISSN 1871–1413, 10.1016/j.livsci.2010.02.014. http://www.sciencedirect.com/science/article/pii/S1871141310000776

Mougou R, Rejeb S, Lebdi F (2002) The role of tunisian gender issues in water resources management and irrigated agriculture. The first regional conference on perspectives on water cooperation: challenges, constraints and opportunities. Workshop on gender and water management in the Mediterranean. Cairo, October 2002

Nelson GC, Rosegrant MW, Koo J, Robertson R, Sulser T, Zhu T et al (2009) Climate change: impact on agriculture and costs of adaptation. Food policy report. IFPRI, Washington, DC. doi: http://dx.doi.org/10.2499/0896295354

Nelson G, Rosegrant M, Palazzo A, Gray I, Ingersoll C, Robertson R, Tokgoz S et al (2010) Food security, farming and climate change to 2050: scenarios, results, policy options. International Food Policy Research Institute, Washington, DC. www.ifpri.org/sites/default/files/publications/climatemonograph_advance.pdf

Robles M (2010) Smallholder access to weather securities: demand and impact on consumption and production decisions. 3ie-DFID impact evaluation workshop for DFID grantees under 3ie's second open window, New Delhi. www.3ieimpact.org/userfiles/doc/Smallholder access to weather securities-Non-Technical.pdf

Rosegrant MW, Paisner MS, Meijer S, Witcover J (2008) Global food projections to 2020: emerging trends and alternative futures. International Food Policy Research Institute, Washington, DC, p 206

Seo SN, Mendelsohn R (2008) Animal husbandry in Africa: climate change impacts and adaptations. AfJARE 2: 1. http://environment.yale.edu/files/biblio/YaleFES-00000214.pdf

Stern N (2006) Review on the economics of climate change, H.M. Treasury, UK. http://www.sternreview.org.uk

The Economist (2010) Adapting to climate change: facing the consequences. The Economist, 25 Nov 2010. Web Dec 2010

Thurlow J, Zhu T, Diao X (2009) The impact of climate variability and change on economic growth and poverty in Zambia, IFPRI discussion paper 00890. International Food Policy Research Institute, Washington, DC

Wiebelt M, Breisinger C, Ecker O, Al-Riffai P, Robertson R, Thiele R (2011) Climate change and floods in Yemen: impacts on food security and options for adaptation. IFPRI discussion paper 1139, International Food Policy Research Institute (IFPRI) (Discussion paper), Washington, DC

World Bank (2007) The impact of sea level rise on developing countries: a comparative analysis. World Bank policy research working paper WPS4136. The World Bank, Washington, DC. http://www-wds.worldbank.org/external/default/WDSContentServer/IW3P/IB/2007/02/09/000016406_20070209161430/Rendered/PDF/wps4136.pdf

World Bank (2010) Brief water sector strategy note. Mimeo, Washington, DC

Yu W, Thurlow J, Alam M, Hassan A, Khan AS, Ruane A, Rosenzweig C et al (2010a) Climate change risks and food security in Bangladesh. EarthScan, London

Yu B, Zhu T, Breisinger C, Hai NM (2010b) Impacts of climate change on agriculture and policy options for adaptation: the case of Vietnam, IFPRI discussion paper 01015. International Food Policy Research Institute, Washington, DC

Chapter 20
Human Dimensions of Climate Change Adaptation: Factors that Influence Behaviors

Eric Toman and Richard Moore

Abstract The need for climate adaptation has become more widely accepted as the inevitability of wide ranging climate-related impacts has become apparent. Limited research, however, has explicitly examined the human dimensions related to these changes and potential adaptation responses. With some exceptions, when human variables have been addressed in adaptation research they have been included in the measurements or estimates of potential future impacts rather than as central drivers of adaptation actions. This has resulted in a limited understanding of the factors that influence adaptation decisions. In this paper, we draw on theories and research in the social sciences to examine variables that influence human behaviors. We then describe a planning approach to inform adaptation decisions given the uncertainty of future climatic conditions. We conclude by discussing the potential for maladaptation where adopted measures may serve to increase rather than decrease vulnerability to climate change.

Keywords Human behaviour • Diffusion of innovations • Scenario planning • Adaptation strategies • Maladaptation

---

E. Toman (✉)
School of Environment and Natural Resources, The Ohio State University,
210 Kottman Hall, 2021 Coffey Road, Columbus, OH 43210, USA
e-mail: Toman.10@osu.edu

R. Moore
School of Environment and Natural Resources, The Ohio State University,
130 Williams Hall, 1680 Madison Ave, Wooster, OH 44691, USA

M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_20,

20.1 Introduction

Substantial scientific research and ongoing observations suggest the climate is changing. Although uncertainties remain, the science of climate change has grown more certain over time. This is evident in the conclusions drawn by the Intergovernmental Panel on Climate Change (IPCC) in their comprehensive reviews of the body of climate science literature. In their fourth, and most recent Assessment Report, the IPCC concluded that "warming of the climate system is unequivocal" and that "most of the observed increase in global average temperatures since the mid-twentieth century is very likely (greater than 90 % likelihood) due to the observed increase in anthropogenic greenhouse gas concentrations" (IPCC 2007a, p. 5, 10).

Resulting policy discussions have been largely dominated by an emphasis on mitigation efforts to reduce anthropogenic greenhouse gas emissions. However, substantial research indicates that the earth's atmosphere is committed to future warming even if all human emissions were stopped immediately due to lags inherent in the climate system (e.g., Wigley 2005; Ramathan and Feng 2008). Based on this research, the IPCC concluded that climatic changes would continue for centuries even if emissions were stabilized at current levels (IPCC 2007a). Thus, while mitigation to reduce or counter the impact with other compensating actions is essential to address the underlying causes contributing to climate change, it is not sufficient to avoid all the projected impacts from a changing climate. Adaptation is defined as "initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects" (IPCC 2007b, p. 809). Current evidence suggests that neither mitigation nor adaptation will be effective on their own to avoid climate change impacts; however, they can be used in a complementary fashion to avoid the most serious future impacts while reducing vulnerability to ongoing changes (IPCC 2007b).

Successful implementation of mitigation or adaptation actions requires both an understanding of climatic changes as well as of human behaviors. While decisions to mitigate or adapt will hopefully be informed by the best available scientific knowledge about current and future conditions, ultimately, the decisions will be made by humans and driven by human variables. Emphasizing this point, in a recent review of global change research in the United States, the U.S. National Academies of Science found that while there had been significant advances in understanding of the climate system at global and continental scales, there had been limited progress applying this knowledge to address resulting impacts (NRC 2007). In a follow-up report, the committee concludes this lack of progress is due in part to a "paucity of social science research and the separation of natural and social science research", as well as a lack of established networks between climate scientists and decision makers to encourage policy-relevant research and support decision-making (NRC 2009). At the same time, decision-makers from government planners to local farmers, including those within the Western Asia and Northern Africa (WANA) region, are seeking information to help them navigate the uncertainties posed by a changing climate. The purpose of this paper is to introduce some concepts from the literature on human behavior applicable to climate adaptation and describe a planning approach to provide a framework for making decisions under uncertainty.

20.2 Human Behaviors

The systematic study of human behaviors is conducted in a variety of disciplines including economics, psychology, anthropology, sociology, and political science among others. Each of these disciplines is guided by particular theoretical assumptions about how humans behave and the factors that influence decisions. Also noteworthy, these disciplines differ in their level of analysis – psychology focuses on individuals, while sociology focuses on groups of individuals, and political science typically examines policy or institutions created or operating within society. In practice there is often substantial overlap between disciplines and levels of analysis (e.g., a sociologist may study a political system or government agency).

In this section, we discuss a well-established line of research, the diffusion of innovations, which examines the adoption of new behaviors across a social system. The earliest diffusion research investigated the adoption of hybrid seed corn among farmers (Ryan and Gross 1943). Since this early work, more than 4,000 research publications have investigated the diffusion of innovations ranging from agricultural and health practices to technology and political reforms (Wejnert 2002). The seminal work in this field was completed by Everett Rogers and his colleagues with findings summarized in Rogers (2003). This research has revealed a number of important concepts that can inform our understanding of adoption of adaptation behaviors by individuals, communities, and governments.

Diffusion of innovations is defined as the spread of ideas, information, or practices within a social system (Rogers 1995). Climate adaptation may include integrating climate information into regular decisions (e.g., selecting varieties of seed with a greater drought tolerance) or adopting a variety of new practices (e.g., creating water retention systems to address increased variability in precipitation). Prior research has found that adoption of such practices proceeds through separate distinct stages and is influenced by characteristics of the innovation as well as those of the individual adopters and the broader social system.

It is important to point out a potential bias within the diffusion literature. When approaching issues from this framework, it is easy to assume that “innovations” are always improvements over the status quo in one way or another. However, that is not necessarily the case. Innovations as defined in this literature are simply new ideas, information or practices. They are not inherently better than existing or traditional approaches. Indeed, in some cases, the adoption of new ideas can actually prove detrimental to social and ecological conditions and may result in unintended negative consequences. We further discuss these ideas below in our section on “maladaptation.” When examples of specific actions are provided in this paper, they are done for illustrative purposes and not to promote their specific adoption as we recognize the suitability of potential adaptation measures is influenced by several ecological and social variables at the local level.

20.2.1 Stages of Adoption

Diffusion research has identified five stages in the innovation-decision process, (1) knowledge, (2) persuasion, (3) decision, (4) implementation, (5) confirmation. We briefly describe each stage according to Rogers (2003). The knowledge stage begins when individuals become aware of the innovation. There are three types of knowledge about an innovation. First is awareness-knowledge, defined as recognition of the innovation. Awareness-knowledge may motivate individuals to seek how-to knowledge (information required to correctly use or implement an innovation) or principles-knowledge (fundamental information about how and why the innovation works). Example descriptions of the three types of knowledge regarding hybrid seed might include (1) awareness of the existence of hybrid seed and purported benefits, (2) more specific information about requirements of the hybrid seed to produce purported yields and compatibility with local conditions, (3) understanding the changes in the hybrid seed from previously used seed and how they effect yield.

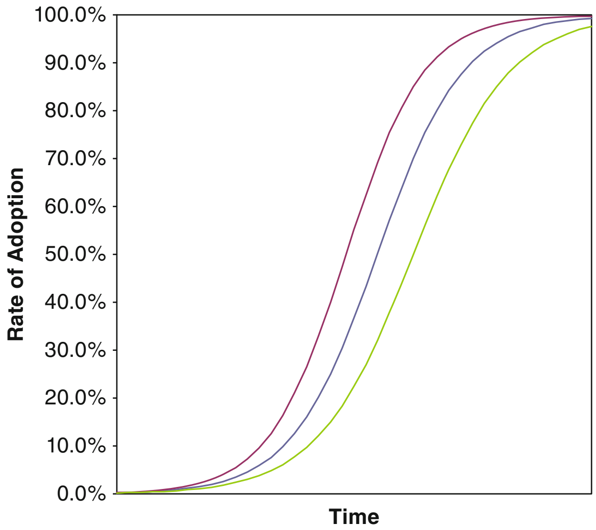
During the second stage, persuasion, individuals form favorable or unfavorable attitudes toward the innovation. During this stage, individuals often turn to peers or other trusted individuals to provide information regarding the likely consequences of implementation. Continuing our example of adopting hybrid seed, at this stage individuals begin to seek information about how the hybrid seed will influence their ability to achieve their desired yield, expected influences on other constraints (e.g., water and nutrient requirements and availability) as well as other values they hold for their property and prior practices (e.g., cultural uses, traditional agriculture practices, species mix, provision of wildlife habitat, etc.). They may also seek normative information, such as whether their neighbors perceive the hybrid seed in a positive or negative manner.

In the decision stage, individuals decide to adopt or reject the innovation. Individuals may implement the innovation on a trial basis, such as planting a portion of the managed property with a hybrid seed and a portion with the traditionally used seed. Demonstrations by others, or incentives (such as free samples or funding support) can increase initial adoptions. Trials, demonstrations, and incentives serve to reduce the remaining uncertainty surrounding the innovation and reduce challenges with initial adoption.

Next, individuals implement their decision. Some uncertainty likely still remains at this point regarding specific details of implementation and expected consequences leading the adopter to seek additional how-to knowledge. For example, the farmer may now seek specific information regarding planting distance, timing, or irrigation rates based on the specific characteristics of their property.

Lastly, during the confirmation stage, adopters evaluate whether the expected benefits of the innovation have occurred and if they are worth the investment.

Fig. 20.1 Shapes of curves for adoption rates over time from Rogers (2003)



For use of a new crop variety, adopters may examine whether the yields matched expectations and provided enough revenue to offset the increased costs of purchasing the seed or meeting the crop's growing requirements. Normative influences can also be important at this stage. For example, adopters may look to see whether other community members also begin using the new crop variety. New behaviors may be discontinued if a more beneficial practice becomes available or if the innovation is perceived as performing poorly or lacking normative approval.

As noted in this overview, different communication channels are employed throughout the decision process. Mass communication approaches may be well suited to building awareness and, thus, is more useful at the knowledge stage. However, following awareness-building, individuals seek more specific information than is available through mass means. Accordingly interpersonal channels become more important during persuasion and decision stages.

The substantial research discussed in Rogers (2003) demonstrates that most innovations follow an S-shaped curve of adoption over time, with relatively few initial adopters in the early stages until a threshold is reach where adoption increases dramatically before leveling off again (Fig. 20.1). The slope of this curve will vary between innovations, with steeper curves for those that are adopted more rapidly.

20.2.2 Characteristics of the Innovation

Characteristics of the new information or practice will influence the likelihood and timing of adoption by potential users. At a general level, most innovations involved in climate adaptation represent preventative innovations. That is, they are adopted primarily to prevent negative impacts from some event in the future. Due to the

Table 20.1 Innovation characteristics influencing adoption

Characteristic	Description
Relative advantage	The degree to which the innovation is viewed as superior to prior practice based on economic, social, or other factors
Compatibility	The degree that the innovation is consistent with the needs, beliefs, experience, norms, and values of the user and the broader society
Complexity	The level of difficulty required to understand and use the innovation
Triability	Ability for users to test the innovation prior to adoption
Observability	Ability to observe the outcomes of the innovation prior to adoption

Adapted from Rogers (2003)

uncertainties of potential future events, preventative innovations require an initial cost to potential adopters while the future benefits are uncertain. Because of this uncertainty, preventative innovations are particularly challenging to encourage.

Five characteristics of the innovation are particularly influential: (1) trialability, (2) observability, (3) compatibility, (4) relative advantage, and (5) complexity of the innovation (summarized in Table 20.1 and discussed below).

Relative advantage is defined as the degree to which the innovation is perceived as superior to the idea or practice it supersedes (Rogers 2003). While economic returns are often considered to be the primary determinant of perceived relative advantage, other potential influences such as social prestige or convenience may also be quite influential in this consideration. For example, it is hard to make the case that purchasing an expensive luxury car provides a relative advantage from a cost perspective; however, such a vehicle may be perceived to offer higher social status. It is important to note that the *perceived* advantages are what matters rather than the actual, objective advantage that an innovation may offer. As the perceive advantage of a particular innovation increases, adoption will be more rapid.

Compatibility is the degree to which the innovation is compatible with existing values, beliefs, norms, and perceived needs of society (Rogers 2003). Regardless of the relative advantages of the new idea or product, adoption will proceed slowly or not at all if it is perceived as being incompatible with these underlying psychological and social variables. To illustrate this point, Rogers (2003) describes a health campaign designed to increase water boiling in a Peruvian village to decrease water borne illnesses. Despite the real health advantages of boiling water, the effort largely failed due to prior norms within the target community that warm drinks should only be consumed by those with an existing illness. Accordingly, boiling water carries a social stigma as those who boil the water are assumed to have an ongoing health condition. In addition to these social considerations, a successful innovation will also be compatible within the local ecological context. While a new hybrid seed may increase crop yield and be viewed as socially acceptable, its success as an innovation will be influenced by its compatibility with local ecological conditions. For example, if new hybrid seed is more susceptible to weather variability or local pests than traditionally used seed varieties, initial adoption may be followed by discontinuance of use after a few seasons. In some cases, traditional crop varieties adapted to local environmental conditions may provide higher long-term harvests although the yearly crop yields may be lower than the improved varieties.

Complexity is determined by the perceived difficulty in adopting and using a new innovation (Rogers 2003). Innovations that are relatively easy to understand tend to be adopted more rapidly than those with a high degree of complexity. This does not mean that complex innovations will not be adopted, rather, it has ramifications for the timing of adoption and the type and intensity of any accompanying communication campaigns. Moreover, as with the above characteristics, the perceived complexity depends on previously held knowledge and practices of the target population. Even for a highly complex innovation, the perceived relative complexity may be low for those with an existing high degree of working knowledge regarding the particular subject.

Trialability refers to the degree the innovation may be tested prior to full adoption (Rogers 2003). For example, a farmer may test a new irrigation system on a portion of his property prior to converting all of his lands to this new system. Completing a trial in this way, allows the farmer to examine the effectiveness of the innovation with less risk as the losses for adopting the new approach will be limited to where the new irrigation system was adopted. If the trials indicate the innovation is successful at offering expected benefits, then the user may choose to adapt a greater proportion of his irrigation system to the new approach in future years. However, if the innovation proves unsuccessful, he will still receive his expected yields on those lands where he used the previous approach to irrigation.

Observability is the degree to which the outcomes of an innovation are apparent to others (Rogers 2003). The adoption of innovations is generally influenced less by formal information campaigns and more as a result of adoption by peers (Rogers 1987). Thus, innovations that provide benefits that can be observed by others will likely be adopted more rapidly than those that provide less obvious benefits. Building on our example above, if a new irrigation systems leads to improved crop yields and increased water availability for meeting other household needs, other community members who see the values of the innovation will be more likely to pursue its adoption.

20.2.3 Characteristics of Adoption Process

Rogers identifies three types of innovation-decision processes regarding the adoption of new innovations (2003). Optional innovations made by an individual are the first category of decisions. In these cases, the decision about whether to adopt or reject an innovation, while potentially influenced by community-level factors, is made by an individual independent of the rest of the social system. Regarding climate adaptation, decisions regarding the adoption of a new crop variety would likely fall into this category.

Several other innovations, including those associated with adaptation to climate change, involve decisions taken at the collective level. These decisions may be made collectively by members of that social system or by a central authority that mandates adoption among the social system. For example, a group of farmers who share access to an irrigation systems may collectively decide to purchase and install a liner to reduce infiltration of the water as it moves through an irrigation canal. As for authority-adaptation decisions, in these cases a select group of individuals has the authority to mandate particular behaviors among the social system. These individuals may gain their power through cultural, political, or economic means and may include a village elder or elected official. In the irrigation example, these individuals may make decisions regarding large-scale investments in water resources planning (e.g., constructing a dam to provide irrigation water throughout the year) or regulations regarding the amount, timing, or manner that irrigation is to be used (e.g., irrigation of a proscribed amount of water is allowed in morning and evening hours).

For decisions regarding climate adaptation, each of these types of innovation decisions will likely be involved. Investments are needed in infrastructure for potential impacts such as sea level rise and ensuring water availability while individuals will also make decisions regarding their own individual behaviors. The type of decision-process may influence the rate of adoption (Rogers 2003). Adoption decisions made by a central authority often result in a faster rate of adoption given the potential for incentives or sanctions (e.g., government-mandated restrictions on water use to reduce water consumption). However, in such cases individuals may find ways to evade the rules during implementation (e.g., developing unauthorized and unmonitored access to water supplies). On the other hand, decisions made collectively by the members of a social group generally have the slowest rates of adoption but once adopted are more likely to be sustained over the long-term if successful.

20.3 Scenario Planning and Adaptation Strategies

As described in several other chapters of this volume, the changing climate has resulted in substantial uncertainty regarding future conditions. This uncertainty complicates planning and decisions about the future. Traditional planning is typically based on assumptions that future conditions will be similar to those seen in the past. Using some combination of professional and traditional knowledge, individuals make judgments about expected future conditions and plan projects to achieve their objectives based on those expected conditions. Plans rarely develop contingencies to address the potential for surprises where future conditions may occur outside the realm of prior experiences. As climatic changes continue to unfold, the uncertainty regarding what to expect in the future will likely continue to increase.

Scenario planning offers a systematic approach to think through a range of potential future conditions (Peterson et al. 2003). This approach to planning involves the development of a range of potential future scenarios to describe future conditions. Each scenario may differ based on varying a few key underlying assumptions.

For example, given the uncertainty regarding future precipitation amounts in the WANA region, scenarios may be developed to depict conditions based on the range of low and high projection levels as well as the timing of precipitation events. Scenarios may be developed from quantitative models as well as qualitative understanding of the system to provide a range of alternative depictions of future conditions that expressly incorporate existing uncertainties (Peterson et al. 2003). Increasingly, decision-makers are recognizing the value of scenario planning to prepare for future impacts from climate change (for example, see Rajalahti et al. 2006 for a World Bank sponsored analysis of scenario planning to plan for investments in agriculture).

20.3.1 Adaptation Strategies

As the climate changes, humans will adapt to the changing conditions. However, the success of the resulting adaptation actions will depend on a variety of factors including the quality of the information regarding future conditions, available alternatives to effectively address changing conditions, the capacity of individuals and communities to adequately address the challenges, along with several additional variables that affect individual and collective behaviors. Moreover, another important contributor to adaptation success, is the timing of adaptation activities. Adaptation can be reactive (e.g., responding after climatic impacts have occurred) or anticipatory (e.g., taking action to reduce vulnerability prior to experiencing impacts). While both types of adaptation approaches are likely, anticipatory behaviors fall into the category of preventative behaviors described above that present particular challenges in encouraging adoption due to the uncertainty of future benefits as these depend on future conditions. This uncertainty, while present whether the decision-maker is an individual considering what seed to plant or a government making decisions about water infrastructure, increases when the time horizon is lengthened. That is, decisions that have a longer life span will face the most uncertain conditions.

Using a scenario-based approach, decision-makers can develop a better understanding of the range of possible future conditions and examine the performance of alternative adaptation actions. Hallegatte (2009) describe this process as assessing the "robustness" of potential adaptation actions against potential future conditions. Such an approach would allow decision-makers to examine the degree to which the different options are sensitive to future climate conditions. The "best" alternatives will be those that are less sensitive to the changing climate and perform well under a range of future conditions. This represents a substantial change from traditional planning approaches that assume one future scenario and seek to identify the optimal approach to achieve the desired outcome (Lempert et al. 2006; Lempert and Collins 2007).

Building on this approach, Hallegatte (2009) provides a framework to increase robustness of adaptation strategies (summarized in Table 20.2) and describes how to examine the sensitivity of different approaches to address climate impacts. None of these approaches is meant to be a panacea to reduce all future climate impacts.

Table 20.2 Framework of adaptation strategies

Type of strategy	Description
No regrets	Strategies that will provide benefits regardless of future climate conditions
Reversible	Decisions that can be easily reversed or modified in the future
Safety margin	Develop strategies based on a pessimistic assessment of future conditions in infrastructure decisions
Soft	Emphasize institutional, financial, or cognitive changes
Reduced decision horizon	Reduce the lifetime of investments/decisions

Based on Hallegatte (2009)

Rather, they are meant to help encourage in-depth consideration of the effectiveness of potential adaptation decisions against a range of future climatic conditions.

"*No regrets*" strategies are those that will provide positive benefits regardless of how the climate changes in the future. Decisions along these lines will meet current needs and are expected to continue to meet similar needs (and perhaps become more important) under a range of future climatic conditions. An example of a no regrets strategy would be reducing leakage from irrigation pipes as this would provide water conservation benefits regardless of future climate conditions.

"*Reversible*" strategies are those that can be efficiently altered or undone in the future as conditions change. These types of decisions recognize the possibility that future conditions may fall outside the range of conditions currently considered probable. Accordingly, investments in adaptation decisions should provide flexibility to allow future modifications if conditions change. This reduces the risk in the investment in the infrastructure associated with adaptation efforts and enable greater options in the future to adapt to changing conditions. As an example of a reversible strategy, Hallegatte (2009) describes the construction of flood protection that is easy to retrofit if future floods require additional protective measures.

"*Safety margin*" strategies consist of adding a buffer to estimates of future conditions (e.g., amount of precipitation, expected flood height, etc.) in anticipation of greater impacts. Water managers in Copenhagen assume run-off from precipitation will be 70 % greater than current levels (a figure expected to be sufficient to deal with worse-case scenario projections of the future) (Hallegate 2009). Including these safety margins is particularly important for long-lived investments that are not easily reversed. For example, for the water resources infrastructure described above, including such estimates when designing and making initial investments results in minor increases in project costs, while redesigning and modifying the system in the future to meet increased run-off needs would increase the costs substantially.

"*Soft*" strategies have a different emphasis from the other approaches discussed here. Using a variety of different means, these approaches use institutional, financial, or educational approaches to encourage consideration of climate influences in decision-making, encourage behaviors that are expected to contribute to reduced vulnerability, or provide security to compensate for losses from extreme events. Such strategies may include institutionalization of efforts to encourage consideration of expected changes in climate, ecological, and social conditions in long-term planning efforts. Another example may include development of education programs to increase awareness of projected future conditions so individuals can make more informed decisions (e.g., selecting more drought resistant seed varieties where decreased water availability is projected). In other cases, particularly where variability is expected to increase, a soft strategy may consist of providing crop insurance to reduce vulnerability to extreme events.

As uncertainty in future conditions increases with time, in the final approach, "*reduced decision horizons,*" decision-makers may emphasize decisions that have a shorter life span in order to reduce the uncertainty associated with long range conditions. Such strategies may include forestry decisions to emphasize tree species that require a shorter growing period prior to harvest or development of less expensive and lower quality buildings in areas where flooding is expected to be of concern in the future (Hallegate 2009).

20.3.2 Evaluating Adaptation Options

Once a range of alternative actions is identified, decision-makers can assess the effectiveness of the alternative approaches under the range of future climate scenarios. It is important to note that climate is not, nor should it be, the only consideration in making decisions. The approach described here provides a means to better integrate climate into the decision-making process. Ultimately, decision-making is about identifying the most appropriate method to achieve a desired outcome. Climate is one of several factors that may influence the success of decisions and robustness (e.g., degree of sensitivity to changing climatic conditions) to climate change is likely only one of several decision-making goals. In some cases, the most robust climate option may not match the goals of the decision-maker (e.g., relying on non-native tree species to enable a shorter forestry rotation if a goal is to provide habitat for native species). Such tradeoffs must be weighed by decision-makers; the framework discussed here provides an additional tool to help weigh decisions based on their sensitivity to climate impacts.

20.4 Maladaptation

An Arab proverb states "Do not stand in a place of danger trusting in miracles." It could be said that we have created many places of danger because rather than adapting, we have "maladapted" while our adaptation planning efforts that assume the status quo appear to be waiting for a miracle. There have been many works describing "adaptation" and "sustainability" but few focusing on the opposite. In either case we need to look synchronically (focused on a particular point in time) and diachronically (examining changes over time) at the structure and function of each ecosystem. This includes the interaction of cultural, physical, and biological phenomena. At one level the goal of society is, as Slobodkin (1968) notes, simply to persist through time through mitigating environmental and cultural perturbations. As noted above, not all innovations or new ideas will necessarily result in increased resilience; some may be more harmful than helpful. This section describes common problems that lead to adopting maladaptive behaviors. Adaptation, according to Rappaport (1984), requires an ordered sequence of self-regulating responses to stresses to the system. In a resilient system, responses will be appropriate to the stressor, be ordered, and reversible.

Rappaport lists seven types of maladaptation. The first are cybernetic, relating to the structure of regulatory systems. Failure to detect a deviation from a standard reference value can result in a society not realizing it has a stressor at hand. For example, while carbon dioxide local and worldwide levels are rapidly increasing, few people realize the extent of the increase or that this is occurring because of anthropogenic behavior. This failure to detect the perturbation tends to increase the probability of it continuing or being amplified in the future. Blockage of the transmission or reception of the message can prevent the necessary decision-makers from knowing about the stressor. Also it is possible that the reference values are set incorrectly. In our case of carbon dioxide levels, it is possible that the reference values were set too high. Our lives are short compared to the long history and prehistory of life on earth so we cannot help but be biased by the timespan in which we live. This is also true for the reference value for the loss of biodiversity. Northern Africa, according to the Convention on Biological Diversity (2010), has a low level of protected areas dedicated to preserve biological diversity. In both of these examples (climate change and loss of biodiversity), the scientific community has struggled to communicate the importance of the potential changes in a manner that resonates with policymakers and decision makers. Thus, in many cases adaptation plans have not been based on the best available science.

Moreover, our scientific understanding of these systems is limited. Ellen and Holly argue that systematic ecological knowledge is "embedded" (Ellen and Holly 2000). Berkes (1993) lists four criteria for this: (1) Symbolic meaning through oral history, place names and spiritual relationships; (2) Distinct cosmologies or world-views as conceptualizations of the environment; and (3) Relations based on reciprocity and obligations towards both community members and other beings, and (4). Resource management institutions based on shared knowledge and meaning. Traditional ecological knowledge (TEK) is often not expressed in ways that scientists have been able to recognize or accept as an ecological science or system of knowledge. TEK can present challenges for collecting agricultural statistical data because sometimes it is based on the assumption of integration rather than separation so ordinal ranking cannot be assumed in the model.

The second type of maladaptation is related to time. For instance, the response to the stressor could come too soon or too late and consequences are largely dependent on the position of the responder vis a vis the system. If a high order responder – for example, a presidential decree – has a premature and/or over response, then the decision is less likely to be reversible and very likely to override lower order responses, such as a lower level politician or community-based decision, which are usually more reversible. Another way time is important is phenology (the study of the timing of animal and plant lifecycle events). The onset of certain stages of plants or animals or environmental cycles such as spring rains are often used by farmers to plan their activities. Failure to get the timing right can result in crop failure due to drought, flood, inappropriate temperatures, or even mistiming with the availability of pollinators.

A third kind of maladaptation relates to the structural organization of the parts. Over segregation or differentiation of the subparts can create too many autonomous or independent units that are difficult to administer resulting in a high cost to manage or regulation. As Richard Adams demonstrated through his historical analysis of the British occupational categories, as a society becomes more centralized and with more parts to be regulated, the percentage of people in the regulating sector of the economy rises (Adams 1975). If the organization of the parts is not well-integrated, a top heavy bureaucracy will result.

A fourth disorder called hypercoherence results when the interdependence reaches levels where a perturbation in one part of the system quickly spreads or affects the rest of the system. These third and fourth types of maladaptation hinge on the concept of "connectedness" of parts which is a central idea in landscape ecology. It often also involves spatial heterogeneity of these parts. As Burel and Baudry (2004) have noted "if spatial structures are important in the regulation of ecological characteristics of a landscape, a strong correlation must exist between elements of the same nature that are linked together." For example, disconnected biological corridors are a prime example whether we are discussing riparian areas of a river or bird migration corridors.

Rappaport's fifth maladaptation is the hierarchical maldistribution of organization. For example, if the world order is maintained at the expense of the local order, it would be difficult to sustain and might result in disorder. Another variation of this is Rappaport's sixth type of maladaptation, which occurs when special purpose subsystems dominate the larger system. For example, if the financial system of a society dominates the larger whole, it may dominate the agencies that are supposed to regulate them.

A seventh type of maladaptation is degradation of the sacred. This can affect either or both biological and social systems. The cause stems from a misappropriate categorization of the sacred. Ideally the cosmological or ideological system should protect the natural environment through a systematic cultural classification of that environment giving priority to preserving biological diversity. In Pharaonic Egypt certain species were sacred (e.g. the sacred ibis, sacred scarab, etc.) or protected as public property because of their economic importance (e.g. papyrus: material for state monopolized paper industry). Environmental features such as the water of the Nile were demarcated as sacred.

Besides Rappaport's types of maladaptation we can think of several more. The scarcity of water in North Africa and Western Asia is an example of Liebig's Law of the Minimum. Growth is controlled not just by the total amount of resources available but by the scarcest resources. Through time the Nile, Tigris, Euphrates, Amu Darya, and Indus Rivers have taught many a kingdom this lesson of water shortage.

Kinship systems including tracing descent, family, residence patterns, and inheritance are essential aspects of adaptation that seem to be often forgotten. Kinship systems are one of the most basic ways humans interface with the natural environment. A maladaptive kinship system will result in environmental degradation. An example might be one that favors a rapid population expansion but within a circumscribed area so that the land is over exploited. The most common type of descent for hunting, gathering, and fishing populations was bilateral kinship, which is adaptive for small groups, low population density, and connections with many relatives. We also see a tendency for urban populations to follow this pattern. Herding and pastoral populations tend towards unilateral, usually patrilineal, descent and the relatives tend to be very cohesive. Many Islamic people follow variations of parallel cousin marriage where it is possible to marry one's father's brother's offspring. This ensures maintaining tight bonds with inheritance rights maintained within the patrilineal line. Likewise, residence patterns can change through time. Bedouin herders traditionally followed a migratory pattern of residence but in more recent times have settled into cities. This change was followed by political claims and land use regarding the territory that they used to occupy.

The last type of maladaptation, intensification of agriculture, often results from others mentioned above. This is the single largest footprint of anthropogenic influence on a large portion of the world's land surface (Vitousek et al. 1997), and has drastically changed the structure and function of terrestrial and aquatic ecosystems. This historic and ongoing transformation is evident in the WANA Region (ICARDA, FAO, AARINENA, CIHEAM 1999). It affects biogeochemical, population, community, and ecosystems process at many levels, powerfully reshaping landscapes (Watzin and McIntosh 1999). Especially since the 1970s, agriculture has been progressing to large-scale, low diversity farming practices that simplified ecosystems through monocropping and has contributed to hypoxic conditions in the Persian Gulf, Indian Ocean, and Mediterranean Sea. Far from being self-regulating and in equilibrium (Ashby 1963; Jarvis 1999), these agroecosystems depend on high inputs of non-renewable resources to maintain their productivity (Watzin and McIntosh 1999) and are characterized by loss of biocomplexity on multiple scales including biodiversity and the complexity of ecological structure and function within agricultural fields (Van Manselt et al. 1998; Altieri 1999; van Elsen 2000; Torsvik et al. 2002; Hole et al. 2005). These simplified agroecosystems are much less nutrient conservative than their natural counterparts and are major sources of nutrient loading, impairment, and biodiversity loss in aquatic systems (Peterson et al. 2001; EPA 2000).

It is possible to create intensification without degradation if biodiversity and feedback loops are recreated through environmental remediation, but to date these cases are the exception. Previous reports have called for increased research to better understand the potential benefits and costs of intensification in the WANA region (ICARDA, FAO, AARINENA, CIHEAM 1999). Usually while ecological complexity of modern agroecosystems is low, social complexity can be high. Complex interactions of human values, beliefs, and social capital and institutions determine the ecological structure and function of agroecosystems (Martens 1986; Stinner et al. 1992).

Therefore, efforts to restore ecological function of agricultural watersheds will be successful only to the degree that they fully integrate human and environmental dimensions of these systems (Weaver et al. 2005; Lansing 2006).

20.5 Conclusions

Prior research has established a strong understanding of the physical science basis for anthropogenic climate change. Among the remaining uncertainties influencing our ability to effectively adapt to changing conditions, we require improved understanding of the factors that influence human behaviors. Ultimately, adaptation depends on human behaviors at individual, collective, or institutional levels. In this chapter, we have drawn upon existing research to describe how new ideas are adopted within a social system and considered an emerging approach to planning that incorporates existing uncertainties in future conditions. Lastly, we discussed different types of maladaptation, where human behaviors can result in decreased ecological and societal resilience in the face of climate change.

We conclude with three points that emerge from the information presented here. First, improved data and understanding of ongoing and future climatic changes, particularly at the global scale where the greatest certainty currently exists, are not enough to lead to adaptation behaviors on their own. Effective adaptation to climate change requires integration of climate science information with improved understanding of the psychological and social processes that influence decision-making. As other chapters here make clear, additional research is needed to reduce uncertainties in future climatic conditions at the local levels and in shorter-term time scales that matter for decision-making. At the same time, additional effort should be made to draw on social science research to better understand human behaviors. This research can inform how decisions are made and examine compatibility of potential adaptation practices with local customs and context.

Second, traditional planning approaches are not likely to be effective in this new era of climate change. Accordingly, it is necessary to think more creatively about how to characterize the future to account for existing uncertainty in future conditions. The scenario planning approach presented here is one method of doing this that will enable decision-makers to examine the sensitivity of alternative adaptation approaches to the changing climate. By incorporating existing uncertainty in the planning process, these approaches are more likely to result in the development and implementation of adaptation approaches that are robust against a range of potential future conditions.

Lastly, while adaptation is necessary to prepare for and address future climatic changes, it is critical that such decisions are made in a systematic manner that draws on the best available climate and social science data and is grounded in the specific social and ecological context within which the decisions are made. Not all potential adaptation decisions are equal and some may actually lead to reduced resilience and increased vulnerability to future changes. Taking an integrated approach to examine potential actions and outcomes will help identify actions that may result in unintended consequences or have a low likelihood of adoption within the targeted social system.

References

Adams R (1975) Energy and structure: a theory of social power. University of Texas Press, Austin

Altieri M (1999) The agroecological dimensions of biodiversity in traditional farming systems. In: Posey D, Dutfield G, Plenderleith K (eds) Human values of biodiversity. Intermediate Technologies, London

Ashby W (1963) An introduction to cybernetics. Wiley, New York

Berkes F (1993) Traditional ecological knowledge in perspective. In: Inglis J (ed) Traditional ecological knowledge: concepts and cases. International Development Research Centre, Ottawa

Convention on Biological Diversity (2010) Fourth national reports. Convention on biological diversity. http://cbd.int/. Accessed 15 Mar 2010

Burel F, Baudry J (2004) Landscape ecology: concepts, methods, and applications. Science Publishers, Enfield

Ellen R, Holly H (2000) Embeddedness of indigenous environmental knowledge. In: Posey D, Dutfield G (eds) Cultural and spiritual values of biodiversity: a complementary contribution to the global biodiversity assessment. UNEP, Nairobi

Hallegate S (2009) Strategies to adapt to an uncertain climate change. Glob Environ Change 19:240–247

Hole DG, Perkins AJ, Wilson JD, Alexander IH, Grice PV, Evans AD (2005) Does organic farming benefit biodiversity? Biol Conserv 122:113–130

ICARDA, FAO, AARINENA, CIHEAM (1999). In: Casas J, Solh M, Hafez H (eds) The national agricultural research systems in the West Asia and North Africa Region. ICARDA, Aleppo

IPCC (2007a) Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds). Cambridge University Press, Cambridge, UK/New York

IPCC (2007b) Climate change 2007: synthesis report. Contribution of working groups I, II and III to the fourth assessment report of the intergovernmental panel on climate change. In: Core Writing Team, Pachauri RK, Reisinger A (eds). IPCC, Geneva

Jarvis S (1999) Nitrogen dynamics in natural and agricultural ecosystems. In: Wilson WS, Ball AS, Hinton RH (eds) Managing risk of nitrates to humans and the environment. Royal Society of Chemistry, Cambridge, pp 2–20

Lansing S (2006) Perfect order: recognizing complexity in Bali. Princeton University Press, Princeton

Lempert RJ, Collins MT (2007) Managing the risk of uncertain thresholds responses: comparison of robust, optimum, and precautionary approaches. Risk Anal 27:1009–1026

Lempert RJ, Groves DG, Popper SW, Bankes SC (2006) A general, analytic method for generating robust strategies and narrative scenarios. Manage Sci 52:514–528

Martens G (1986) Traditional agriculture in southeast Asia. Westview Press, Boulder

National Research Council (2007) Evaluating progress of the U.S. climate change science program: methods and preliminary results. National Academy of Sciences, Washington, DC

National Research Council (2009) Informing decisions in a changing climate. Panel of strategies and methods for climate-related decision support. National Academy of Sciences, Washington, DC

Peterson B, Wollheim WM, Mulholland PJ, Webster JR, Meyer JL, Tank JL, Marti E, Bowden WB, Valett HM, Hershey AE, McDowell WH, Dodds WK, Hamilton SK, Gregory S, Morrall DD (2001) Control of nitrogen export from watersheds by headwater streams. Science 292:86–89
Peterson G, Cumming GS, Carpenter SR (2003) Scenario planning: a tool for conservation in an uncertain world. Conserv Biol 17:358–366
Rajalahti R, van der Heijden K, Janssen W, Pehu E (2006) Scenario planning to guide long-term investments in agricultural science and technology theory and practice from a case study on India. Agriculture and rural development discussion paper 29, The World Bank, Washington, DC
Ramathan V, Feng Y (2008) On avoiding dangerous anthropogenic interference with the climate system: formidable challenges ahead. Proc Natl Acad Sci USA 105:14245–14250
Rappaport R (1984) Pigs for the ancestors: ritual in the ecology of a New Guinea people, 2nd edn. Yale University Press, New Haven
Rogers EM (1987) The diffusion of innovations perspective. In: Weinstein N (ed) Taking care: under- standing and encouraging self-protective behavior. Cambridge University Press, Cambridge, pp 79–94
Rogers EM (1995) Diffusion of innovations, 4th edn. The Free Press, New York
Rogers EM (2003) Diffusion of innovations, 5th edn. The Free Press, New York
Ryan B, Gross N (1943) The diffusion of hybrid seed Corn in two Iowa communities. Rural Sociol 8:15–24
Slobodkin L (1968) Toward a predictive theory of evolution. In: Lewontin RC (ed) Population biology and evolution. Syracuse University Press, Syracuse, pp 187–205
Stinner D, Glick I, Stinner B (1992) Forage legumes and cultural sustainability: lessons from history. Agric Ecosyst Environ 40:233–248
Torsvik V, Øvreås T, Thingstad F (2002) Prokaryotic diversity – magnitude, dynamics, and controlling factors. Science 296:1064–1066
United States Environmental Protection Agency (2000) 2000 national water quality inventory. U.S. EPA Office of Water, Washington, DC
Van Elsen T (2000) Species diversity as a task for organic agriculture in Europe. Agric Ecosyst Environ 77:101–109
Van Manselt J, Stobbelaar D, Hendriks K (1998) Comparison of landscape features in organic and conventional farming systems. Landsc Urban Plan 41:209–227
Vitousek P, Mooney HA, Lubchenco J, Melillo JM (1997) Human domination of Earth's ecosystems. Science 277:494–499
Watzin M, McIntosh A (1999) Aquatic ecosystems in agricultural landscapes: a review of ecological indicators and achievable outcomes. J Soil Water Conserv 54:636–644
Weaver M, Moore R, Parker J (2005) Understanding grassroots stakeholders and grassroots stakeholder groups: the view from the grassroots in the Upper Sugar Creek. Annual Meeting of the Political Science Association, Washington, DC
Wejnert B (2002) Integrating models of diffusion of innovations: a conceptual framework. Annu Rev Sociol 28:297–326
Wigley TML (2005) The climate change commitment. Science 307:1766–1769

Part VI
Regional Agricultural Adaptation and Mitigation Framework for Climate Change in WANA

Chapter 21
Regional Framework for Climate Change Adaptation and Mitigation in the WANA Region

Ghassan Hamdallah

Abstract WANA Region is mostly arid or semiarid, therefore climate extremes (particularly drought) are frequent events. Agriculture is constrained with limited land and water resources, as well as inadequate capital investment and poor marketing facilities. Climate change (CC) is a global recognized phenomenon including warming, sea level rise and greenhouse gas emissions. In spite of the fact that several scenarios are forecasting occurrence of CC events, degrees of certainty are questioned by many researchers, to the extent of even citing some CC benefits from temperature rise and CO_2 enrichment in enhancing agriculture outputs. The agriculture sector, as much as it could be a victim of CC; has a significant mitigation role. International organizations focused lately on CC mitigation and adaptation plans, including the FAO Conference on CC Adaptation and Mitigation in Beirut in 2006 and the ICARDA International Conference on CC and Food Security in Jordan in 2010. A Regional Adaptation Framework is presented to address climate change including a multidisciplinary approach, covering the following issues: (i) move from emergency to risk management, (ii) sustainable management of the natural resource base (land, water, forestry, fisheries); (iii) relevant policy reform and legislation; (iv) enabling capacity to adapt to climate change with regional cooperation and partnership; and (v) enhancing the role of research including potential of resources, land and water and indigenous water-saving techniques.

Keywords Aridity • Food security • Preparedness plans • Green house gas emissions • Global warming • Risk management • Sustainable management • Crop insurance • Vulnerability • Applied research

---

G. Hamdallah (✉)
Ex. FAO Senior Regional Land & Water Officer,
PO Box 143745, Amman 11814, Jordan
e-mail: ghassan.hamdallah@gmail.com

M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_21,

21.1 Introduction

21.1.1 WANA Region Coverage and General Features

The WANA Region is designated to refer to the West Asia and North Africa by the Consultative Group for International Agricultural Research (CGIAR). It includes various countries in the Mid East, Near East and N. Africa. The membership list of WANA, recognized by both FAO and AARINENA, includes 27 countries.[1] However, due to different regional coverages used by various International Organizations; statistics ought to be taken from a *"global and general regional perspective"* rather than for each country.

Principal characteristics of the WANA Region are as follows:

- About 70 % arid or semi-arid area; with agriculture highly vulnerable to climate change;
- Represents about 10 % of world population, but has only 2 % of World Internal Renewable Water Resources;
- Majority of countries fall within the Water Deficiency Level of 500 m^3/capita/year;
- Some nine countries receive their main water resources from "outside their borders", posing the controversial issues of *international, shared, or transboundary water resources.*

21.1.2 Risks Associated with Aridity and Other Man-Made Events

Aridity in WANA represents the most serious risk to both agriculture and human livelihood. The repeated waves of drought that the region witnessed during the last few years, had their toll on agricultural production, with some reported losses of up to 30–40 % during 1999/2000 drought in Iraq, Jordan, Morocco, and Syria.

Evidently, agriculture in the Region is extremely vulnerable to climate change, due to the vagaries of precipitation leading to crop failure, loss of livestock and eventually ecological immigration. Climate change is now clearly observed in the Region since all the predictive models forecast increased temperatures in all countries accompanied by a decline in rainfall (FAO 2008).

[1]The designated countries are: Afghanistan, Algeria, Bahrain, Cyprus, Djibouti, Egypt, Islamic Republic of Iran, Iraq, Jordan, Kuwait, Lebanon, Libya, Malta, Mauritania, Morocco, Oman, Pakistan, Palestine, Qatar, Saudi Arabia, Somalia, Sudan, Syria, Tunisia, Turkey, United Arab Emirates, and Yemen.

21.1.3 The Region's Agriculture

WANA Region embraces a wide diversity among its 27 member countries related to the agriculture sector's contribution in the GDP. This contribution ranges from negligible in GCC countries and Jordan; to 10–20 % in Morocco, Algeria, Iran, Tunisia, Egypt, Turkey, Yemen and Sudan; or up to 20–30 % in Pakistan and Syria (Zehni 2011).

The Region was a self-sufficient area in food items in the 1960's, while at present the majority of these countries are net food importers, where the overall self-sufficiency rate in cereals was only 49 % in 1999/01. This high dependence on imported food items poses a real threat to national food security, a risk that became clear to all countries in the aftermath of the global food crisis in 2007/2008.

In addition, some fierce competition is witnessed over securing water for agriculture, which is becoming a scarce commodity required badly for other economic sectors. Many people would question the feasibility of spending over 2/3 of the nation's water on one sector (agriculture) that hardly contributes 5 % to the GDP.

21.1.4 Regional Priorities for Agriculture and Food Security

An FAO Regional Consultation convened in Cairo in October 2010 proposed a *Regional Priority Framework* to guide the FAO Programme of Work and Budget for the period 2010–2019. This Consultation identified the following five regional priorities:

- Enhancing food security and nutrition.
- Fostering agricultural production and rural development for improved livelihoods;
- Sustainable management of natural resources;
- *Responding to climate change impacts and developing adaptation strategies;* and
- Preparedness for, and response to, food and agriculture emergencies.

21.2 Climate Change

21.2.1 A Global Phenomenon

Climate Change implies a list of cause and effect relationships, but generally may result in great harm at considerable cost. Carbon dioxide (CO_2) and water supplies are essential for plant growth (its enrichment called fertilization); yet climate change is likely to disrupt those supplies through floods and droughts.

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) established an understanding of anthropogenic warming and that the globally averaged net effect of human activities since 1750 has been one of warming (IPCC 2007).

Sea Level Rise is another significant issue, which could be a threat to Nile Delta in Egypt and the Coastal area of the Gulf. Intrusion of Seawater could contaminate rivers and affect aquifers, as well. However, it should be noted here that there are some genuine uncertainties related to estimates and forecasts on this issue.

Agriculture sector is likely to be one of the victims of climate change, but it is also considered a contributor through greenhouse gas emissions. Agriculture also has a significant potential as it contributes substantially to the adaptation and mitigation measures. Carbon sequestration and the positive contribution of forests constitute a major mitigation mechanism to alleviate the negative impacts of climate change.

21.2.2 Projected Impacts on Agriculture

Cline in his book entitled *Global Warming and Agriculture: Impact Estimates by Country* reported that agricultural production in developing countries may fall by an average of 16 %. This is a clear call for policymakers to address this phenomenon now and before the world's developing countries are adversely and irreversibly affected (Cline 2007).

However, in the long term projections related with climate change; there are uncertainties, particularly related to the lack of information on many specific regions. Uncertainties on the magnitude of climate change could also apply to the effects of technology impacts on productivity, global food demands and the numerous possibilities of adaptation mechanisms.

21.2.3 Regional Impacts in the Near East

More than 80 % of the models agree that most of the Region will have a decrease in water availability (expressed as runoff) of up to 40 mm per year, and that the decrease will be twice as high in the Anatolian Plateau. However, water availability could increase between 0 and 40 mm/year from southern Algeria to southern Egypt, most of Sudan and Somalia in Africa, the southern Arabian Peninsula and the south of western Asia (FAO 2008).

These forecasts depict clearly the split in opinions among scientists on the various forecasted scenarios. Vulnerability is directly related to a country's ability, or inability to adapt. *Annex I* provides a Country-by-country data on impacts and showing some indicators describing current vulnerability patterns and climate-related risks (FAO 2008).

21.3 A Regional Adaptation and Mitigation Framework for the WANA Region

21.3.1 Regional Adaptation Framework

Proposing a *Regional Framework* for climate change adaptation covering a vast area like WANA is a challenging task. Given the complexities in terms of climatic, geographic and anthropogenic varying features within the Region; it becomes quite plausible to focus on capacity building, normative work and increasing the resilience of agricultural and rural communities. Following are some of the key issues in the regional adaptation framework:

21.3.1.1 Moving From Emergency to Risk Management

It is established that the risk associated with an emergency (like drought) is a function of the magnitude of exposure and the societal vulnerability. The fire-fighting approach is generally the norm in facing natural hazards, whereby massive transfers of food, feed, water and relief items are conducted.

However, in addition to conducting an *urgent relief* to the affected communities; some sustainable actions and mitigation measures ought to be initiated right after the emergency. An active *Restoration Programme* needs to be implemented (for at least 3 years) in order to rehabilitate the ecological productivity of the affected areas and restore vegetation composition.

The identified technical, institutional and policy options ought to be discussed with the relevant community, as well as with the development partners (national and international organizations and NGO's), resulting in an Action Plan for community development. *Stakeholders' participation* in all phases of rehabilitation/development project planning and implementation is inevitable as the beneficiary community is the real guarantee of any project's success and sustainability.

21.3.1.2 Sustainable Management of the Natural Base

Water Resources Management

- Attach the water resources planning and oversight to the highest political level possible, to ensure good governance;
- Focus on *Water Demand Management*, after giving due attention to the supply management for urban and agricultural areas;
- Adopt all technical and economic tools to realize the slogan of *"More Crop Per Drop"*, which FAO is promoting (FAO 2002).
- Strictly enforce the legislation related to killing of illegal wells and adopt the "*rational pumping of ground water"*.

Land Management

- *Increasing output* from each ha of agricultural land through vertical expansion, as horizontal extension may lead to farming marginal lands of low potential;
- *Optimal use of inputs* including: an increase in the amount of fertilizer applied from the region's low current average of about 70 kg/ha of nutrients up to 100 kg/ha. This increment of 30 kg/ha of fertilizers will considerably increase productivity, as crop response to fertilizer application could be as high as 40 kg/ha in yield for every 1 kg/ha of nitrogen added (Hamdallah 2000).
- Likewise, similar increments can be heralded about the right choice of *seed varieties, pest management* and proper agricultural practices. Of significant importance also is the reduction in post-harvest losses that can be as high as 45 % in tomato crop, as reported by a World Bank, FAO, IFAD study in Egypt in 2009.
- Adopt well-designed *plans to curb land degradation* due to salinization, desertification and erosion.
- The ending phase in the *Value-chain of agricultural produce* is the *access to markets*, and thus improving the farm income.

Forestry Management

The *low-forest cover* status of the region warrants sound policies and practices necessary for conservation of indigenous resources through emphasizing the following actions.

- Preparing a *Land Use Map* (using Remote Sensing) to delineate clearly the Forest Areas for their proper protection, rehabilitation and development.
- Participating in the *Clean Development Mechanism* (CDM) which accepts afforestation and reforestation. Some countries such as Kuwait, Oman, United Arab Emirates and Egypt are practicing afforestation and reclamation of desert areas, using *treated wastewater*[2] *for irrigation.*
- Majority of the Region countries are identified as "*Low Forest Cover Countries (LFCC)*" and therefore can benefit from the relevant international initiatives and special programmes, such as UN Forum on Forests (UNFF) and the FAO Commission on Forestry (COFO).

Rangelands Management

Paying due attention to continued deterioration of the fragile range ecosystems is urgent because of the importance of these transhumance areas for the livelihood of inhabitants of Bedouins, who constitute a significant portion of the population

[2] Quite suitable for irrigation since wastewater is treated up to the tertiary stage in all GCC States.

(25–30 %) of some countries such as Mauritania, Jordan and Saudi Arabia. Following are some salient points:

- *National integrated development plans* are needed for these under-privileged communities to improve their health and educational standards. In addition, creating some jobs for the youth and women to improve the household income is strongly required through encouraging small food processing, bee-keeping, as well as making and selling some handcraft materials.
- Rangeland areas (*below the 200 mm rainfall isohyet*) have to be delineated and mapped to help in drafting development plans and in addressing needs of pastoralists and livestock owners.
- *Protect the fragile rangeland ecosystems* through banning any intensive farming operations aimed at utilizing rangelands for crop production. Some past ill-planned governmental activities like clearing of indigenous trees and plant cover have resulted in grave ecological consequences, including serious land degradation.
- Revise and *amend land tenure policies* that facilitate and promote rangeland rehabilitation. Existing local laws (*Hema systems* governing grazing rights) in some countries where the tribal *Al-urf* or *community consensus* can be a powerful tool for range conservation and restoration if well-negotiated with local communities.

Fisheries Resources Management

The Region encompasses a wide geographical area of different marine and freshwater ecosystems and fisheries. Moreover, fisheries in the Region rely upon ecosystem services and goods that are often shared with other coastal countries. This warrants regional cooperation to ensure adopting responsible management and sustainable exploitation. Following are some relevant key issues:

- Adopting *conservation and rational management* for the best utilization of living marine resources, as well as the sustainable development of aquaculture in areas such as the *Gulf, the Sea of Oman and the Mediterranean*.
- Establishment of a *Centre for Marketing Information* and Advisory Services for Fishery Products in the Region.
- Introduction of the *spatial dimension* in fisheries management and aquaculture planning through the proper Use of Geographic Information System (GIS) in Fisheries Management.
- Banking on the data acquired by FAO related to *"Trends and Pattern of Capture Fisheries Production in the Near East and North Africa Region (1950–2007)"*
- *Climate change and its impact on the fisheries and aquaculture sectors in the Region* was addressed through specific regional multidisciplinary workshops such as "*Adapting to Climate Change: the Ecosystem Approach to Fisheries and Aquaculture in the Near East and North Africa Region"*. This literature should be consulted and considered in drafting Fisheries Management Plans, vis-a-vis the vagaries of climate change, (FAO 2008).

21.3.1.3 Policy Reform and Legislation

A National Mitigation Plan

Governmental policies related to Climate Change and/or other perils need to be re-visited in order to draw preparedness plans at household, provincial, regional and national levels. To guarantee the successful implementation of mitigation and rehabilitation strategies; the full participation of stakeholders becomes instrumental in streamlining the process from the onset to completion and onwards.

A major task in the work related to Climate Change is the support to policy planning of adaptation strategies. The *assessment of impacts* (intensity and duration) and assessment of the vulnerability of affected community or region are of prime importance for the eventual identification of adaptation and mitigation activities.

Climate Change Mitigation Strategies needs to be integrated within the *National Development Plans*[3] in order to have synergy and harmony, as well as securing budget allocations along with other Governmental plans.

Establishing a Compensation Fund

Consider establishing a *viable fund for environmental compensation* to affected communities due to climate anomalies, like cold-freezing waves, prolonged drought, floods, as well as other trans-boundary emergencies. Experiences in some countries in the Region showed good response and positive impact to the compensation schemes, like in Jordan and Syria (drought and frost damage), Sultanate of Oman (high floods in 2010) and Morocco (procurement of farmers crops or animals in drought years).

Feed Incentives (subsidized barley) are deemed a necessary act to assist Jordanian herders and keeping their herds off of the range, in order to allow its restoration.

Crop Insurance

Evidence is accumulating on the connection between climate change and the increasing incidence of crop damaging weather events of extreme severity. In spite of the recognized importance of crop insurance; its implementation is still limited. The main obstacle to the scheme adoption is the *finance* needed to sustain such initiatives.

Based on the above, some strong governmental involvement is required for insuring the risk management in agriculture. This means, in practice, that governments are active not only from an overall policy sense; but also in securing a workable

[3] In Jordan, the Drought Strategies and Action Plan were included in the Agriculture Law, which is integrated in the Five Year Development Plan.

mechanism for *operating and financing the scheme*. Such issue needs to be addressed in cooperation with private business (banks and funding firms), as well as with marketing agents and food processing enterprises.

As part of this business-like trend, greater acceptance of *contract farming* arrangements are witnessed, where insurance is one of many services provided to growers along with inputs. While crop and forest losses are only a part of this, there are some estimates that the costs associated with crop-damaging weather events are doubling each decade (FAO 1999).

It should be noted here that The *World Trade Organization* (WTO) regulations generally forbid governments from subsidizing agriculture directly; but subsidizing of agricultural insurance can be permitted. To face this WTO regulation, it is clear that demand for crop insurance will increase in those economies that wish to implement a policy of permitted subsidization of their farmers.

21.3.1.4 Adaptive Capacity and Regional Cooperation

Adapt to Climate Change

Building the *adaptive capacity* of a country or community is of prime importance to cope with climate change or any emergency. *National Preparedness Plans* and pre-conceived actions represent the key elements in enhancing the countries' *resilience* and in having appropriate coping mechanisms. It is established that the magnitude of climate change impact is a function of *Vulnerability and Intensity/Duration* of the peril (Wilhite 2002).

To underscore this point of varied degree of severity, a comparison is often made between the impacts of the 1950's *US Great Plains Drought* with the one which devastated the *West African Sahel* during 1968–1974. While the drought episode in the US had passed almost unnoticed; the African Sahel region lived through grave conditions, whereby over 200,000 people and millions of their animals died (Fleischhauer 2000).

To help initiating National Preparedness Plans to cope with drought; FAO provided technical assistance to three member countries in the Region, including Jordan, Syria, and Iran Islamic Republic, through the *FAO Technical Cooperation Projects (TCP)*. For each country, the Mitigation Strategies and Plan of Action were developed.

As part of the societal awareness in the state of risk or emergency; a *National Workshop* was deemed necessary to alert all sectors of the society of the event (drought was targeted) and to have a wide national dialogue with all relevant governmental institutions (Ministries of Agriculture, Water, Environment, Social Development and Interior). Legal, policy, socio-economic, as well as administrative issues were discussed to reach consensus on implementing the Plan of Action. One major issue was deliberated and agreed on related to: who is responsible for "*Declaring the State of Drought*" in the country, which was the Cabinet of Ministers in Jordan, for example.

Banking on Indigenous Knowledge

The WANA Region, due to its long and deep-rooted history, acquires a rich heritage of indigenous knowledge in coping with climate anomalies, particularly the most common and recurrent event, *drough*t, which was heralded in the holy books (*the Bible and the Koran)*. Any viable adaptation strategy and the plan of action have to reckon with local techniques that need to be validated, in terms of their efficiency, being well-adapted to the environment and for cost-effectiveness. A wealth of knowledge exists in techniques and innovations for water harvesting. For example *aflaj* for underground water translocation and distribution are still functioning in Saudi Arabia, Sultanate of Oman and Islamic Republic of Iran, as well as Romanian wells, throughout the Region.

Soil and water conservation techniques have been developed in the Region, including the famous *Terrace Agriculture in Yemen*; mountain lakes in Tunisia; run-off and flood-spreading techniques in Iran and supplementary irrigation that have been practiced for centuries in most of these countries.

Regional Cooperation for Climate Change Adaptation

Regional cooperation and adopting collaborative programmes is inevitable in dealing with challenges of climate change, due to its transboundary nature and magnitude that is often beyond the adaptive capacity or resources of any individual country or sub-region. Such arrangements can promote the capacity to deal with regulations through sanitary and phyto-sanitary standards, in addition to food safety risk management and enhance bargaining positions when countries need to purchase food from international markets (FAO 2009).

For developing the preparedness plan and climate change adaptation strategies; a basic and essential requirement is the bio-physical and meteorological data at national and regional level, which also should be connected at the global level. Appropriate *Networking and Data Exchange*, harmony and knowledge-sharing among countries of the Region is of prime importance. A regional initiative is needed for strengthening the institutional capacity in drought early warning, drought monitoring and impacts assessment, as well as promoting co-ordination mechanisms for drought response by various stakeholders.

Realizing the importance of this issue, Morocco established the *National Drought Mitigation Observatory*, which has a direct connection with the Meteorological Service of Morocco, as well as with Meteo France. It should be stressed that the regional and international cooperation related to information sharing cannot be over-emphasized.

Establishing Regional Food Security Programmes

Food security is a real concern for a majority of countries in the region, as these are net importers of major food items. Save few countries in the region like Turkey, Syria and Sudan; the remaining ones are suffering from deficiency in certain food items at different levels, particularly in cereals. This is in spite of the fact that several countries have achieved self-sufficiency in some items like white meat, eggs, sugar; hence the basic deficient commodity is still *"cereals"*.

In the development plans of almost all these countries, *Food Security* comes as a top priority and as a primary national goal. Countries while trying to achieve this goal are confronted with limited arable lands and water shortages (almost all fresh water resources available for agriculture are already committed).

Several UN agencies, as well as international and regional funding organizations, including: FAO, IFAD, World Bank, Islamic Development Bank, and many others have made some serious efforts towards supporting *Food Security Programmes*, at national and regional levels. FAO, by virtue of its mandate in food and agriculture, initiated a *Special Programme for Food Security (SPFS)* in 1994, with full ledged Secretariat and staff. In addition, FAO convened the World Food Summit in Rome in 1996 which raised, to the highest level, awareness of the enormous dimensions of hunger and malnutrition in the world.

According to FAO, mainly because of high food prices in 2007 and 2008; the number of hungry people in the world increased by over 100 million to reach a total of about 1 billion hungry and malnourished, (about 15 % of the world's population). At the same time it is been anticipated that by 2050 the world's population is expected to reach 9.2 billion people. Meeting the food needs of the planet while conserving the basic natural resources is among the foremost challenges of our time (FAO 2009).

Climate change represents a major source of risk for long-term food security, due to the expected declining yields and greater frequency of extreme weather events. Agriculture, forestry and fisheries will have to adapt to climate change, but can also help mitigate the effects of climate change, as the useful synergies exist between adaptation and mitigation.

Recently a new issue emerged as a main concern to food security at the global level. Liquid biofuels produced basically from agricultural commodities have increased more than threefold from 2000 to 2008, by which date they accounted for about 10 % of world's coarse-grains utilization. Increased use of food crops for liquid biofuel production may offer new income opportunities for farmers but could have serious implications for food security (FAO 2009).

FAO held its *Second Forum on Climate Change in the Near East* in Beirut, Lebanon, in June 2011, with a focus on agriculture and food security. The Forum took stock of countries' knowledge and gaps, with an opportunity to exchange experiences. The meeting was briefed on international financial mechanisms to support climate change adaptation and food security goals, including the *Global Environment Fund (GEF).* The meeting developed a declaration on the commitment to address climate change, agriculture and food security, and a roadmap for implementation was announced,

There is urgent need for action towards establishing a *Global Partnership for Agriculture*, *Food Security and Nutrition* that has been called for at the recent high level fora, including the *G8 Summits,* to improve coordination and coherence in international strategies and policies.

21.3.1.5 Enhancing the Role of Applied Research

Genetic Resources Research

There is a wealth of indigenous wild relatives and landraces existing in the Region which are adapted to the climate extremes and stresses, including drought, heat stress, soil salinity, saline water, etc. Genetic resources research in the Region is not well-developed. Some well-based national breeding programmes (for plant and animal genetic resources) need to be established and should be given support. Their work programme includes: collection, classification, identification, conservation and propagation of these genetic materials that ought to be preserved in a *Gene Bank*. This is an important step as the *registration and accreditation* of these resources is a requisite for *property rights purposes*.

Sharing of information on these genotypes with regional and international Gene Banks should be encouraged, particularly the Gene Bank at ICARDA in Aleppo, Syria. Due to the wide biodiversity and the variety of climate stresses; a breeding research programme needs to be initiated in the region for crop selection and adoption. Scientific collaboration is also required at the global level to benefit from sharing the experiences of those specialized centers.

The *Global Crop Biodiversity Trust* has commissioned in 2005 a number of regional conservation strategies, including one for the Near East and North Africa (NENA) that was published in 2006. The NENA Strategy was developed under the auspices of the Association of Agricultural Research Institutes of the Near East and North Africa (AARINENA) and with inputs from a wide range of partners and relevant international Organizations (Zehni 2011). The Region Countries should try adopting this strategy entitled: *Towards a Regional Strategy for the Conservation of Plant Genetic Resources in West Asia and North Africa (WANA).*

Land and Water Research

According to FAO, in order to meet world food demands, about 90 % (80 % in developing countries) of the growth in crop production will have to come from intensification, particularly through higher yields and increased cropping intensity. Only 10 % would come from expansion of arable land and this can only be achieved through active research programmes for producing more food, feed and fiber from each hectare of land.

Applied research on land and water should focus on the impact of some parameters on crops, including: deficit irrigation, supplementary irrigation, crop water requirements, potential for using brackish and salt water, crop response to mineral fertilizers, impact of fertilizer application under rainfed farming, improved seeds of certain cultivars, and re-use of treated wastewater for agriculture.

Land tenure and land use need to be amended/revised in the context of climate change situation, which imposes some priority setting and changing land use patterns, with consideration given to the impact on resource-poor farmers and the vulnerable groups.

Animal Resources Research

Livestock has an impact on climate change through *CO_2, NO_2 and CH_4* emissions, which contribute about 18 % to global warming. Due to the potential negative impact on livestock; serious research programmes should explore this impact. In some countries like Sudan, the livestock sector represents some 80 % of their total agricultural exports. Therefore, more research is required to enhance the sector productivity and to introduce the *Value Chain* concept to this significant source of income to people.

Evaluation of Adaptation Strategies

Adaptation strategies ought to be analyzed and evaluated to validate their appropriateness and effectiveness, as well as being sustainable and of scalable nature.

Enhancing national capacity in assessment of regional climate change by focusing on the environmental concerns related to agriculture and economy. This necessitates cooperation and partnership between development partners, researchers, policy makers, private sector, trade and industry, as well as NGO's and CSO's.

21.4 Concluding Remarks

The following concluding remarks can be made on climate change adaptation and mitigation strategies:

(a) Climate change adaptation is a top priority for the agriculture sector and is required for meeting food security objectives.
(b) A shortage of information is recognized on the extent of national coordination mechanisms and local strategies for coping with adaptation measures and mitigation.
(c) There are generally limited investment and public financial resources available for adaptation, particularly for rural development programmes.
(d) There is a clear link between mitigation and adaptation in the agriculture sector and therefore a regional *climate change model* is required, particularly for understanding vulnerability to water resources.
(e) Obvious need exists for cooperation and exchange of experiences among countries in the region, particularly due to the common themes that emerged from preliminary country studies.

(f) Rainwater harvesting is a unique practice in the southern coast of the Mediterranean since the Roman times. Validation of this traditional knowledge and upgrading it with modern technologies would prove advantageous.
(g) A proactive partnership is needed between Member Countries and International/Regional Organizations and institutions, for launching cooperative programmes to enhance national adaptive capacities in Climate Change Adaptation.
(h) Higher productivity and resilience of production systems are essential for raising rural incomes, improving access to food for the poor and enabling local agriculture to be more prepared for mitigating the impact of climate change.

21.5 Recommendations

Member Countries are *called-upon* to:

i. Review their national legal and institutional frameworks to create a *Responsible Authority* in charge of the management of Climate Change impacts, including the basis for declaring the *State of Emergency* in the country.
ii. Integrate the Climate Change adaptation and mitigation strategies within national development plans, particularly long term and contingency plans for natural resources management.
iii. Give top priority to implementing national plans for climate change adaptation and mitigation, as well as dissemination of information and awareness of the public on the issue, including the establishment of *Early Warning Systems*.
iv. Develop well-designed programmes/projects banking on indigenous heritage particularly water management and water saving techniques, seeking funding from national public sector and international/regional funding institutions.
v. Promote sharing experiences and networking related to regional climate change mitigation plans in collaboration with United Nations Agencies and Development Partners such as FAO, WMO, IFAD, GEF, UNEP, World Bank, as well as relevant Regional and International Funding Institutions.

To Regional and International Organizations and Potential Donors

i. Provide technical support to Member Countries for developing and implementing action plans on climate change adaptation and mitigation strategies.
ii. Give due attention to national experience-sharing and Regional Information Networking on Climate Change in the WANA Region, focusing on the regional dimension of the phenomena.
iii. Provide technical assistance to financially-capable countries (*Trust Fund modality*), as well as assisting other countries to prepare fundable project documents for submission to donors.
iv. Recognizing the complexity and the multi-sectoral nature of the intervention measures for coping with climate change; it is essential to establish linkages with other relevant initiatives of UNCCD, GEF, WMO, UNEP, as well as collaboration with regional and international funding institutions.

Annex I: Climate Change Impacts and Vulnerability of the Countries of the Near East Region

Country	Vulnerable sectors and possible impacts of climate change	Common climate-related disasters[1]	% of total population under desertification risk[2] 1997	Total actual renewable water resources per capita (m^3/inhab/year)[3]	% of potential arable land actually in use[4] 1997	Projected % change in agricultural production capacity for 2070–2099 with respect to 1961–1990 baseline[5]
Afghanistan	Access to safe drinking water may worsen.[6]	Landslides (2006). floods	98	2,608	265	−13
Algeria	Vulnerable to natural hazards such as floods and drought.[7]	Floods (1969)	53	443	63	−26
Azerbaijan	Decrease in water resources. Projected rise of the Caspian Sea level. Winter pastures may be negatively affected.[8]	Floods (1995)	59	3,584	51	
Bahrain	Low-lying areas of the country's islands vulnerable to sea level rise[9]	None		157		
Cyprus	Sea level rise vulnerability index[10]=6 Damage on marine environment. More frequent. Intense and longer droughts and heat waves. Water stress.[11]	Windstorms (1969). Extreme temperatures	93	965	33	
Djibouti	Sea level rise vulnerability index =0.37 Ground water recharge may be affected. Increased risk of floods and other extreme events.[12]	Floods (1989), drought	0	421	0	

(continued)

(continued)

Country	Vulnerable sectors and possible impacts of climate change	Common climate-related disasters[1]	% of total population under desertification risk[2] 1997	Total actual renewable water resources per capita (m^3/inhab/year)[3]	% of potential arable land actually in use[4] 1997	Projected % change in agricultural production capacity for 2070–2099 with respect to 1961–1990 baseline[5]
Egypt	Reduced productivity of crops and increased water requirements. Heavily populated Nile Delta vulnerable to sea level rise.[13] Sea level rise vulnerability index–0.15	Floods (1994), windstorms	0	794	2,893	28
Iran	Change in length of growth period and number of freezing days.[14] Damage from intense cyclones originating in Arabian Sea.[15]	Drought (1999), floods	95	1,970	385	–18
Iraq	Possible impacts on Tigris-Euphrates stream flow.[16] Increasing irrigation demand.[17]	Drought (1969), floods	95	2,971	131	–32
Jordan	Increasing irrigation demand.[18] Possible rainfall decrease adds additional stress to already scare water resources.[19]	Drought (1999), floods windstorms, high temperatures	100	157	72	
Kazakhstan	Spring wheat decreases, winter wheat increases, with overall net decrease projected. Rangelands changes project decrease in wool production.[20] Glacier decreasing in northern Tien Shan.[21]	Extreme temperatures (1997), floods, wildfires	96	7,116	478	28

Kuwait	Low coastal areas vulnerable to sea level rise. Storm surges affect coastal oil production.[22]	Floods (1997)	0	8	500
Kyrgyz	Decreased cropland for cereals.[23] Glacier decreasing in northern Tien Shan.[24]	Landslides (1994), windstorms, floods	100	3,952	164
Lebanon	Increased stresses on water resources. Shift of arable area to more arid climate zone. Negative impacts on citrus, olive, apple and sugar beet production.[25]	Windstorms (1992), floods	49	1,189	114
Libya	Recurring droughts and dependence on rainfed agriculture. Possible desertification of Jifara Plain in northwest.[26]	None	97	106	88
Malta	Shorter rainy season will decrease crop production.[27] Sea level rise vulnerability index=507	None	0	128	33
Mauritania	Decreased water resources. Dependence on water originating outside border. Degradation of arable land. Degradation of pasture and loss of livestock.[28]	Drought (1980), floods	98	3,826	15

(continued)

(continued)

Country	Vulnerable sectors and possible impacts of climate change	Common climate-related disasters[1]	% of total population under desertification risk[2] 1997	Total actual renewable water resources per capita (m^3/inhab/year)[3]	% of potential arable land actually in use[4] 1997	Projected % change in agricultural production capacity for 2070–2099 with respect to 1961–1990 baseline[5]
Morocco	Ouergha watershed will likely see changes in runoff.[29] Sea level rise vulnerability index = 0.24	Drought (1999), floods	80	934	76	−30
Oman	Seawater intrusion into freshwater aquifers[30] Storm surges affect coastal oil production.[31] Decreasing groundwater level.	Windstorms (2007)	0	336	6,300	
Pakistan	Changes in growing season length affect wheat production. Decreased wheat yield projection is possible.[32] Glacier extent affects Indus River basin.[33] Glaciers in Himalayas will recede.[34]	Floods (1992), drought, windstorms	99	1,415	392	−20
Qatar	Increasing water stress. Storm surges affect coastal oil production.[35]	N.A.	0	86	800	
Saudi Arabia	Water stress will increase due to warmer temperature.[36]	Floods (2003), windstorms	0	96	380,000	−10
Somalia	Food shortage may worsen under warmer temperature and extreme weather events.	Floods (1997), drought, ocean surges	96	1,377	43	

Sudan	Decreased precipitation and increased temperature and evaporation will lead to reduced groundwater recharge. Water stress will increase. Dependence on water originating outside border. Projected decrease of millet and sorghum.[37]	Drought (1991), floods	86 Desertification of arable areas, arable zone shifts southward.	1,879	15	−50
Syria	Possible impacts on Tigris-Euphrates stream flow.[38] Increasing irrigation demand.[39]	Drought (1999), floods, windstorms, land slides	79	1,441	98	−16
Tajikistan	Hydropower generation could be affected.[40] Decrease of glaciers and ice cover. Changing temperature and rainfall pattern could negatively affect agriculture.[41]	Floods (2004)	90	2,537	45	
Tunisia	Mediterranean coastline vulnerable to sea level rise. Increased water stress.[42]	Floods (1979), drought	38	459	150	
Turkey	Decreasing stream flow continues in western basins.[43] Possible impacts on Tigris-Euphrates stream flow.[44]	Flood (1998)	70	2,953	110	−4
Turkmenistan	Increase water requirement for cotton and wheat, Reducing glacier threatens river water availability.[45]	Flood (1993)	77	5,004	195	

(continued)

(continued)

Country	Vulnerable sectors and possible impacts of climate change	Common climate-related disasters[1]	% of total population under desertification risk[2] 1997	Total actual renewable water resources per capita (m^3/inhab/year)[3]	% of potential arable land actually in use[4] 1997	Projected % change in agricultural production capacity for 2070–2099 with respect to 1961–1990 baseline[5]
UAE	Seawater intrusion into freshwater aquifers[46] Storm surges affect coastal oil production.[47]	None	0	49	3,900	
Uzbekistan	High temperatures and water deficit may have negative impact on crops and pasture vegetation productivity, and livestock.[48] Rainfall increase may lead to occurrence of flash floods. Reduction in snow and ice reserves reduces water availability.[49]	Floods (2005), Landslides	88	1,904	104	1
Yemen	Risk of desertification. Increasing irrigation demand.[50]	Floods (1982), drought	100	198	30,900	–17

References

Cline W (2007) Global warming and agriculture: impact estimates by country. Center for Global Development. Peterson Institute for International Economics, Washington, DC

FAO (1999) Insurance of crops in developing countries. Commodities and trade division. FAO, Rome

FAO (2002) Crops and drops: making the best use of water for agriculture. FAO, Rome, p 22

FAO (2008) Climate change: implications for agriculture in the near east, NERC/08/INF/5, Regional conference, Cairo, 1–5 Mar 2008

FAO (2009) World summit on food security. FAO, Rome

Fleischhauer E (2000) Address on behalf of the UNCCD. In: Proceedings of the central and Eastern European workshop on drought mitigation, Budapest, 12–15 Apr 2000, pp 11–16

Hamdallah G (2000). Soil fertility management: the need for new concepts in the region. In: Proceedings of the FAO regional workshop on soil fertility management through farmer field schools in the near east, Amman, 2–5 Oct 2000

IPCC (2007) Climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds). Cambridge University Press, Cambridge, UK

Wilhite D (2002). Building institutional capacity to cope with drought: moving from crisis to risk management. FAO regional workshop on capacity building on drought mitigation in the near east. Rabat, 1–5 Nov 2002

World Bank, FAO, IFAD (2009) Improving food prices in the Arab countries. The World Bank, Washington, DC

Zehni M (2011) Towards a regional strategy for the conservation of plant genetic resources in West Asia and North Africa (WANA). Presented on behalf of AARINENA at the international conference on adaptation to climate change and food security in WANA region, Kuwait, 13–16 Nov 2011

Chapter 22
Adaptation Strategies for Different Sectors in the WANA Region: Summary of Breakout Group Discussions

Mannava V.K. Sivakumar, Faisal Awawdeh, Nasri Haddad, Ibrahim Hamdan, Mark Holderness, Rattan Lal, Ibrahim Ortas, and Ramasamy Selvaraju

Abstract To develop informed decisions on practical adaptation strategies in the WANA region, breakout groups were constituted for four different sectors: Crops; Livestock, Grasslands and Rangelands; Land Use, Forestry, Fisheries and Aquaculture; and Institutions, Policy and Cooperation. Summaries of the discussions in the different breakout groups are presented in this chapter.

M.V.K. Sivakumar (✉)
Climate Prediction and Adaptation Branch, World Meteorological Organization (WMO), 7bis, Avenue de la Paix, 1211 Geneva 2, Switzerland
e-mail: msivakumar@wmo.int

F. Awawdeh
National Center for Agricultural Research and Extension (NCARE), Baqaa, Jordan

N. Haddad
International Center for Agricultural Research in the Dry Areas (ICARDA), P. O. Box 950764, 11195 Amman, Jordan

I. Hamdan
Association of Agricultural Research Institutions in the Near East and North Africa (AARINENA), c/o ICARDA, P.O. Box 851758, 11185 Amman, Jordan

M. Holderness
Global Forum on Agricultural Research, FAO/NRRD, Rome, Italy

R. Lal
Carbon Management and Sequestration Center, School of Environment and Natural Resources, The Ohio State University, 2021 Coffey Road, 422B Kottman Hall, Columbus, OH 43210, USA

I. Ortas
Department of Soil Science and Plant Nutrition, Faculty of Agriculture, University of Cukurova, Adana, Turkey

R. Selvaraju
Climate, Energy and Tenure Division (NRC), Food and Agriculture Organization of the United Nations (FAO), Viale delle Terme di Caracalla, Rome 00153, Italy

M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_22,

Keywords Crops • Livestock, Grasslands and Rangelands • Land Use, Forestry, Fisheries and Aquaculture • Institutions, Policy and Cooperation

22.1 Introduction

To develop informed decisions on practical adaptation strategies in the WANA region, breakout groups were constituted for four different sectors: Crops; Livestock, Grasslands and Rangelands; Land Use, Forestry, Fisheries and Aquaculture; and Institutions, Policy and Cooperation. The main purpose of the discussions was to suggest the appropriate ways to promote adaptation planning and implementation and their integration into the sustainable development planning in different countries in the WANA region.

Summaries of the discussions in the different breakout groups are presented below.

22.2 Crops

22.2.1 Crop Production Management

Climate change will necessitate changes to the particular crops grown in specific areas in the region if production is to be maintained or enhanced where possible and resilience is to be enhanced. Germplasm characteristics will need to be more closely tailored to the new conditions and management practices will need to be reviewed and adjusted to extract the maximum benefit from the new conditions i.e. we will need to move to 'climate-smart agriculture'.

22.2.1.1 Crop Improvement

The region needs to capitalise on recent advances permitting fine-tuning of germplasm to the new conditions by the NARS and Advanced Research Institutions by:

(a) Improved crop tolerance to abiotic stresses (heat, salt, drought, etc.)
(b) Improved crop tolerance to biotic stresses (pests ,diseases)
(c) Utilisation of molecular breeding and other biotechnological techniques in crop breeding
(d) Taking advantage of existing genetic variability in land races of major crops through surveys organized by the regional system of genetic variability in relation to the stresses imposed by climate change. This must include capitalising on the indigenous knowledge of farming communities of the earlier performance of germplasm under climate shocks.
(e) Where possible integrating crop and livestock production to the benefit of both.

22.2.1.2 Crop Management Practices

(a) *Conservation agriculture*: can strengthen both mitigation and adaptation to climate change. It provides multiple benefits including lower production costs, higher yield, better soil structure, reduced erosion and better organic matter retention inc. carbon capture. The national agricultural research programmes need to ascertain in what crop production situations it can provide benefit.
(b) *Crop production practices*: National research systems must review and adapt agricultural management practices from land preparation to harvest to ensure adaption to climate change induced stresses.
(c) *Pest management:* revised control programmes are required to manage emerging pests and changes in distribution of trans-boundary pests. These may require new approaches for pest management and may need co-ordinated quarantine actions for emerging and spreading pest insects and disease.
(d) *Organic farming*: Organic Farming may offer significant benefits under climate change scenarios (reduced inputs reducing farmer financial risk and reduced greenhouse gas contributions) and its appropriate deployment in affected environments should be explored.

22.2.1.3 Diversification and Intensification of Production Systems

(a) *Diversification:* The NARS across the region must explore the possible enhanced potential for production system resilience through crop diversification (high value crops, water efficient crops, changes to cropping systems and rotations more suitable to the new conditions etc.)
(b) *Intensification*: The NARS must identify those cropping areas which might benefit from intensification (relay cropping, shorter crop rotations, short duration crops) which have the potential to create more rural jobs and enhance rural incomes.

22.2.2 Biodiversity Conservation and Utilization

Much of the diversity of crops, crop relatives and related wild plant species has already disappeared or is under threat from climate change. For conservation and practical utlisation reasons, what remains of this diversity must be maintained through:

(a) *In situ* collection of crop land races and their wild relatives which have survived in existing areas subject to abiotic stress intensification (saline soils, water deficiency etc.). These must be conserved *in-situ* in farmers field where possible or in the national gene banks and gene banks of international centers.
(b) Evaluation and multiplication of promising plant material should be undertaken on a regional network of testing sites through joint cooperation between the NARs and the specialized international research centers. The resulting characterized

material should be utilised in breeding programs to develop crop germplasm/varieties resistant to climate change impact.

22.3 Livestock, Grasslands and Rangelands

The constraints/challenges, the adaptation strategies to address these challenges, the benefits that can accrue from the implementation of these adaptation strategies and the policy interventions needed are presented in the Table 22.1.

Table 22.1 Constraints/challenges, the adaptation strategies to address these challenges, the benefits that can accrue from the implementation of these adaptation strategies and the policy interventions for Livestock, Grasslands and Rangelands

Constraints/Challenges	Adaptation strategies	Benefits of adaptation	Policy intervention
Feed scarcity both in quantity and quality, high cost of feeds Rangeland degradation, species disappearance Expansion of croplands	Improve crop-livestock integration (nutrient cycling) Herd management (herd splitting, culling, species diversification or substitution) Rehabilitate rangelands (water harvesting, grazing management, re-seeding) Use alternative feed resources (feed blocks, cactus, fodder trees)	Improves productivity, income, food security Prevents rural–urban migration Prevents overgrazing, land degradation and repeated crop failures	Policy to reduce number of animals Rangeland management policy (community participation, cross-border cooperation on grazing rights) Representing livestock keepers in policy dialogue Policies to limit inappropriate expansion Payment for ecosystem services
Animal health problems Vaccination coverage is very low Limited capacity in disease diagnosis Limited capacity in disease monitoring and surveillance Limited capacity in forecasting diseases and linking to CC	Improve vaccination coverage through improved vet capacity Improving capacity in disease diagnosis, disease monitoring and surveillance Creating sub-regional capacity in disease forecasting diseases and linking to CC	Improves productivity, income, food security Prevents loss of livestock assets, zoonosis, and rural–urban migration Prevents disease spread and loss of income due to trade restrictions Improves public health and welfare	Cross-border cooperation in the prevention of trans-boundary animal diseases ADs and zoonosis as per the OIE regulations

(continued)

Table 22.1 (continued)

Constraints/Challenges	Adaptation strategies	Benefits of adaptation	Policy intervention
Low productivity, adapted genetic resources	Designing national breeding programs, selective culling, conservation of adapted breeds (in-situ and ex-situ) Improve overall husbandry (feeding, health, housing, welfare) Livestock insurance scheme	Prevents loss of adapted genetic resources, allows ID and traceability Improves food production and system efficiency Improves market access (domestic and international)	Cross-border cooperation in livestock trade, transfer of animal genetic resources, knowledge, breeding programs, animal identification and traceability Policies that encourage local products that serve certain niche markets (branding)
Restriction of access to rangelands, pasture and water – conflict			Policies that allow animal movements, grazing rights and access to water Establishing local and regional conflict resolution mechanisms
Inappropriate policies, regulations, land use and tenure			Improve land use and land tenure policies
Limited market access Low price of animals	Use of producers groups Create market information system Capacity building in value addition to primary products	Improves income of producers Prevents rural–urban migration Contributes to conserving adapted breeds	Policies that encourage competitiveness of smallholders Policies that encourage local products that serve certain niche markets (branding)
Droughts, increased transhumance, increased livestock trade, TADs	Livestock insurance scheme based on index Conserve feeds, strengthen vet quarantine system	Keeps livestock keepers job; allows to feed animals during scarcity, prevents TADs	Establishing early warning systems
Urban and periurban system	Manure management	Reduces GHG emissions	Animal waste management policy

(continued)

Table 22.1 (continued)

Constraints/Challenges	Adaptation strategies	Benefits of adaptation	Policy intervention
Urban encroachment Animal waste management Contamination of soil and water Human health concerns, pollution Reducing land holding	Incentives for O fertilizer use, nutrient cycling Use quality feeds Selective culling of unproductive animals, improved herd health Minimize involuntary culling	Puts carbon back to soil and improves system productivity (crop yield and livestock productivity) Culling mediocre ones will release feed for fewer productive animals and hence reduces GHG emissions	Education in consumption behavior to help consumers to change from animal source foods to plant source foods

22.3.1 Human Dimension of Sustainable Livestock Development

(a) Aging population of livestock keeping families (foreign labor, lack of young replacement)
(b) Feminization of agriculture (women are more involved in livestock activities than men)
(c) Loss of knowledge on how to raise livestock
(d) Reducing number of people engaged in the sector
(e) Conflict for access to grazing rights and water
(f) Ring of poverty of smallholders around cities (urban and periurban areas) due to loss of assets (land, capital), soaring feed prices, and competition with large scale producers

22.3.2 Priority Areas of Action in the Different Sub-regions Over the Next 5–10 Years

(a) Rehabilitation of rangelands: research on mapping species-based vegetation coverage in the grasslands to identify the most beneficial species
(b) National breeding program for adapted animal genetic resources
(c) Cross-border cooperation in the prevention of trans-boundary animal diseases and zoonosis

(d) Livestock early warning systems and livestock insurance scheme
(e) Conflict resolution among pastoralists for access to natural resources, trade, etc. (e.g. Somalia, Sudan and Mauritania)
(f) Improving marketing within and between countries
(g) Conflict resolution through policies on land use to limit the effects of encroachment of urban and cropping land into livestock farms and grasslands
(h) Education in consumption behavior to help consumers to change from animal source foods to plant source foods

22.4 Land Use, Forestry, Fisheries and Aquaculture

22.4.1 Current Constraints and Challenges Faced in the WANA Region Exacerbated by Climate Change

(a) Lack of detailed soil and land use maps.
(b) Accuracy of soil, plant and climate data
(c) Lack of databases and accessibility to soil, water and forestry information
(d) Lack and mismanagement of policy information
(e) Capacity building
(f) Sharing of common resources of the region
(g) Predicting the change in land and forestry and consequences on climate change
(h) Land use out of agricultural use
(i) Land fragmentation
(j) Inappropriate water use techniques
(k) Forest fires
(l) Irrational fishing practices
(m) Tailoring of adaptation measures to the heterogeneous WANA region

22.4.2 Win–Win Options for Adaptation to Climate Change

(a) Protect environment to save biodiversity to reduce the effects on climate change
(b) Efficient use of water and land (forestry and fishery as well)
(c) Better management of soil and crop for increase organic matter to increase the yield
(d) Utilization of crop residues through biogas units to secure alternative energy sources for poor farmers.
(e) Appropriate agricultural operations (i.e., fertilizer use, other inputs, land use, and ecosystems management) can improve the crop yield.

(f) Use of municipal wastes as an organic material in depredated area can be important for soil quality and carbon sequestration.
(g) Contract farming
(h) Use of marginal water and organic sources in agriculture and forestry
(i) Use of byproducts of fishery as income generation source.
(j) Reforestation and protection of forests in the high rainfall zones
(k) Integrated watershed management
(l) The concept of a green box should be enhanced to reduce gas emission to atmosphere

22.4.3 Appropriate Policy Interventions Needed to Promote Implementation of the Identified Options for Adaptation to Climate Change

(a) Open access policy for information regarding land and water resources for adaptation to climate change at the national, international and scientific organization levels.
(b) Subsidize the farmers to increase their income for better adaptation and sustainable agriculture.
(c) Adopt new technologies in agriculture, forestry and aquaculture.
(d) New technology need for waste water as source of water and nutrients.
(e) Migrate from national to regional policy regarding environment protection.
(f) Promote awareness about climate change and adaptation and their relationship with soil and water use.
(g) Upgrading of educational curricula to include climate change and adaptation in the disciplines of soil and land use.
(h) Adoption of integrated watershed management.
(i) Long term monitoring of climate change and land use and the changes in plant and animal productivity

22.4.4 Identify Human Dimensions of Sustainable Development and Propose Ways to Effectively Address Them

(a) Strengthening gender equality in agriculture production and forestry.
(b) Improving infrastructure in rural areas.
(c) Training and education at community level to higher education.
(d) Promoting technical and financial incentives to increase environment protection at household level.
(e) Adopting sustainable practices for land and water use and for fishing and forestry.

22.4.5 *Priority Areas of Action in the Different Sub-regions of WANA for Next 5–10 Years*

(a) Land use policy needs to be coordinated at the national and regional level in the WANA region. Detailed soil maps should be prepared for each nation. Using soil maps, land and water use maps can be created to assess available resources and their capabilities under climate change. All inputs and adaptation techniques will be chosen according to land use and soil functions. Also land use maps are needed to assess the internal feedback mechanisms of climate change i.e., the impacts of land use on climate change in order to formulate adaptations. Soil and land maps can be used for planning around cities, green basket lands, and lands that are at the risk of degradation. Land use maps can be used in multiple layers of data for decision making.
(b) Establishment of national and regional databases on land, water and climate.
(c) Adoption of technology to increase output per unit area.
(d) Innovative technologies such as modern agriculture mechanization, soil and crop management, organic and chemical fertilizers, new variants of seed and biotechnology-nanotechnology should get priority for sustainable agriculture.
(e) Full utilization of GIS and geoinformation technology in Agriculture, Forestry, Fishery. The use of ICT in agriculture shall be highlighted as it has a major role in providing data needed for adaptation. This can help in monitoring the climate change indicators.
(f) Early protection and monitoring forest fire systems by using satellite technology
(g) Linking research with decision making (from science to policy-making).
(h) Empowerment of extension services from scientific discovery to farmers level.
(i) Enhancing on-farm research and involvement of the farmers as end users of research and technology.
(j) Stratification of adaptation measures according to agro-ecological zones in WANA region.
(k) Transboundary issues (fisheries, water, and other sources) should be organized at the regional levels.
(l) Agriculture, forestry and fisheries should receive support at the governmental level. The support should be focussed on improving production, improving soil quality, technology adoption and reducing soil degradation in terms of climate change.

22.5 Institutions, Policy and Cooperation

22.5.1 *Policy and Institutional Issues*

(a) Socioeconomic research component on climate change impact needs to be strengthened

(b) Scientific community is sending conflicting messages to policy makers (e.g. water use); Policy should focus on water sector upper/lower riparian water rights (e.g. Egypt), research and legislation issues
(c) Integrate climate change adaptation in community-based development plans
(d) Need to upgrade meteorological observation facilities and capacity for climate change modeling; need for institutional collaboration; developing appropriate networks for systematic measurements, climate observation and modeling.
(e) Include incentives and institutional support for payments for ecosystem services, mitigation
(f) Need new institutional setup for better coordination of climate change adaptation strategies; improve communication with policy makers.
(g) Develop policy mechanisms to link up/coordinate different ministries at national level; There should be a clear message on shared responsibility: Climate change issues are not the responsibility of one single ministry but a collective responsibility; not only at the federal government level but also at the local governance level.
(h) Integrate gender dimensions into agricultural development and climate change adaptation strategies
(i) Education and capacity development: include climate change early in the curricula
(j) At the national level, it is important to link climate change adaptation to other development issues important for policy makers (e.g. employment, water scarcity, etc.)
(k) At the regional level, there is a need for new collaborations for tackling common problems, e.g. dust/sand storms
(l) Combining research, capacity building, policy and communication
(m) Need for funding allocation in national budgets to ensure sustainability of initiatives on climate change adaptation and mitigation.

22.5.2 Priority Areas of Action in Policy and Institutional Issues

(a) Community of practice to follow up on important issues for climate change adaptation; institutional coordination with regional and international organizations and involve all partners in production value chain at the national level
(b) Address the food security argument while looking carefully at the sustainability of natural resources, water issues, etc.
(c) Cost of inaction is high, hence consider options for payment of ecosystem services
(d) Bring climate change adaptation to the community level – local implication of policies not just at national level; focus on most vulnerable communities.
(e) Consider scenarios and implications

Part VII
Conference Declaration

Chapter 23
International Conference on Adaptation to Climate Change and Food Security in West Asia and North Africa

Kuwait Declaration

Kuwait City, 13–16 November 2011

The International Conference on Adaptation to Climate Change and Food Security in West Asia and North Africa (WANA) was held at the Kuwait Institute of Scientific Research (KISR) from 13 to 16 November 2011. It was jointly sponsored by the World Meteorological Organization (WMO), the Association of Agricultural Research Institutions in the Near East and North Africa (AARINENA), the Food and Agriculture Organization (FAO) of the United Nations, the International Center for Agricultural Research in the Dry Areas (ICARDA), the Global Forum for Agricultural Research (GFAR), the Ohio State University, the Kuwait Institute for Scientific Research, the Meteorological Department of the State of Kuwait and the European Union. The Conference was attended by around 80 participants from 18 countries and nine international and regional organizations and institutions.

The participants expressed their deep concern at the implications of climate change for food security and the sustainability of productive systems in the region. The participants welcomed the initiative taken by the organizers in addressing these important issues and thanked His Highness Sheikh Sabah Al-Ahmed Al-Jaber Al-Sabah, The Amir of the State of Kuwait for his patronage of the Conference and the Kuwait Institute of Scientific Research for hosting the Conference and for providing all the necessary facilities.

Agriculture is the primary source of livelihoods and revenue for the majority of the population in many countries in the WANA region and over 70 % of the poor in WANA live in rural areas. Cereal yields in the WANA region are currently half the world average and all countries in the region are net importers of food. Over 70 % of the land area is rangelands and traditional livestock provide the major support for livelihoods. Increasing human population in the region is placing greater pressure on natural resources and expansion of cultivated land is leading to a decrease in pasturelands and forests leading to land degradation and desertification which are being exacerbated due to increased livestock population. WANA is one of the most water scarce regions in the world with 1,100 m^3/capita water availability which is

M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_23,

12 % of the global average and water overuse or misuse is exacerbating environmental degradation.

Climate change has multi-dimensional impacts on agro-ecosystems in West Asia and North Africa, including increases in temperature, declines in renewable fresh water availability, sea level rise, salinity, increased frequency and intensity of extreme events (droughts and floods), and shifting of cropping zones and biomes. Vulnerability to climate change is exacerbated by widespread poverty, particularly in the rural areas where 34 % of the population lives below the poverty line. Climate change projections show a 2–3 °C rise in much of region by 2050 and a reduction of precipitation by 10–20 %, although with variable local changes.

Climate change will affect the four dimensions of food security: availability, accessibility, food utilization, food system stability. Crop productivity is projected to decrease over the WANA region due to reduced precipitation and increased frequency and intensity of droughts. Climate change directly affects the quality and quantity of the forage that can be produced in a given ecoregion and an overall productivity decline in livestock nomadic system is expected due to erratic rainfall and decline in the moisture regime. Climate change is projected to have adverse impacts on ecosystem functions and services due to disruptions in life-support processes.

The Conference identified several key recommendations, knowledge gaps, and opportunities for policy makers, researchers and extension systems, international organizations, and NGOs to implement programs designed to minimize short- and long-term vulnerability of the WANA region to climate change.

Principal recommendations are to:

- Integrate science, practices and policy by mainstreaming adaptation into existing projects and programs; initiate and strengthen cooperation among academic and research institutions, international organizations, and NGOs; and enhance coordination among relevant ministries and institutions at the local, national and regional levels to better understand how farmers, fishermen, foresters and herders, are coping with climate change for improving transfer of best practices;
- Enhance capacity building activities in the region and strengthen the climate, crop, livestock and fishery data collection capability, analysis and modeling through increased public and private investment in climate change adaptation; enhance capacity to access other available financial resources and develop social safety nets so that poor people could be given access to development programmes and insurance;
- Stimulate multi-disciplinary research on climate change and food security and develop innovative strategies that contribute to socio-economic sustainability of the production systems in fragile environments through promotion of effective risk management and risk reduction strategies;
- Strengthen regional cooperation and exchange of successful experiences among countries through the creation of a Network for Climate Change and Food Security in West Asia and North Africa;
- Develop innovative financial mechanisms to scale up technical and financial support for the adaptation efforts of the WANA countries;

- Examine alternative scenarios for the future food security in the region, implications of climate change impacts and the positive and negative implications of potential policy choices in this area; and
- Communicate and engage wider society in understanding the implications of climate change with communities becoming part of the adaptation solutions themselves.

The participants urge development partners and the private sector to fund the implementation of programs that reflect the recommendations outlined above that deal with the mitigation and adaptation to climate change while advancing food security in West Asia and North Africa.