Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change: Impact Assessment and Adaptation Options

Agriculture is one of the most climate-sensitive of all economic sectors. Moldova is one of the many countries where the majority of the rural population depends on agriculture—directly or indirectly—for their livelihood. The risks associated with climate change pose an immediate and fundamental problem in the country.

The study proposes a clear and comprehensive plan for aligning agricultural policies with climate change; developing the capabilities of key agricultural institutions; and making needed investments in infrastructure, support services, and on-farm improvements. Developing such a plan ideally involves a combination of quality quantitative analysis; consultation with key stakeholders, particularly farmers and local agricultural experts; and investments in both human and physical capital. The experience of Moldova, highlighted in this work, shows that it is possible to develop an initiative to meet these objectives, one that is comprehensive and empirically driven as well as consultative and quick to develop.

The approach of the study is predicated on strong country ownership and participation, and is defined by its emphasis on “win-win” or “no regrets” solutions to the multiple challenges posed by climate change for farmers in Moldova. The solutions are measures that increase resilience to future climate change, boost current productivity despite the greater climate variability already occurring, and limit greenhouse gas emissions—also known as “climate-smart agriculture.”

Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change: Impact Assessment and Adaptation Options applies this approach to Moldova with the goal of helping the country mainstream climate change adaptation into its agricultural policies, programs, and investments. The study projects impacts of climate change on agriculture across Moldova’s three agro-ecological zones through forecast variations in temperature and rainfall patterns so crucial to farming. It offers a map for navigating the risks and realizing the opportunities, outlined through a series of consultations with local farmers. A detailed explanation of the approach is provided for those who want to implement similar programs in other countries of Europe, Central Asia, and anywhere else in the world.

The study is one of four produced under the World Bank program “Reducing Vulnerability to Climate Change in European and Central Asian Agricultural Systems.” The other countries included in this series are Albania, the former Yugoslav Republic of Macedonia, and Uzbekistan. The results from the four studies are consolidated in the book Looking Beyond the Horizon: How Climate Change Impacts and Adaptation Responses Will Reshape Agriculture in Eastern Europe and Central Asia.

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Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change
Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change

*Impact Assessment and Adaptation Options*

William R. Sutton, Jitendra P. Srivastava, James E. Neumann, Ana Iglesias, and Brent B. Boehlert

THE WORLD BANK
Washington, D.C.
Contents

Preface xi
Acknowledgments xiii
About the Authors xv
Abbreviations xvii

Executive Summary 1
   Introduction 1
   Vulnerability of Moldova’s Agriculture to Climate Change 4
   Stakeholder Consultations 10
   Menu of Adaptation Options 12
   Options for National Policy and Institutional Capacity Building 13
   Options for Specific AEZs 14
   Note 17

Chapter 1  Current Conditions for Moldovan Agriculture and Climate 19
   The Agriculture Sector in Moldova 19
   Exposure of Moldova’s Agricultural Systems to Climate Change 23
   Moldova’s Current Adaptive Capacity 29
   A Framework for Evaluating Alternatives for Investments in Adaptation 34
   Structure of the Report 36
   Notes 36

Chapter 2  Design and Methodology 39
   Overview of Approach 39
   Climate Scenarios and Impact Assessment 41
   Development of Adaptation Menu 45
   Assessing Risks to Livestock 48
   Uncertainty and Sensitivity Analysis 49
   Notes 50
Chapter 3  Impacts of Climate Change on Agriculture in Moldova 51
Climate Impacts on Crops and Horticulture 52
Climate Impacts on Livestock 54
Climate Impacts on Water Resources 55
Effect of Irrigation Water Shortages on Crop Yields 64
Notes 66

Chapter 4  Identification of Adaptation Options for Managing Risk to Moldova’s Agricultural Systems 67
Options for Consideration 67
Recommendations from Farmers 70
Prioritized Options from the World Bank Team 73
Greenhouse Gas Mitigation Potential of Adaptation Options 74

Chapter 5  Cost-Benefit Analysis 79
Scope and Key Parameters 79
Results of Quantitative Analyses—Cost-Benefit Assessments 81
Other Economic Analyses 88
Sensitivity Analyses 95
Analysis of Livestock Sector Adaptation 96
Summary of Quantitative Results in AEZs 97
Notes 101

Chapter 6  Options to Improve Climate Resilience of Moldova’s Agricultural Sector 103
Options at the National Level 103
Options at the AEZ Level 106
Categorization of Short-, Medium-, and Long-Term Options 112
Note 114

Glossary 115
Bibliography 123

Boxes
1.1 Developing a Range of Climate Scenarios 24
1.2 Adaptive Capacity Assessment from Farmer Consultations 32
2.1 Impact Assessment Modeling Tools 44
4.1 Index-Based Insurance 75
Contents

Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change

http://dx.doi.org/10.1596/978-1-4648-0045-0

Figures

ES.1 Effect of Climate Change on Average Monthly Temperature for the Southern AEZ (Cahul), 2040s 8
ES.2 Effect of Climate Change on Average Monthly Precipitation for the Southern AEZ (Cahul), 2040s 8
ES.3 Estimated Effect of Climate Change on Mean Monthly Runoff, 2040s 9
ES.4 Adaptation Measures at the National Level 15
ES.5 Adaptation Measures for the Northern AEZ 15
ES.6 Adaptation Measures for the Central AEZ 16
ES.7 Adaptation Measures for the Southern AEZ 16
1.1 Area Planted by Crop in Moldova, 2000–09 21
1.2 Estimated Value of Agricultural Production in 2005–07 at Sales Prices for Crops in Moldova 22
1.3 Effect of Climate Change on Average Monthly Temperature for the Southern AEZ (Cahul), 2040s 27
1.4 Effect of Climate Change on Average Monthly Precipitation for the Southern AEZ (Cahul), 2040s 27
1.5 Wheat Yield in Selected Relevant Countries, Average 2007–09 33
1.6 Grape Fresh Yield in Selected Relevant Countries, Average 2007–09 34
2.1 Flow of Major Study Action Steps 40
2.2 Analytic Steps in Action 3: Quantitative Modeling of Adaptation Options 43
3.1 Mean Monthly Irrigation Water Demand over All Moldovan Basins, 2040s 57
3.2 Estimated Climate Change Effect on Mean Monthly Runoff for All Moldovan Basins 58
3.3 Mean Monthly Storage in the Dubasari Reservoir in the Base Year (2010s) and Baseline (2040s) and for the Three Climate Scenarios (2040s) 62
3.4 Reduction in Monthly Reservoir Volume, 2010s and 2040s 63
5.1 Estimated Crop Revenues per Hectare for the 2040–50 Decade before Adaptation Actions Are Taken 81
5.2 Cost-Benefit Analysis for Newly Irrigated Crops in the Central AEZ 82
5.3 Cost-Benefit Analysis for Rehabilitated Irrigation Infrastructure for Crops in the Central AEZ 83
5.4 Cost-Benefit Analysis for Improved Water Use Efficiency in the Central AEZ 84
5.5 Cost-Benefit Analysis for Improved Drainage in the Central AEZ through New Drainage Infrastructure 85
5.6 Cost-Benefit Analysis for Improved Drainage in the Central AEZ through Rehabilitated Drainage Infrastructure 86

Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change
http://dx.doi.org/10.1596/978-1-4648-0045-0
5.7 Cost-Benefit Analysis for Optimizing Crop Varieties in the Central AEZ
5.8 Cost-Benefit Analysis for Optimized Fertilizer Use in the Central AEZ
5.9 Net Present Value for Hail Nets to Protect Selected Crops in the Central AEZ
5.10 Impact of Improving Basin-Wide Irrigation Efficiency
5.11 Preliminary Analysis of the Benefits and Costs of Water Storage in the Reut Basin
5.12 Detailed Sensitivity Analyses: Optimized Varieties for Irrigated Maize in the Central AEZ
5.13 Detailed Sensitivity Analyses: Optimized Varieties for Rainfed Maize in the Central AEZ
6.1 Adaptation Measures at the National Level Based on Team and National Conference Assessment
6.2 Adaptation Measures for the Northern AEZ Based on Team and National Conference Assessment
6.3 Adaptation Measures for the Central AEZ Based on Team and National Conference Assessment
6.4 Adaptation Measures for the Southern AEZ Based on Team and National Conference Assessment

Maps
ES.1 Effect of Climate Change on Temperature through 2040s for the Three Climate Impact Scenarios 6
ES.2 Effect of Climate Change on Precipitation through 2040s for the Three Climate Impact Scenarios 7
1.1 Agro-Ecological Zones in Moldova 20
1.2 Effect of Climate Change on Temperature through 2040s for the Three Climate Impact Scenarios 25
1.3 Effect of Climate Change on Precipitation through 2040s for the Three Climate Impact Scenarios 26
3.1 River Basins in Moldova 55
3.2 Irrigated Areas in Moldova 56
3.3 Mean Percentage Change in Runoff, 2040s Relative to the Historical Baseline 59

Tables
ES.1 Key Climate Hazards, Impacts, and Adaptation Measures at the National and AEZ Levels 5
ES.2 Effect of Climate Change on Crop Yield 2040–50 Relative to Current Yields under Medium-Impact Scenario, No Irrigation Water Constraints and without New Adaptation Measures 9
Contents

ES.3 Effect of Climate Change on Forecast Annual Irrigation Water Shortfall by Basin and Climate Scenario 10

ES.4 Effect of Climate Change on Crop Yield 2040–50 Relative to Current Yields for Irrigated Crops, Including Effects of Reduced Water Availability 11

1.1 Value of Agricultural Products in Moldova, 2008 21

1.2 Livestock Count by Agro-Ecological Zone 22

2.1 Approach for Two Quantifiable Farm-Level Adaptation Options 47

3.1 Effect of Climate Change on Crop Yield 2040–50 Relative to Current Yields under Medium-Impact Scenario, No Irrigation Water Constraints and without New Adaptation Measures 52

3.2 Effect of Climate Change on Crop Yields through 2040s across the Three Climate Scenarios 53

3.3 Irrigation Water Requirement Changes Relative to the Current Situation to 2040s under the Three Climate Scenarios, for Each Crop and AEZ (Assuming No CO₂ Fertilization) 54

3.4 Effect of Climate Change on Forecast Annual Irrigation Water Shortfall by Basin and Climate Scenario 61

3.5 FAO Crop Response Factors 65

3.6 Effect of Climate Change on Crop Yield 2040–50 Relative to Current Yields for Irrigated Crops, Including Effects of Reduced Water Availability 65

4.1 Adaptation Options for Consideration 68

4.2 Greenhouse Gas Mitigation Potential of Adaptation Options 76

5.1 Adaptation Measures with High Net Benefits: Northern AEZ 98

5.2 Adaptation Measures with High Net Benefits: Central AEZ 99

5.3 Adaptation Measures with High Net Benefits: Southern AEZ 100

6.1 Recommended Adaptation Options at the National Level 105

6.2 Adaptation Options for the Northern AEZ 107

6.3 Adaptation Options for the Central AEZ 110

6.4 Adaptation Options for the Southern AEZ 111
Changes in climate and their impact on agricultural systems and rural economies are already evident throughout Europe and Central Asia (ECA). Adaptation measures now in use in Moldova, largely piecemeal efforts, will be insufficient to prevent impacts on agricultural production over the coming decades. There is growing interest at country and development partner levels to have a better understanding of the exposure, sensitivities, and impacts of climate change at farm level, and to develop and prioritize adaptation measures to mitigate the adverse consequences.

Beginning in 2009 the World Bank embarked on the Regional Program on Reducing Vulnerability to Climate Change in ECA Agricultural Systems for selected ECA client countries to enhance the ability of these countries to mainstream climate change adaptation into agricultural policies, programs, and investments. The multi-stage program has included activities to raise awareness of the threat, analyze potential impacts and adaptation responses, and build capacity among client country stakeholders and ECA Bank staff with respect to climate change and the agricultural sector. This report is the culmination of efforts by the Moldovan institutions and researchers, the World Bank, and a team of international experts headed by the consulting firm Industrial Economics, Inc. (IEc) to jointly undertake an analytical study, Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change.

The approach of this volume is predicated on strong country ownership and participation, and is defined by its emphasis on “win-win” or “no regrets” solutions to the multiple challenges posed by climate change for the farmers of Eastern Europe and Central Asia. The solutions are measures that increase resilience to future climate change, boost current productivity despite the greater climate variability already occurring, and limit greenhouse gas emissions—also known as “climate-smart agriculture.”

Specifically, this report provides a menu of climate change adaptation options for the agriculture and water resources sectors, along with specific recommendations that are tailored to three distinct agro-ecological zones (AEZs) within Moldova. This menu reflects the results of three inter-related activities, conducted jointly by the team and local partners: (1) quantitative economic modeling of baseline conditions and the effects of climate change and an array of adaptation
options; (2) qualitative analysis conducted by the expert team of agronomists, crop modelers, and water resources experts; and (3) input from a series of participatory workshops for national decision makers and farmers in each of the AEZs. This report provides a summary of the methods, data, results, and adaptation options for each of these activities.

This study is part of the World Bank’s ECA Regional Analytical and Advisory Activities (AAA) Program on Reducing Vulnerability to Climate Change in ECA Agricultural Systems. Moldova is one of four countries to participate in the program, with the other country participants being Albania, the former Yugoslav Republic of Macedonia, and Uzbekistan. A book, *Looking Beyond the Horizon: How Climate Change Impacts and Adaptation Responses Will Reshape Agriculture in Eastern Europe and Central Asia*, covering all four countries was published in April 2013 (the book can be found at http://dx.doi.org/10.1596/978-0-8213-9768-8). The book also contains a technical appendix with details on the methodologies applied.
Acknowledgments

This book was written by a team led by William R. Sutton when he was in the Sustainable Development Department in the Europe and Central Asia Region of the World Bank, together with Jitendra P. Srivastava, and in collaboration with a team from Industrial Economics, Inc. (IEc) comprising James E. Neumann, Ana Iglesias, and Brent B. Boehlert. We are grateful to Dina Umali-Deininger, Sector Manager, Agriculture and Rural Development, Sustainable Development Department, Europe and Central Asia Region, for the valuable support and guidance, and to Ron Hoffer (ECSSD) for his constructive suggestions. We would like to thank the Country Director, Ukraine/Belarus/Moldova Country Unit, and the Country Manager for Moldova for their support in furthering the agenda on climate change and agriculture.

Members of the IEc team also include Kenneth M. Strzepske, Peter Droogers, Samuel Fankhauser, Andrew Schwarz, Richard Adams, Johannes Hunink, Sonia Quiroga, Richard Swanson, Silvia Pana-Carp, and Anatol Fala. The World Bank team also comprised Ana Bucher, Åsa Giertz, Gretel Gambarelli, Anatol Gobjila, Sunanda Kishore, Brendan Lynch, John Mackedon, and Tamara Ursu.

From the government of Moldova, we are grateful for policy guidance and support provided by the Ministry of Agriculture and Food Industry (MAFI) and the Ministry of Environment, to the study steering committee, co-chaired by Mr. Vasile Bumacov of MAFI, and Mr. Corneliu Marza of the Ministry of Environment, and without whom this study would not have been possible. Other members of the steering committee or other key institutions included representatives from the State Hydrometeorological Service, the Field Crops Institute Selectia, the Plant Protection Institute, the Pomiculture and Viticulture Institute, the Soils Institute, and Apele Moldovei, all of whom also generously provided data and insights to support the study. The study greatly benefitted from the important contributions made through valuable inputs, comments, advice, and support provided by academia, civil society and NGOs, farmers, the donor community, and development partners in Moldova throughout this program.

We gratefully acknowledge the Bank-Netherlands Partnership Program (BNPP) and the Trust Fund for Environmentally and Socially Sustainable Development (TFESSD) for providing funding for the program.
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### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>AAA</td>
<td>Analytical and Advisory Activities Program</td>
</tr>
<tr>
<td>AEZ</td>
<td>agro-ecological zone</td>
</tr>
<tr>
<td>B-C ratio</td>
<td>benefit-cost ratio</td>
</tr>
<tr>
<td>CMI</td>
<td>Climate Moisture Index</td>
</tr>
<tr>
<td>DSSAT</td>
<td>Decision Support System for Agrotechnology Transfer</td>
</tr>
<tr>
<td>ECA</td>
<td>Europe and Central Asia</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agriculture Organization of the United Nations</td>
</tr>
<tr>
<td>GCM</td>
<td>global circulation model</td>
</tr>
<tr>
<td>GDP</td>
<td>gross domestic product</td>
</tr>
<tr>
<td>GIS</td>
<td>Global Information Systems</td>
</tr>
<tr>
<td>IFPRI</td>
<td>International Food Policy Research Institute</td>
</tr>
<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>MAFI</td>
<td>Ministry of Agriculture and Food Industry</td>
</tr>
<tr>
<td>MoE</td>
<td>Ministry of Environment</td>
</tr>
<tr>
<td>NPV</td>
<td>net present value</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>operations and maintenance</td>
</tr>
<tr>
<td>SHS</td>
<td>State Hydrometeorological Service</td>
</tr>
<tr>
<td>SPAM</td>
<td>Spatial Production Allocation Model</td>
</tr>
<tr>
<td>UNDP</td>
<td>United Nations Development Programme</td>
</tr>
<tr>
<td>WEAP</td>
<td>Water Evaluation and Planning System</td>
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Executive Summary

Introduction

Agricultural production is inextricably tied to climate, making agriculture one of the most climate-sensitive of all economic sectors. In countries such as Moldova, the risks of climate change for the agricultural sector are a particularly immediate and important problem because the majority of the rural population depends either directly or indirectly on agriculture for their livelihoods. The rural poor will be disproportionately affected because of their greater dependence on agriculture, their more limited ability to adapt, and the high share of income they spend on food. Climate impacts could therefore adversely affect food security and economic growth in vulnerable rural areas and undermine the progress that has been made in poverty reduction.

Recent flooding and drought events in Moldova have underscored these risks; although no single weather event can be directly tied to climate change, an increase in extreme temperature and rainfall events such as these is consistent with the best known science on the impacts of climate change.

The need to adapt to climate change in all sectors is on the agenda of national governments and development partners. International efforts to limit greenhouse gases and mitigate climate change now and in the future will not be sufficient to prevent the harmful effects of temperature increases, changes in precipitation, and increased frequency and severity of extreme weather events.

At the same time, climate change can also create opportunities, particularly in the agricultural sector. Increased temperatures can lengthen growing seasons, for example. Higher carbon dioxide (CO₂) concentrations can enhance plant growth, and in some areas, additional rainfall and availability of water resources can increase yields.

However, the risks of climate change cannot be effectively dealt with, nor the opportunities effectively exploited without a clear plan for adaptation, including steps to align agricultural policies with climate change, develop key agricultural institution capabilities, and make needed infrastructure and on-farm investments. Developing such a plan would ideally involve a combination of high-quality quantitative analysis and consultations with key stakeholders, particularly farmers, as well as in-country agricultural experts.
In order to be effective, a plan for adapting the sector to climate change must include investments to strengthen both human and physical capital. Many of these investments will also yield instant returns under current climate conditions, in terms of increased agricultural productivity and improved competitiveness of the agricultural sector. However, the capacity to adapt to changes in climate, both in mitigating risks and in taking advantage of those opportunities that climate change can create, is in part dependent on financial resources, and adaptive capacity is particularly low among small-holder farmers in Moldova. As a result, development partners will continue to have an important role in enhancing the adaptive capacity of the Moldovan agriculture sector.

Another important factor for Moldova’s development of an adaptation plan for agriculture is furthering Moldova’s work toward European Union (EU) accession. Moldova is a partner under the Eastern Partnership, which recently started as a venture of Member States of the EU and their Eastern European partners. Moldova has also already developed and is implementing a special EU-Moldova Action Plan in 2004 to guide economic, political, and institutional reforms as a first stage toward EU accession. Along with these needed reforms, the EU encourages specific action toward climate change preparedness and adaptation. As outlined in a 2009 EU White Paper on the topic, these actions could include systematic assessment of climate risks, development of outreach initiatives to train farmers in such areas as improving water use efficiency, and identification of needs for financing of adaptation measures. These are some of the steps undertaken in this study.

These challenges motivated the World Bank and the government of Moldova to embark on a joint study to identify and prioritize options for adapting the agricultural sector to climate change.

The approach for this study was centered on four objectives:

• Raising awareness of the threat of climate change
• Analyzing potential impacts on the agricultural sector and assessing adaptive capacity
• Identifying practical adaptation responses and the potential for greenhouse gas emission reductions
• Building capacity among national and local stakeholders to assess the impacts of climate change and to develop adaptation measures in the agricultural sector, defined to encompass crop (including cereals, vegetables, fruits, and forage) and livestock production.

The work included awareness raising, stakeholder consultations, and rigorous impact analysis through modeling. The analysis has been conducted to provide results that are specific to three agro-ecological zones (AEZs) of Moldova, to key crops important to the Moldovan agricultural economy, and across a range of future climate change scenarios. The overall findings of the study are as follows:

• Temperature will increase and precipitation will become more variable in Moldova as a result of climate change. These findings are consistent with recent changes
Executive Summary

Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change

- **Farmers in Moldova are not suitably adapted to current climate.** This effect is sometimes called the “adaptation deficit,” which in Moldova is large. As a result, many of the climate adaptation measures recommended in this study can have immediate benefits in improving yields, as well as improving resiliency to future, more severe climate change.

- **The direct temperature and precipitation effect of future climate change on crops in Moldova will be to reduce most yields.** Climate change is forecast to reduce yields of wheat, maize, alfalfa, grapes, vegetables, and pasture. Apple yields are expected to remain relatively constant, with a slight decline for irrigated apples in the Southern AEZ. As noted below, reductions in available irrigation water can further reduce crop yields. However, in areas where irrigation water continues to be available, irrigation can lessen the negative effects of climate change as well as reduce yield variability. These findings were presented to Moldovan farmers who concurred that these effects are consistent with current trends and their experience.

- **Declining precipitation and increasing irrigation water demands mean that climate change could lead to increased competition for water resources, leaving a wide gap in unmet irrigation demands if no adaptation measures are implemented.** As Moldova grows, all water demands will increase, but climate change will also cause irrigation water demand to increase because of higher temperatures and lower precipitation. Specific water modeling for each AEZ and river basin suggests that, even without climate change, increases in non-agricultural demand for water will cause shortages in the next several decades. With climate change, the Reut basin in particular, but also the Upper and Lower Nistru basins, could see severe irrigation water shortages.

- **The direct effects of climate change on the livestock sector, particularly beef cattle, chickens, and even sheep, could be negative, but methods to reliably quantify this effect are not currently available for application to Moldova.** However, it is anticipated that the temperature-stress effect on livestock would be experienced gradually over time; farmers confirmed that they have not seen an immediate impact of climate change on their livestock production.

- **National-level adaptation and capacity building are high priorities.** Policy changes and institutional capacity improvements that could be undertaken immediately include: enhancing farmer access to new varieties, technology, and information through farmer education; improving dissemination of meteorology forecasts to farmers, especially for extreme events; investigating options for reforming crop insurance to decrease administration costs and improve affordability; and encouraging private sector involvement in efforts to adapt to climate change. Institutional capacity improvements should focus on identifying seeds for drought-tolerant varieties and temperature-tolerant livestock breeds on the current international market for adoption in Moldova, as well as training farmers in more efficient use of water and to make use of new.
weather forecast information. The World Bank’s analysis indicates these measures have high cost-benefit ratios, and are also favored by Moldovan farmers.

- **At the AEZ and farm levels, high-priority adaptation measures include:** on-farm water efficiency, rehabilitation of secondary irrigation infrastructure, and provision of more climate-resilient seed varieties together with information on cultivating them effectively for high yields (in all AEZs). All of these measures also have high benefit-cost ratios and are favored by Moldovan farmers.

Table ES.1 provides a summary of the key findings of this assessment, including the climate change impacts (incorporating assessments of sensitivity, adaptive capacity, and vulnerability), climate hazards that cause those impacts, and the adaptation options to address the impacts at both the national and AEZ levels. A check mark indicates that the corresponding adaptation option will either reduce the climate change impact directly or will do so indirectly by closing the adaptation deficit.

**Vulnerability of Moldova’s Agriculture to Climate Change**

Overall, Moldova has dry and mild winters with little snow, and warm summers beginning with intense periods of rainfall followed by lengthy dry periods. Analysis of recent climate data and information gathered from farmer workshops both support an increasing trend in temperature in Moldova. Farmers also have observed an increasing trend in extreme heat events. The analysis undertaken in this study indicates that this trend will accelerate in Moldova in the near future, as shown in map ES.1. Although there remains uncertainty as to the degree of warming that will occur in Moldova, the overall warming trend is clear and is evident in all three AEZs, with average warming over the next four decades of over 2°C. This can be compared with the increase of less than 0.6°C observed over the last 50 years.

Precipitation changes are much more uncertain than temperature changes, as indicated in map ES.2. The medium-impact forecast indicates a decline in precipitation nationally of about 5 millimeters per month. The range of outcomes across the low- and high-impact alternative scenarios is consistent with a drop in precipitation by the 2040s, but the decadal pattern of forecast precipitation reflects uncertainty in the modeling of climate over the next four decades. Uncertainty at the AEZ level is even higher, and annual precipitation declines could be as large as 9.9 millimeters per month, with all AEZs significantly affected.

The national averages, however, are less important for agricultural production than the seasonal distribution of temperature and precipitation. Temperature increases are likely to be higher and precipitation declines greater in July and August relative to current conditions, and the summer temperature increase could be as much as 7°C in the Southern AEZ of Moldova. In addition, forecast precipitation declines are greatest in the June-to-September period. Figures ES.1 and ES.2 present the monthly baseline and forecast temperatures and precipitation for the Southern AEZ.

These seasonal changes in climate have clear implications for crop production, if no adaptation measures are adopted beyond those that farmers already employ...
Table ES.1 Key Climate Hazards, Impacts, and Adaptation Measures at the National and AEZ Levels

<table>
<thead>
<tr>
<th>Climate change impact</th>
<th>Cause of impact (exposure)</th>
<th>Adaptation measure to address impact</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>National level</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improve farmer access to technologies and information</td>
</tr>
<tr>
<td>Reduce crop yield</td>
<td>Higher temperatures</td>
<td>✓</td>
</tr>
<tr>
<td>reductions</td>
<td>Increased pests</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>and diseases</td>
<td>✓</td>
</tr>
<tr>
<td>Reduce crop yield</td>
<td>Lower and/or</td>
<td>✓</td>
</tr>
<tr>
<td>reductions</td>
<td>more variable precipitation</td>
<td>✓</td>
</tr>
<tr>
<td>Reduce crop yields</td>
<td>Decreased river runoff</td>
<td>✓</td>
</tr>
<tr>
<td>reductions</td>
<td>and increased crop</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>water demands</td>
<td>✓</td>
</tr>
<tr>
<td>Reduce crop quality</td>
<td>Change in growing season</td>
<td>✓</td>
</tr>
<tr>
<td>reductions</td>
<td>Increased pests</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>and diseases</td>
<td>✓</td>
</tr>
<tr>
<td>Reduce livestock</td>
<td>Higher temperatures</td>
<td>✓</td>
</tr>
<tr>
<td>productivity declines</td>
<td>(direct effect)</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Reductions in forage</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>crop yields (indirect</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>effect)</td>
<td>✓</td>
</tr>
<tr>
<td>Increase crop damage</td>
<td>More frequent and severe</td>
<td>✓</td>
</tr>
<tr>
<td>occurs more frequently</td>
<td>hail events</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>More frequent and severe</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>drought events</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>More frequent and severe</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>flood events</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>More frequent and severe</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>high summer temperature</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>periods</td>
<td>✓</td>
</tr>
</tbody>
</table>
Executive Summary

Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change

http://dx.doi.org/10.1596/978-1-4648-0045-0

Average annual temperature for the Southern AEZ

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Decade</th>
<th>Base</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.75–10.50</td>
<td>Base</td>
<td>14.0</td>
<td>13.5</td>
<td>13.0</td>
<td>12.5</td>
</tr>
<tr>
<td>10.50–11.25</td>
<td>2010s</td>
<td>12.0</td>
<td>11.5</td>
<td>11.0</td>
<td>10.5</td>
</tr>
<tr>
<td>11.25–12.00</td>
<td>2020s</td>
<td>11.0</td>
<td>10.5</td>
<td>10.0</td>
<td>9.75</td>
</tr>
<tr>
<td>12.00–12.75</td>
<td>2030s</td>
<td>10.5</td>
<td>10.0</td>
<td>9.75</td>
<td>9.0</td>
</tr>
<tr>
<td>12.75–13.50</td>
<td>2040s</td>
<td>10.0</td>
<td>9.75</td>
<td>9.0</td>
<td>8.25</td>
</tr>
<tr>
<td>13.50–14.25</td>
<td></td>
<td>9.75</td>
<td>9.0</td>
<td>8.25</td>
<td>7.5</td>
</tr>
</tbody>
</table>

Map ES.1  Effect of Climate Change on Temperature through 2040s for the Three Climate Impact Scenarios

Climate impact scenarios, 2040s

(a. Baseline)

(b. Low impact)

(c. Medium impact)

(d. High impact)

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(such as changing planting dates in response to temperature changes). The results for climate change impacts to crops if no adaptation is implemented are summarized in table ES.2. These show that yields across all crops in Moldova’s agricultural sector (besides apples) will decrease under the medium-impact scenario, mainly as a result of heat and water stress.

Across AEZs under the medium-impact scenario, crop yields decline. Particularly severe declines can be seen for wheat and alfalfa. Apple yields on the other hand remain relatively consistent, with irrigated yields in the Southern AEZ and rainfed yields in the Northern and Central AEZ declining slightly, and rainfed yields in the Southern AEZ slightly increasing.

The water resource management implications of climate change should also be of great concern in Moldova, because climate change both increases irrigation water demand and decreases overall water supply in the country. For example, irrigation water demand increases by roughly 10–15 percent overall for all scenarios and all crops relative to historical conditions, and to a greater degree

Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change

http://dx.doi.org/10.1596/978-1-4648-0045-0
during the summer months. At the same time, overall water availability declines because of increased heat and lower summer precipitation, as illustrated in figure ES.3. For all three scenarios, the overall trend is that more water is required to maintain current yields, and that grapes, apples, and vegetables in particular will need substantially increased amounts of water. In addition, all Moldovan water basins across all scenarios show reduced mean runoff during the irrigation season. In the Reut basin in particular, river flows fall by over 60 percent in the high-impact scenarios relative to the historical baseline.

The net effect of falling water supply and rising irrigation demands, combined with the forecast for increased water demands from the municipal and industrial sectors due to overall economic growth, is a significant reduction in water available for irrigation. The forecast indicates that these factors could result in water shortages occurring within the next decade, with severe water shortages in the
Executive Summary

Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change

Figure ES.1 Effect of Climate Change on Average Monthly Temperature for the Southern AEZ (Cahul), 2040s

Figure ES.2 Effect of Climate Change on Average Monthly Precipitation for the Southern AEZ (Cahul), 2040s
Table ES.2 Effect of Climate Change on Crop Yield 2040–50 Relative to Current Yields under Medium-Impact Scenario, No Irrigation Water Constraints and without New Adaptation Measures

<table>
<thead>
<tr>
<th>Irrigated/rainfed</th>
<th>Crop</th>
<th>Northern</th>
<th>Central</th>
<th>Southern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigated</td>
<td>Maize</td>
<td>−8</td>
<td>−6</td>
<td>−9</td>
</tr>
<tr>
<td></td>
<td>Wheat</td>
<td>−14</td>
<td>−30</td>
<td>−34</td>
</tr>
<tr>
<td></td>
<td>Alfalfa</td>
<td>−7</td>
<td>−13</td>
<td>−18</td>
</tr>
<tr>
<td></td>
<td>Grapes</td>
<td>−4</td>
<td>−3</td>
<td>−5</td>
</tr>
<tr>
<td></td>
<td>Apples</td>
<td>0</td>
<td>0</td>
<td>−3</td>
</tr>
<tr>
<td></td>
<td>Vegetables</td>
<td>−5</td>
<td>−9</td>
<td>−13</td>
</tr>
<tr>
<td>Rainfed</td>
<td>Maize</td>
<td>−9</td>
<td>−3</td>
<td>−10</td>
</tr>
<tr>
<td></td>
<td>Wheat</td>
<td>−36</td>
<td>−38</td>
<td>−45</td>
</tr>
<tr>
<td></td>
<td>Pasture</td>
<td>−17</td>
<td>−22</td>
<td>−19</td>
</tr>
<tr>
<td></td>
<td>Alfalfa</td>
<td>−13</td>
<td>−18</td>
<td>−12</td>
</tr>
<tr>
<td></td>
<td>Grapes</td>
<td>−4</td>
<td>−3</td>
<td>−2</td>
</tr>
<tr>
<td></td>
<td>Apples</td>
<td>−2</td>
<td>−4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Vegetables</td>
<td>−9</td>
<td>−13</td>
<td>−9</td>
</tr>
</tbody>
</table>

Note: Results are average changes in crop yield, assuming no adaptation, no irrigation water constraints, and no effect of CO₂ fertilization, under a medium-impact scenario. Shading is darker the larger the decline in crop yield.

Figure ES.3 Estimated Effect of Climate Change on Mean Monthly Runoff, 2040s
Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change

Table ES.3 Effect of Climate Change on Forecast Annual Irrigation Water Shortfall by Basin and Climate Scenario

<table>
<thead>
<tr>
<th>Basin</th>
<th>Low impact 2040s</th>
<th>Medium impact 2040s</th>
<th>High impact 2040s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m³ thousands</td>
<td>% shortfall</td>
<td>m³ thousands</td>
</tr>
<tr>
<td>Lower Nistru</td>
<td>79</td>
<td>0.2</td>
<td>62</td>
</tr>
<tr>
<td>Reut</td>
<td>213</td>
<td>0.6</td>
<td>2,000</td>
</tr>
<tr>
<td>Upper Nistru</td>
<td>26</td>
<td>0.3</td>
<td>37</td>
</tr>
<tr>
<td>Kogilnic</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Prut</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>318</td>
<td>0.2</td>
<td>2,099</td>
</tr>
</tbody>
</table>

2040s under all climate scenarios, but especially under the high-impact scenario. Water shortfalls for the irrigation sector are outlined in table ES.3—the estimates presented are the amounts and percentage shortfalls relative to total water amounts demanded in the basin for irrigation purposes. The most severe irrigation water shortages by the 2040s are forecast to occur in the Reut basin, an area where irrigation is prevalent and most agricultural production is highly reliant on irrigation to maintain current yields. Shortages are also forecast for the Upper and Lower Nistru basins, though these are not likely to be as severe as in the Reut basin. No shortage of irrigation water is forecast for the Kogilnic and Prut basins.

Three climate change stressors therefore combine to yield an overall negative impact on crop yields throughout Moldova as follows:

1. The direct effect of temperature and precipitation changes
2. The increased demand for irrigation water even as yields decline
3. The fall in water supply associated with higher evaporation and lower rainfall.

All of these effects worsen during the summer growing season. The net effect of these three factors on irrigated agriculture is illustrated in table ES.4. The table shows that all crops in all AEZs and basins and across all scenarios are negatively affected by climate change.

The direct effects of climate change on livestock also could be severe, but the methods available for quantifying these are relatively untested. There is a robust body of literature establishing that temperature increases do lower livestock productivity, but modeling tools suitable for quantifying the effect in the Moldovan context are not available.

Stakeholder Consultations

Extensive stakeholder consultations with local government officials, farmers, and local experts were a critical guiding force for the study and, in particular, for the adaptation measure results. At these workshops, farmers confirmed that they had already experienced changed-climate effects, particularly drought, high
temperatures, frosts, and hail (which is a specific problem for orchards and vineyards), wider temperature fluctuations (including high summer and low winter temperatures), and wider variations in day and night temperatures. Farmers were already taking the following adaptive measures in response to climate change and severe climate events, such as:

- Expanding water supply for irrigation by building small-scale storage reservoirs, harvesting rainwater, and making greater use of local water sources for irrigation, such as creeks and groundwater
- Applying protective measures such as moving vegetable production to greenhouses, using mulch or other plant protection on soil, installing plant protection belts, or using hail nets
- Changing agronomic practices, such as planting patterns, crop rotation and inter-cropping, chemical soil augmentation, using drought-resistant varieties.

Farmers also identified a number of impediments to adaptation, including a lack of timely meteorological information to respond effectively; limited access

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Crop</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AEZ/river basin</td>
<td>Northern</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Upper Nistru</td>
</tr>
<tr>
<td>Low impact</td>
<td>Maize</td>
<td>−23</td>
</tr>
<tr>
<td></td>
<td>Wheat</td>
<td>−6</td>
</tr>
<tr>
<td></td>
<td>Alfalfa</td>
<td>−20</td>
</tr>
<tr>
<td></td>
<td>Grapes</td>
<td>−13</td>
</tr>
<tr>
<td></td>
<td>Apples</td>
<td>−7</td>
</tr>
<tr>
<td></td>
<td>Vegetables</td>
<td>−14</td>
</tr>
<tr>
<td>Medium impact</td>
<td>Maize</td>
<td>−13</td>
</tr>
<tr>
<td></td>
<td>Wheat</td>
<td>−19</td>
</tr>
<tr>
<td></td>
<td>Alfalfa</td>
<td>−12</td>
</tr>
<tr>
<td></td>
<td>Grapes</td>
<td>−9</td>
</tr>
<tr>
<td></td>
<td>Apples</td>
<td>−6</td>
</tr>
<tr>
<td></td>
<td>Vegetables</td>
<td>−10</td>
</tr>
<tr>
<td>High impact</td>
<td>Maize</td>
<td>−18</td>
</tr>
<tr>
<td></td>
<td>Wheat</td>
<td>−39</td>
</tr>
<tr>
<td></td>
<td>Alfalfa</td>
<td>−21</td>
</tr>
<tr>
<td></td>
<td>Grapes</td>
<td>−16</td>
</tr>
<tr>
<td></td>
<td>Apples</td>
<td>−18</td>
</tr>
<tr>
<td></td>
<td>Vegetables</td>
<td>−21</td>
</tr>
</tbody>
</table>

Note: Shading is darker the larger the decline in yield.
to alternative crop varieties (particularly seeds), and limited access to know-how through extension and other services to make the best use of these varieties; and poor or limited access to irrigation water and to technologies to make the most efficient use of irrigation infrastructure.

The adaptive capacity of farmers in Moldova is clearly stressed by changes in overall climate. The combination of heat waves, droughts, and intense storms is especially disruptive. On-farm adaptation responses have been numerous and partially successful, but farmers believe that larger investments in infrastructure are needed. This includes improved water storage, and better drainage and irrigation systems, which likely need to be effectively coupled with farmer training to make the best use of enhanced infrastructure. Although the findings in each AEZ differed somewhat, a set of themes emerged as priority measures to adopt to improve adaptive capacity in response to climate change impacts:

- **Rehabilitate irrigation infrastructure and enhance irrigation efficiency.** In all three AEZs, farmers recommended rehabilitating existing irrigation systems. Many farmers specifically mentioned drip irrigation as a technology that in their view has great potential to increase yields for Moldovan agriculture.

- **Build additional storage.** Both in the Northern and Central AEZs, farmers recommended constructing small-scale reservoirs to store runoff from the spring months for irrigation during the summer.

- **Increase farmers’ access to agronomic technology and know-how.** Many cited the need for information and equipment sharing mechanisms, demonstration plots, and farmer education forums to build adaptive capacity to both current and future climate change.

- **Apply moisture conservation techniques.** Farmers in the Northern and Southern AEZs ranked this as an important adaptation response, with a focus on conservation tillage, mulching and plastic covering, and intercropping.

- **Enhance the provision of meteorological information, particularly for extreme events.** Reaching smallholder farmers with the most relevant agricultural meteorological information remains a challenge in Moldova, even in areas where the hydrometeorological infrastructure and institutional capabilities are strong.

- **Improve market structure.** Farmers emphasized that better provision of information on agricultural market prices and trends would assist in making farms more productive and provide a win-win adaptive response.

**Menu of Adaptation Options**

The results of the quantitative crop and water resource modeling, the team’s qualitative analysis, and farmer consultations form the basis for the report’s recommendations for improving the resilience of Moldova’s agricultural sector to climate change. The results reflect four criteria for prioritizing options from among a large menu of 29 farm-level adaptation options, 14 infrastructure options, 13 programmatic options, and 4 indirect adaptation options. The four criteria for prioritizing options are:
Executive Summary

Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change

http://dx.doi.org/10.1596/978-1-4648-0045-0

- Net economic benefits (quantified benefits minus costs)
- Expert assessment of ranking for those options that cannot be evaluated in economic terms
- “Win-win” potential, defined as measures with a high potential for increasing the welfare of Moldovan farmers, with or without climate change
- Favorable evaluation by the local farming community, based on the results of the first and second stakeholder consultations.

Adaptation options were evaluated based on their potential to increase resilience to climate change, using the above-stated evaluative criteria. Some options, if adopted, could potentially yield benefits in the form of greenhouse gas mitigation. In particular, measures such as soil conservation (which can enhance the retention of carbon in the soil) and optimization of agronomic practices (which can reduce energy and fertilizer use) could yield greenhouse gas mitigation as well as climate change adaptation benefits. While it was not possible to quantitatively evaluate these benefits in a comprehensive manner, a qualitative analysis of the potential for recommended measures to yield greenhouse gas mitigation benefits is also included in this report.

Options for National Policy and Institutional Capacity Building

Four measures for adoption at the national level were identified based on the qualitative analysis of potential net benefits by the team, together with recommendations from farmer stakeholder and expert groups:

- Increase farmers’ access to technology and information through farmer education, both generally and on adapting to climate change. The expert team recommends that the capacity of the existing extension agency be improved in two areas: (1) better support for agronomic practices at the farm level, including implementation of more widespread demonstration plots and access to better information on the availability and best management practices of high-yield crop varieties, with a particular focus on drought- and pest-resistant varieties; and (2) support for the same measures but with a focus on maintaining yields during extreme water stress periods, which are likely to be more frequent with climate change. The first part of this recommendation is a short-term measure to close the adaptation deficit, and the second part is a long-term measure to ensure that yield gains are not undermined by future climate change. Investing in extension had a high cost-benefit ratio in the quantitative analysis. Building better links between research and on-farm outcomes is also a part of this measure.

- Improve the dissemination of hydrometeorological information to farmers. In every farmer meeting, participants noted a need for better weather information, especially for improved warnings on extreme events. The current lead hydrometeorological institution in Moldova is a capable organization that has access to good equipment; however, it may require additional training and funding to better disseminate climatological information to farmers. Those capabilities are urgently needed to support better farm-level decision-making. Economic
analysis of a relatively modest hydrometeorological investment in areas such as training and annual operating costs suggests that the benefits of such a program would likely exceed costs.

- **Investigate options for crop insurance, particularly for drought.** The Moldovan Country Note published by the World Bank in 2009 notes that crop insurance, while presently available in Moldova, is not viable for the vast majority of agricultural producers. This conclusion was supported in the farmer workshops, although farmers remain eager to explore insurance options. The Country Note also suggests that one possible way to expand coverage could be through the piloting of a privately run, index-based weather insurance program. This approach has many potential advantages over traditional multiple-peril crop insurance, including simplification of the product, standardized claim payments to farmers in a district based on the index, avoidance of individual farmer field assessment, lower administrative costs, more timely claim payments after loss, and easier accommodation of small farmers within the program. The program may be particularly suitable for Moldova, where the institutional hydrometeorological capacity is relatively sophisticated and could support an index-based approach. The drawback of an index-based approach may be the inability to readily insure coverage of damage from pests. Overall, an effort is needed at the national level to fully investigate these options, because insurance systems need to be carefully designed to maintain incentives for farmers to continue to invest in drought damage mitigation and resilience measures such as improving their water use.

- **Encourage private sector measures that efficiently adapt to climate change.** There may be a tendency to assume that adaptation to climate change is necessarily a public sector function. But as the economic analysis conducted here has demonstrated, there is strong private sector incentive (with economic benefits greatly exceeding costs) for measures that will improve the resiliency of Moldovan agriculture to climate change. The national government should focus on putting in place policies that enable the private sector to effectively assist in adaptation. An example of such an arrangement would be to combine public sector testing of seed and livestock varieties, recommendations on the best varieties through extension services, and private sector provision of those varieties. In addition, farmers noted the need for better market information, including crop price information.

An overall set of adaptation measures at the national level were identified as indicated in figure ES.4, which links climate change hazards to impacts, and impacts to national-level adaptation options. Measures shaded in darker green represent options that were recommended by both the team’s assessment and the National Conference group.

**Options for Specific AEZs**

As summarized in figures ES.5 through ES.7, a number of options emerge from the quantitative, qualitative, farmer, and National Conference evaluations of measures as most advantageous for adapting to climate change in each Moldovan AEZ.
Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change

Figure ES.4  Adaptation Measures at the National Level

<table>
<thead>
<tr>
<th>Climate hazard</th>
<th>Impact</th>
<th>Adaptation</th>
</tr>
</thead>
</table>
| • Decreased and more variable precipitation  
  • Higher temperatures  
  • Reduced river runoff  
  • Increased frequency and severity of extreme events | Reduced, less certain, and lower quality crop and livestock yields | Encourage private sector involvement to improve agricultural productivity  
Implement national policy on development of market infrastructure  
Improve farmer access to technologies, crop varieties, and information  
Improve dissemination of hydromet information to farmers  
Extend farmers’ access to financial resources and create incentives to adapt  
Investigate options for crop insurance |

Figure ES.5  Adaptation Measures for the Northern AEZ

<table>
<thead>
<tr>
<th>Climate hazard</th>
<th>Impact</th>
<th>Adaptation</th>
</tr>
</thead>
</table>
| • Decreased and more variable precipitation  
  • Higher temperatures  
  • Reduced river runoff  
  • Increased frequency and severity of extreme events | Reduced, less certain, and lower quality crop and livestock yields | Improve livestock varieties, management, nutrition, and health  
Improve irrigation water quality  
Optimize agronomic inputs: fertilizer application and soil moisture conservation  
Improve irrigation water infrastructure and basin-wide efficiency  
Improve access to information and training  
Improve farm-level irrigation efficiency  
Improve crop varieties |
Executive Summary

Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change

http://dx.doi.org/10.1596/978-1-4648-0045-0

Improve livestock varieties, management, nutrition, and health
Optimize agronomic inputs: fertilizer application and soil moisture conservation
Rehabilitate irrigation capacity
Encourage farming systems based on compatibility of natural resources
Train on water use efficiency and moisture conservation
Rehabilitate and build new small-scale water storage
Improve farm-level irrigation efficiency
Improve crop varieties

Figure ES.6 Adaptation Measures for the Central AEZ

- Decreased and more variable precipitation
- Higher temperatures
- Reduced river runoff

- Increased frequency and severity of extreme events

Reduced, less certain, and lower quality crop and livestock yields
Crop failure

Figure ES.7 Adaptation Measures for the Southern AEZ

- Decreased and more variable precipitation
- Higher temperatures
- Reduced river runoff

- Increased frequency and severity of extreme events

Reduced, less certain, and lower quality crop and livestock yields
Crop failure

Climate hazard
Impact
Adaptation

High priority
Medium priority

Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change
http://dx.doi.org/10.1596/978-1-4648-0045-0
Note

1. For example, for their suitability for Moldovan climate, terrain, and soil conditions.
The Agriculture Sector in Moldova

Moldova is located in Eastern Europe and is landlocked. It has a surface area of 33,843 km² (UNDP 2009), and is bordered by Romania to the West, and Ukraine to the North, East, and South. Administratively, Moldova is divided into 32 districts, 3 municipalities, and 2 autonomous regions.

For the purposes of this study, Moldova is divided into three agro-ecological zones (AEZs), as shown in map 1.1. The area within each of these AEZs shares some of the same characteristics in terms of terrain, climate, soil type, and water availability. As a result, baseline agricultural conditions, climate change impacts, and adaptive options will be similar within each AEZ, with differences between AEZs that are important for developing specific adaptation plans.

The terrain of Moldova comprises primarily open and undulating plains with fertile chernozem soils and productive agricultural land. The country’s territory is 75 percent agricultural land and 13 percent forest (Ministry of Environment and Territorial Development 2000). The regions shown in map 1.1 reflect differences across the country. The lightest region is the Northern AEZ, which is a hilly zone with forests, steppe, and meadow vegetation. It has the most fertile soil with a high water holding capacity, which makes this zone the most suitable of the three zones for field crops. The medium shaded region is the Central AEZ, which is hilly and has deep valleys, has less fertile soil, and is best for perennial crops like orchards and vineyards. The darkest region is the Southern AEZ, which has steppe to meadow terrain with both highly fertile and not as fertile types of soils. Due to higher temperatures and lower rainfall, this zone has only marginal production in the absence of irrigation. Overall, the elevation of the country ranges from 5 to 429 meters above sea level, where elevation is mostly in central and northern Moldova (Ministry of Environment and Territorial Development 2000). The hilly terrain results in high rates of soil erosion, especially in the Northern and Central AEZs.
Recent Trends in Moldovan Agriculture

Agriculture has traditionally been the backbone of the Moldovan economy but the sector has been shrinking and growth has been outstripped by other sectors; agriculture’s contribution to gross domestic product (GDP) declined from 28 percent in 1999 to 11 percent in 2009 (World Bank 2010). However, Moldova is still an agrarian society, with the agriculture sector providing 32.8 percent of total employment in 2007 (World Bank 2009a). But with 90.8 percent of the rural population earning less than US$5 a day (World Bank 2009b), the vast majority of people are poor and highly vulnerable to any event that affects their crops. In 2007, natural hazards were estimated to cause annual losses of 3.5–7 percent of Moldova’s GDP—losses that were mostly in the agricultural sector (World Bank 2007).

The total value of agricultural production in 2008 was US$1.7 billion (National Bureau of Statistics 2009). As shown in table 1.1, more than half the value of production (67.6 percent) was in the plant sector, with the remainder in the animal production and services sector.

Although cereal field crops such as wheat and maize are grown extensively and occupy about 65 percent of the cropping land (see figure 1.1), their
contribution by value is comparable to that for grapes and apples, which garner a higher price. Trends within the field crop sector over the last decade indicate a slight decline in areas planted overall (see figure 1.1). The total crop area declined by 4.1 percent from 2000 to 2009. Many high-value vegetable crop areas declined significantly in this period while a few crop areas increased substantially, such as those devoted to soybean production (National Bureau of Statistics 2009).

Livestock has long been an important component of the Moldovan agricultural economy, though it is not very profitable. Livestock counts have declined significantly over the past decade, including the number of cattle and pigs, which fell by 40 and 16 percent respectively between 2001 and 2010. As noted above, however, livestock production still contributes a large share of agricultural output.

Table 1.1 Value of Agricultural Products in Moldova, 2008

<table>
<thead>
<tr>
<th>Description</th>
<th>Value (US$ millions, 2008$)</th>
<th>% of sectors listed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereals</td>
<td>384</td>
<td>30.3</td>
</tr>
<tr>
<td>Fibers</td>
<td>2</td>
<td>0.1</td>
</tr>
<tr>
<td>Fruit and tree crops</td>
<td>309</td>
<td>24.4</td>
</tr>
<tr>
<td>Livestock</td>
<td>385</td>
<td>30.5</td>
</tr>
<tr>
<td>Vegetables</td>
<td>186</td>
<td>14.7</td>
</tr>
<tr>
<td>Total</td>
<td>1,266</td>
<td>100</td>
</tr>
</tbody>
</table>


Figure 1.1 Area Planted by Crop in Moldova, 2000–09

Table 1.2 shows livestock counts by AEZ. Generally, the Southern AEZ has
the most livestock per unit area, with the exception of cows, which occur in the
greatest density in the Northern AEZ. Livestock densities are relatively com-
parable among AEZs with the exception of pigs; there are twice as many pigs per
square kilometer in the Central AEZ compared to the Northern AEZ, and four
times as many pigs per square kilometer in the Southern as compared to the
Northern AEZ.

**Crop Focus for This Study**
This study focused on seven crops, including two field crops (wheat and maize),
two fruits (apples and wine grapes), a generic vegetable crop, and two crops used
for livestock production (alfalfa and grassland pasture). The approach was based
on extensive consultations with the Moldovan steering committee, particularly
the Ministry of Agriculture and Food Industry (MAFI). Figure 1.2 provides

<table>
<thead>
<tr>
<th></th>
<th>Northern</th>
<th>Central</th>
<th>Southern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle</td>
<td>69</td>
<td>51</td>
<td>41</td>
</tr>
<tr>
<td>Goats</td>
<td>39</td>
<td>29</td>
<td>43</td>
</tr>
<tr>
<td>Pigs</td>
<td>55</td>
<td>113</td>
<td>209</td>
</tr>
<tr>
<td>Birds of all species</td>
<td>5,015</td>
<td>8,796</td>
<td>8,646</td>
</tr>
<tr>
<td>Sheep</td>
<td>267</td>
<td>262</td>
<td>275</td>
</tr>
</tbody>
</table>

**Figure 1.2 Estimated Value of Agricultural Production in 2005–07 at Sales Prices for Crops in Moldova**

estimates of the agricultural production value of five of the study’s focus crops and other agricultural products (production estimates for hay were not available). Moldova has a wide range of agricultural production, which makes it difficult to fully represent the agricultural sector with only seven crops. However, the most important and high-value crops were selected for the analysis. Grapes, wheat, maize, and apples made up about 40 percent of total agricultural value in Moldova in 2008.

**Exposure of Moldova’s Agricultural Systems to Climate Change**

The potential impacts of climate change on the world food supply have been estimated in several studies (Parry et al. 2004). Results show that some regions and crops may improve production, while others will suffer yield losses. The implications of climate change for Moldovan agriculture could be substantial. Increased temperature speeds up crop phenology, which typically means there is less time for crops to develop the harvestable portions of the plant. High-temperature and drought stress during critical growth periods can also reduce yields. In addition, excess water from floods can be damaging. For some crops, (for example, winter wheat), increased temperatures can enhance yields.

Increased temperatures generally decrease livestock production potential, and decrease water availability by decreasing soil moisture, increasing evapotranspiration, and reducing the yield of water storage reservoirs through increased evaporation. The effect of precipitation on crops and water resources is generally more uniform than for temperature, at least for rainfed crops, with greater precipitation leading to higher yields and less precipitation reducing yields. The seasonal pattern of precipitation, however, is critically important for rainfed crops; shifts in these patterns can be particularly important and require detailed monthly and daily data for analysis.

**Forecast Climate Changes for Moldova**

The first step in understanding the exposure of Moldova’s agricultural systems to climate change is to understand the potential for changes in climate from the baseline. This study attempts to capture a broad range of climate model forecasts by identifying high-impact, medium-impact, and low-impact scenarios by decade from 2010 to the year 2050. The scenarios are designed to represent a broad range in the potential for climate to affect agriculture, as defined by a change in an indicator called the Climate Moisture Index (CMI) (see box 1.1 for an explanation).

Maps 1.2 and 1.3 summarize the resulting forecasts of changes in climate at the AEZ level by decade from the baseline period to 2050. Map 1.2 presents changes in annual average temperatures by AEZ from the decade beginning in 2000–50. Under all scenarios, average temperatures increase gradually from the baseline to 2050, with the largest increases under the high-impact scenario and the smallest increases under the low-impact scenario. This increasing trend in temperatures is consistent with the observed historical trend and with information gathered from farmer workshops conducted in Moldova.
Box 1.1 Developing a Range of Climate Scenarios

Climate change analyses require forecasts of how temperature, precipitation, and other climate variables of interest might change over time. Because there is great uncertainty in climate forecasts, it is best in a study such as this one to attempt to characterize a range of alternatives as well as a “central case” forecast.

The central concept used to select future climate scenarios was based on measures most likely to be relevant for the degree of impacts of climate to the agricultural sector. Because both temperature and precipitation affect agricultural productivity, scenarios were chosen based on a Climate Moisture Index, or CMI. The CMI is based on the combined effect of temperature and precipitation, and as it is linked to soil moisture, it is believed to be well correlated with potential agricultural production.

Each scenario in our study corresponds to a specific global circulation model (GCM)/greenhouse gas (GHG) emissions scenario combination.

These scenarios were among those used by the Intergovernmental Panel on Climate Change (IPCC) in its fourth assessment of the science of climate change (“Special Report on Emissions Scenarios,” or SRES) (IPCC 2007a; 2007b).

The study team relied on the three most commonly used GHG emissions scenarios: B1, A1B, and A2. A “wet” CMI scenario means that the location experienced the smallest impact (or change in) CMI—that is the “low impact” scenario. A dry scenario corresponds to high potential impact. The specific global general circulation model selected for the medium scenario is closest in consistency with the model mean CMI from a total of 56 readily available emission scenario–GCM combinations. An example of the GCM/emission scenario combinations chosen for Moldova is shown in the table.

The advantages of this approach are that it provides a representation of a full range of available scenarios for future climate change in a manageable way, and that all climate scenarios are based on distinct GCM results. These results are themselves internally consistent in terms of the key GCM outputs the team used as inputs to the crop, livestock, and water resource impact modeling.

<table>
<thead>
<tr>
<th>This study’s scenario</th>
<th>Global general circulation model basis for the scenario</th>
<th>Relevant IPCC SRES scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>High impact</td>
<td>Centre National de Recherches Météorologiques, Coupled Model 3 (FRANCE)</td>
<td>A1B</td>
</tr>
<tr>
<td>Medium impact</td>
<td>Center for Climate Modeling and Analysis, Coupled GCM 3.1.t63 (CANADA)</td>
<td>A1B</td>
</tr>
<tr>
<td>Low impact</td>
<td>Goddard Institute for Space Studies, Model ER (US)</td>
<td>A2</td>
</tr>
</tbody>
</table>

The data analysis conducted in this study supports the conclusion that the historical trend in temperature will accelerate in Moldova in the near future. Although uncertainty remains as to the degree of warming that will occur, the overall warming trend is clear and evident in all three AEZs, with average warming over the next 50 years greater than 2°C for the medium scenario. This can be
compared with an increase of 0.6°C observed from 1951 to 2001 (Deradur et al. 2007). Warming could be more modest, but average temperature changes for the low-impact scenario nonetheless represent an increase of about 1°C. In all scenarios, the warming trend relative to current conditions is of approximately the same magnitude across the three AEZs. The range of current temperatures across AEZs is small, with average temperatures in the Northern AEZ only 0.6°C lower than those in the Central and Southern AEZs.

Map 1.3 presents changes in precipitation by AEZ and by decade from the baseline to the 2040s. For precipitation, by 2050 the low, medium, and high scenarios indicate uncertainty in the magnitude of change, but all three scenarios forecast a decrease in precipitation. Use of the global circulation model (GCM) also indicates that the decadal trend in precipitation is not smooth over time. This is consistent with current climate science, which suggests that short-term and long-term trends in precipitation can vary substantially, with some scenarios showing increases in precipitation in the short term, decreases in the long term, and vice versa.

Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change
http://dx.doi.org/10.1596/978-1-4648-0045-0
Precipitation changes are much more uncertain than temperature changes, as indicated by comparing map 1.2 with map 1.3. The medium-impact forecast indicates a decline in precipitation nationally of about 5 millimeters per month, with most of this decline occurring in the Northern AEZ. Uncertainty at the AEZ level is even higher, but annual precipitation declines could be as much as 9.9 millimeters per month, with all AEZs significantly affected.

The national averages, however, are less important for agricultural production than are the seasonal distributions of temperature and precipitation. Temperature increases are likely to be higher and precipitation declines greater in July and August relative to current conditions—the summer temperature increase could be as much as 7°C in the Southern AEZ. In addition, forecast precipitation declines are greatest in the June-September period, when summer crops need water most. Figures 1.3 and 1.4 present the monthly baseline and forecast
Figure 1.3  Effect of Climate Change on Average Monthly Temperature for the Southern AEZ (Cahul), 2040s

Figure 1.4  Effect of Climate Change on Average Monthly Precipitation for the Southern AEZ (Cahul), 2040s
temperatures and precipitation for the Southern AEZ. Overall, Moldova has dry and mild winters with little snow, and warm summers that begin with intense periods of rainfall followed by lengthy dry periods.

Three major problems affecting agriculture in Moldova include droughts, floods, and soil erosion. The severity and frequency of extreme events, such as drought, rain storms, hail, frost, and floods have been increasing over time, and are predicted to continue to increase (World Bank 2007). Droughts have severe impacts on agriculture that could be exacerbated by climate change. A severe drought in 1994, for example, resulted in a decline of 30 percent in GDP and 26 percent in agricultural output (World Bank 1995). Another drought in 2007 devastated Moldovan agriculture with a 55.5 percent decline in the winter wheat harvest over the previous year, a 72.4 percent decline in maize, a 71.4 percent decline in sunflowers, a 64.2 percent decline in peas, and a 33 percent reduction in cattle holdings. The overall loss was estimated at US$1 billion (World Bank 2007b). Droughts are most prominent in the central and southern regions of Moldova (Business Consulting Institute 2008). In northern Moldova, droughts occur once every 10 years, whereas in central Moldova, it is once every five to six years, and in southern Moldova, once every three to four years. Overall, nine years of droughts that affected more than one district occurred from 1990 to 2007 (Prepelita 2007), costing Moldova, on average, US$1.6 to 20 million per year (World Bank 2007).

Climate change could also potentially increase the frequency and magnitude of flooding. While precipitation is expected to decrease by the 2040s in all three scenarios (see map 1.3) and rainfall is expected to be less frequent, rainfall events are expected to be larger. Almost half of all Moldovan communities are located in flood-prone areas and approximately 45,000 hectares of agricultural land have been waterlogged (Business Consulting Institute 2008). Moldova loses on average US$5 million per year from flooding (Acva project).

Soil erosion is primarily a result of poor land management. The problem affects 43 percent of agricultural land, with 6.4 percent considered highly eroded. Rates of soil loss vary from 5 to 10 tons per hectare to over 30 tons per hectare for slightly and severely eroded land, respectively (Sutton et al. 2008). Chernozem soil accounts for a significant number of soil types in Moldova. It is one of the most fertile types of soil, but is also one of the most vulnerable to specific events such as heavy rain and droughts. Erosion is primarily prominent in the central and northern areas of Moldova (Business Consulting Institute 2008) and leads to average losses of US$40 million per year in foregone agricultural production (World Bank 2007).

The results of the study’s detailed modeling of the effects of climate change on the key crops in Moldova are included in chapter 3.4 As described in greater detail in that chapter, the forecast changes in climate summarized in maps 1.2 and 1.3 present the following key vulnerabilities for Moldova:

- Virtually all rainfed crops have a high potential for yield declines, with the highest risks for wheat, maize, and pasture, particularly in the Southern AEZ.
• Irrigated crops can be better buffered from the effects of high temperatures and low rainfall, but to do so requires additional irrigation water. However, even if additional irrigation water is available, climate change is still likely to reduce irrigated yields somewhat, especially for wheat.
• One of the most important effects of climate change in Moldova will be on water resources. With a greater demand for irrigation water, and reduced precipitation leading to reductions in water supply, water shortages are likely for all sectors but particularly for sectors such as agriculture for which high demand coincides with reduced supply conditions during the summer growing season.
• Livestock is vulnerable both directly and indirectly to higher temperatures and productivity is expected to decline.

**Moldova’s Current Adaptive Capacity**

Assessing adaptive capacity in Moldova’s agricultural sector is challenging because it reflects a very wide range of socioeconomic, policy, and institutional factors at the farm, regional, and national levels. Some considerations in determining the variation in adaptive capacity across the country include current climatic exposure (described above), social structures, institutional capacity, knowledge and education, and access to infrastructure. Specifically, areas under marginal rainfed production will have less adaptive capacity than areas that are more productive and irrigated. In addition, financial resources are one of the most important factors in determining adaptive capacity, as most planned adaptations are costly; by this measure, Moldova ranks relatively low in overall adaptive capacity in the agriculture sector. Finally, agricultural systems that are poorly adapted to the current climate are indicative of low adaptive capacity for future climate changes.

This section reviews three aspects of adaptive capacity: (1) current agricultural policies and institutional capacities at the national level, (2) evidence of adaptive capacity at the farm-level based on consultations with Moldovan farmers, and (3) a brief review of evidence that Moldovan agricultural systems may be poorly adapted to the current climate for the crops featured in this study, reflecting a considerable adaptation deficit.

**National Policies and Institutional Capacity**

From a national perspective, a high degree of adaptive capacity in the agricultural sector can be characterized by: (1) a high level of functionality in the provision of hydrometeorological and relevant geo-spatial data to farmers to support good farm-level decision-making; (2) provision of other agronomic information through well-trained extension agents and well-functioning extension networks; and (3) in-country research oriented toward innovations in agronomic practices in response to forecast climate changes. In addition, systems should be in place to ensure that collective water infrastructure is well-maintained and meets the needs of the farming community. There should also be systems for resolving conflicts between farmers and other users over water provision. In Moldova,
some of these conditions exist, but most are currently inadequate, as outlined below.

- **Agricultural research capabilities have a long history in Moldova but are not oriented toward climate change adaptation, and may have a poor connection to farmer extension.** There is a wide range of technical expertise within the Moldovan agricultural research community. Their ability to provide comprehensive and high-quality data to support this study, for example, was an indicator that the research community in Moldova is well informed and capable of generating policy-relevant results. These agricultural research institutes, however, have not yet focused on climate change as a major risk to agricultural production, and are not as effectively coordinated with the extension service as they could be. Further, research could be better focused on leveraging advances in seed varieties and farming practices shown to be effective in other countries, and on coordinating with the extension service to demonstrate these results locally, particularly for small-scale farmers.

- **Many farms are small and have limited resources for adaptation investments.** Results of the study’s farmer consultations and available data on Moldovan agriculture suggest that many farms in Moldova remain small and have limited financial capabilities. Production on most small farms cannot be mechanized due to financial constraints, which in turn limits adaptive capacity.

- **Agricultural markets are limited.** Many farms in Moldova are subsistence farms that produce for family consumption and have no market links. Many farmers operate as individuals, and organized activities in marketing and other areas are limited. A few entrepreneurial landowners are developing businesses (vegetable and fruit production, especially grapes) aimed at wholesale markets, and the number of such producers is gradually increasing. In the consultations, however, farmers stressed that they have a shortage of agricultural market information, which impedes their decision-making.

- **Crop insurance is available to farmers, but has been poorly subscribed.** In 2004, a law in Moldova introduced a subsidized insurance scheme through MOLDASIG, a state-owned company, and the first of 30 insurance companies that currently offer insurance policies covering agricultural risks. In 2006, MOLDASIG issued policies worth 3 million Lei to 80 large farms, 70 percent of which insured against hail, and the rest against winter frost. No policies were provided for drought. In 2006, the government financed 80 percent of the premium cost of insurance, and planned to finance 50–60 percent of premium costs in the following years. As MOLDASIG grows, the government will take on contingent liabilities and will provide increasing subsidies into the future. As of May 2007, the agricultural insurance market in Moldova was very small; however, the World Bank recommended insurance as a good way to mitigate extreme weather events such as hail, frost and droughts. Insurance is cited to spread risk into the future and over a large number of people. Index-based insurance was specifically recommended rather than the currently established multiple-peril crop insurance (MPCI).
Current agricultural subsidies are inefficiently implemented. Most agricultural subsidies in Moldova are recurrent subsidies rather than investment subsidies, and are provided to large rather than small farms. After 2001, subsidies in Moldova increased, especially in the cereal and oil seed markets, despite the World Bank’s advice to improve the quality of taxation and customs rather than increasing revenue levels. These subsidies are generally inefficient and fail at helping the poor. Moreover, there has been no evidence that subsidizing agricultural inputs, such as fertilizer, irrigation operations, energy, and pesticides, promotes long-term growth. Additionally, large farms are generally less efficient than individual family farms, so directing subsidies at large-scale corporate farms is not useful. These inefficiencies are reflected in the stagnation of the agricultural sector during a period of increased subsidies. In 2004, MDL 236 million, or 37 percent of total public expenditures, went to farm subsidies and to a growing number of subsidy schemes. Most subsidies from MAFI between 2001 and 2004 were credit incentives to stimulate participation in credit programs through grants to farmers who repaid agricultural loans. In 2006, plans included reducing inefficient subsidies, such as machinery and technology station (MTS) subsidies, and directing agricultural subsidies toward producer cooperatives rather than large farms. Recently, the World Bank suggested that Moldova redirect agricultural subsidies towards more efficient investment grants, and that Moldova reduce agricultural subsidies by MDL 350 million, especially for larger farms, as part of budget consolidation and tighter fiscal policy. In the 2006 Agriculture PER report, the Bank also recommended that subsidies be more streamlined and optimized to support increased productivity. Historically, the largest and least efficient subsidies were for a value-added tax (VAT) paid on fertilizers and pesticides, and for a VAT charged on outputs. These subsidies benefit larger commercial farms and encourage overuse of fertilizers and pesticides. By changing the types and recipients, subsidies might be able to promote agricultural growth.

Policy on seed provision could be improved. Appropriate seeds and seedlings are one way for farmers to be prepared for severe weather. Improved seed varieties are also a crucial part of creating a high-value export market. The World Bank has proposed a variety of measures to improve seed varieties, some of which include: importing advanced agricultural technology, including seeds; improving farmers’ access to seeds; and liberalizing the use of EU seeds and seedlings. Seed improvements can lead to benefits such as higher agricultural production, increased rural incomes, greater food security, and improvement in the rural economy.

Moldova’s agriculture policies are well planned, but resources for implementing them are limited. MAFI oversees the agricultural sector, and is administratively linked to the major research institutions. Furthermore, the hydrometeorological institution in Moldova has a high level of capability, is well-run, and appears eager to support farmer decision-making. However, strategies and legislation do not always translate into programs and projects, mainly because most of
the activities included in these strategies require investments that are too large for the state budget. Implementation is also hindered by the limited professional capacities of some relevant institutions. Hence, continued international donor support is crucial for ensuring and expanding implementation.

Crop Yields and Practices for Selected Crops
One observable indicator of adaptive capacity is the degree to which Moldova’s current agricultural crop yields and practices keep pace with those in other countries and with international averages for key crops (box 2.1 describes adaptive actions that Moldovan farmers are already taking). This indicator can provide a sense of what is sometimes termed the adaptation deficit, or the degree to which...
agricultural systems may not be adapted to the current climate. If crop yields are relatively low by international standards, it suggests that current marginal production may have little resiliency in the face of new climate stresses, and a high potential to be devastated by climate changes.

Relative yields for two important Moldovan crops—wheat and grapes—were reviewed through analysis of FAO data. FAO statistics suggest that overall wheat production—reflecting a mix of rainfed and irrigated wheat—is a little over 2 tons per hectare. This is lower than yields for other parts of Europe and the world (figure 1.5). One reason is that Moldova has a relatively small area of irrigated wheat. Other reasons for comparatively low yields in Moldova include distortions and imperfections in agricultural input and output markets, and weak public services; public support programs biased against family farmers; delays in farm restructuring and undeveloped agricultural land markets; limited access to finance; unsustainable management of soils; and high vulnerability to natural events such as droughts, floods, frosts, and severe storms (World Bank 2005, 2008).

For grapes, Moldova has a relatively low overall yield compared to other parts of Europe and the rest of the world (figure 1.6). The yield in Moldova is about 4.5 tons per hectare, half as much as the world average of 9.0 tons per hectare. As a comparison, India has the highest average grape yields at 30 tons per hectare (Papademetriou and Dent 2001). In Moldova, yields generally fall far short of this level.

The overall conclusion of our review is that for wheat and grapes, there remains significant room for enhancing adaptive capacity to current climate in Moldova. It should also be noted that a large portion, 89.3 percent, of Moldovan agriculture is rainfed (World Bank 2009a). As indicated later in this report, many of the high-priority options for adapting Moldovan agriculture to climate change have very high cost-benefit ratios for adaptation options that focus on improving irrigation efficiency and irrigation water availability.
A Framework for Evaluating Alternatives for Investments in Adaptation

The need to adapt to climate change in all sectors is now clear. International efforts to limit greenhouse gases and, in the process, to mitigate climate change now and in the future will not be sufficient to prevent the harmful effects of temperature increases, changes in precipitation, and increased frequency and severity of extreme weather events.

At the same time, climate change can also create opportunities, particularly in the agricultural sector. Increased temperatures can lengthen growing seasons, higher carbon dioxide concentrations can enhance plant growth, and in some areas rainfall and the availability of water resources can increase as a result of climate change.

The risks of climate change cannot be effectively dealt with, and the opportunities cannot be effectively exploited, without a clear plan for aligning agricultural policies with climate change, for developing key agricultural institutional capacity, and for making needed infrastructure and on-farm investments. Developing such a plan ideally involves a combination of high-quality quantitative analysis and consultation of key stakeholders, particularly farmers and in-country agricultural experts.

Another important motivating factor for Moldova’s development of an adaptation plan for agriculture is furthering Moldova’s work toward European Union (EU) accession. Moldova is a partner under the Eastern Partnership, which recently started as a venture of EU member states and their Eastern European
partners. Moldova has also already developed and is beginning to implement a special EU-Moldova Action Plan in 2004 to guide economic, political, and institutional reforms as a first stage towards accession. Along with these needed reforms, the EU encourages specific action toward climate change preparedness and adaptation. As outlined a 2009 EU White Paper on the topic, these actions could include systematic assessment of climate risks, development of outreach initiatives to train farmers in such areas as improving water use efficiency, and identification of financing needs for adaptation measures. These are the steps undertaken in this study.

This study provides a framework for evaluating alternatives for investment in adaptation, for the Moldovan national government, potentially assisted by the donor community, and for the private agricultural sector. The framework has two critical components:

1. **Rigorous quantitative assessments that consider not only current climate but several scenarios of future climate change, supplemented by the judgments of the team.** The quantitative analyses relied on local data to the extent possible to (a) assess the risks of climate change to specific crops and areas of the country, and (b) assess whether the costs of investments justify the benefits in terms of enhancing crop yields now and in the future. In addition, the study considered the specific water resource availability conditions at the basin level, for the baseline period and the future.

2. **Structured discussions with local experts and farmers to evaluate both the potential for specific adaptation strategies to yield economic benefits as well as the feasibility and acceptability of these options.** The input of Moldovan farmers to this process proved critical to ensuring that the quantitative analyses were reasonable and that the team did not overlook important adaptation actions.

Further, the study provides a ranking of the options based on both quantitative and qualitative results. The ranking can be used to establish priorities for policy makers in enhancing the resilience of the Moldovan agricultural sector to climate change. Two types of results from this study should therefore be most critical for Moldovan policy makers:

1. **Specific infrastructure improvement actions, such as improving on-farm irrigation efficiency and rehabilitating irrigation capacity, should be high priorities for Moldovan and international donor investments.** It is important to remember, however, that this study maintained a broad focus, so the results do not represent project-level feasibility evaluations, but rather broad-scale scoping studies. As a result, pursuit of specific investments may require additional, more detailed feasibility studies.

2. **Creating conditions for farmers to make wise investments themselves to enhance their own adaptive capacity is important.** A number of the farm-level adaptive actions identified here focus on changes in practices, such as better optimizing inputs and use of heat- or drought-tolerant seed varieties, that farmers can
readily implement themselves. Policy makers should be aware, however, that many Moldovan farmers currently lack the training and the information (for example, weather forecasts) to implement these practices wisely and effectively. National policy makers should therefore consider making these results focal points for expanding and improving outreach and information services to farmers that explicitly consider adaptation to current climate and forecast changes in climate in the future.

The most effective plans for adapting the sector to climate change will involve both human capital and physical capital enhancements; however, many of these investments can also enhance agricultural productivity right now, under current climate conditions. These options, such as improving farmers' access to agriculturally relevant weather forecasts, will yield benefits as soon as they are implemented and provide a means for farmers to autonomously adapt their practices as the climate changes.

**Structure of the Report**

The remainder of this report consists of five chapters. Chapter 2 summarizes the methodology for the study. Chapter 3 reviews the results of the impact assessment, chapter 4 describes the stakeholder and other qualitative processes employed to identify and evaluate adaptation options, chapter 5 outlines the results of the cost-benefit analysis for selected options, and, finally, chapter 6 presents the overall results for specific adaptation options at the national level and for each AEZ.

**Notes**


2. Ibid.


4. A further factor in evaluating vulnerabilities is the fertilizing effect, for some crops, of increases in ambient CO2 concentrations. Those results are reviewed in chapter 3.


Overview of Approach

The overall scope of the assessment of adaptation options is as follows:

- **Geographic scope**: The analysis was conducted at the agro-ecologic zone (AEZ) level (demonstrated in map 1.1), using representative farms in each of the zones.
- **Crops**: Based on the abilities of existing crop models, consultation with Moldovan counterparts, and the availability of appropriate data to support modeling, the following crops were evaluated quantitatively: wheat, maize, alfalfa, apples, wine grapes, vegetables, and rainfed pasture (grasslands).
- **Future climate**: Three future climate scenarios were developed based on projections of temperature and precipitation at the country level in 2050. The three scenarios were designed to reflect a range of global circulation model (GCM) outcomes for agriculture that include a low-, medium-, and high-impact outcome. The climate scenarios were selected based on a country-level analysis, and then applied consistently across all three AEZ regions.
- **Time period**: Results were generated by using decadal averages from 2010 to 2050 (that is, 2010s, 2020s, 2030s, and 2040s).
- **Economic assumptions**: The results were also based on two economic projections: continuation of current conditions, prices, and markets, and an alternative crop price projection through 2050 as developed and recently published by the International Food Policy Research Institute (IFPRI).
- **Baseline for evaluation**: Benefits and costs were evaluated of each of the options relative to the “current conditions” baseline. As a result, in some cases the benefits and costs of adaptation options may reflect benefits of both adapting to climate change and improving the current agricultural system. Such options are identified as *win-win* in nature.

The overall study was conducted in three stages, as outlined in figure 2.1. The first stage, focused on awareness raising and developing an overall methodology and scope for the study, began in October 2009 with an
awareness-raising workshop organized by the World Bank and MAFI. This first stage continued in March 2010 with an initial mission by the team and concluded with the acceptance of an inception report and work plan by the Moldovan counterparts.

The second stage was the climate impact assessment for the agricultural sector, beginning with data collection and culminating in a capacity building session. At the conclusion of the impact assessment, the team conducted a stakeholder consultation using a participatory process with farmers to continue awareness-raising. The consultation established a reasonable baseline for the analysis, and gathered ideas for adaptive measures to assess in the third stage. A small team travelled to each of the agro-ecological zones to report on the results of the initial climate impact assessment modeling and collect input on adaptation options that might be pursued in response to these projected impacts.

The third stage involved refinement of the impact assessment and additional analysis to develop the quantitative analysis, a qualitative assessment, and
recommendations from Moldovan farmers for the adaptation menu. In April, a second stakeholder workshop was arranged with farmers, to provide them an opportunity to review and comment on the draft results from this report. The study culminated in the Moldovan National Dissemination and Consensus Building Conference, held April 12, 2011; this report reflects the outcomes of that conference.

The remainder of this chapter describes three key steps in the quantitative analysis. The next section describes how future climate scenarios were developed and applied to conduct an agricultural sector climate impact assessment. These scenarios modeled a baseline of the effects of changed climate on the current agricultural system, before adaptation. The section titled “Development of Adaptation Menu” provides details on the assessment of the effect of specific adaptation options on crop yields and farm revenues. The section titled “Assessing Risks to Livestock” provides an overview of assessment of risks to livestock.

It should be noted that this chapter focuses on the methods used in the quantitative analysis. The final set of results in chapter 6, however, includes elements of quantitative modeling, qualitative assessment, and participatory strategies among farmers. The other elements are described in more detail in chapter 4.

**Climate Scenarios and Impact Assessment**

Overall, there are four steps in the development of the impact methodology: (1) identify major agricultural growing regions in Moldova; (2) gather baseline data; (3) develop climate projections; and (4) use baseline and climate projection data to conduct the impact assessment.

**Step 1: Identify Agricultural Growing Regions of Moldova**

Results were generated for “representative farms” in each of the major agricultural production regions of Moldova, at least one of which must be in each of the three AEZs. Presenting the results at this spatial scale allows the use of baseline data from meteorological stations that are co-located with agricultural regions, and avoids needing to either interpolate data between stations or rely upon global sources of gridded data (which have already used interpolation). Note that this approach focuses the analysis on regions that are currently active in agricultural production and does not evaluate regions that may become newly suitable for agriculture as the climate changes.

Information was collected on rainfed and irrigated crop coverage across Moldova based on remote sensing data from several international sources (for example, MIRCA dataset for 26 irrigated and rainfed crops at ~5 minute resolution, McGill dataset for 175 crops at ~5 minute resolution, SPAM (Spatial Production Allocation Model) dataset of detailed global crop maps from IFPRI). Local data were also provided and were used whenever possible.
Step 2: Gather Baseline Data

Baseline meteorological, soils, and water resources data were provided from in-country and global sources. The station-level meteorology data provided by local Moldovan sources were exceptional in its quality and comprehensiveness, and provided an excellent basis for analysis. In-country data on soil and water resource parameters were also excellent. Data requirements included the following:

- **Meteorological.** The crop modeling methodology required at least 10 years of daily historical data in the major agricultural regions of Moldova.

- **Soil characteristics.** Crop modeling requires data on soil type, suitability, erosion potential, and hydrology characteristics.

- **Water resources.** Water resources modeling requires at least 10 years of average daily (preferred) or monthly historical river flow data for gauging stations along the main stem rivers of each major drainage basin in Moldova. These were provided by in-country sources. In addition, locations and active storage volumes of each major reservoir were obtained from in-country sources.

Where global sources of data were used, gridded meteorological data were translated to the agricultural production regions and to spatially average daily data for grid cells covering the region. However, as noted above, the data provided for Moldova were exceptionally comprehensive and so there was little need for global data other than to provide a cross-check on local results.

Step 3: Develop Climate Projections

The climate projections combine information from the baseline datasets with projections of changes in climate obtained from the global circulation model (GCM) results prepared for the United Nations Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. As noted in box 1.1, three climate scenarios were developed for Moldova. The scenarios are defined by the Climate Moisture Index (CMI), which is an indicator of the aridity of a region. Based on the average of CMI values across Moldova, driest, wettest, and “medium” scenarios were selected from among the 56 available GCM combinations deployed by IPCC for 2050. The following two subtasks were then conducted:

1. **Generate decadal monthly changes in precipitation and temperature.** Monthly changes in climate were generated based on differences between future projections of temperature and precipitation and twentieth century baseline outputs for each GCM. Following the literature, absolute changes in temperature and relative changes in precipitation were presented.

2. **Translate these monthly decadal changes to daily changes.** Crop modeling under future climate change also requires daily data for the 2010–50 period, but the GCMs only produce 12 monthly outputs for each decade between 2010 and
2050 (that is, four sets of 12 monthly values). Therefore, decadal monthly changes were used, combined with the earliest decade of available in-country daily station data, to scale the future projections.2

**Step 4: Conduct Impact Assessment**

The impact assessment uses the process-based crop model DSSAT and CropWat to analyze changes in crop yields across Moldova for wheat, maize, and pasture, and CropWat for all other crops analyzed. The CLIRUN model is used to analyze changes in water runoff. The WEAP (Water Evaluation and Planning System) model is then applied, using the inputs from CLIRUN to analyze potential basin-level shortages in water available to agriculture. CropWat is used to determine crop water and irrigation requirements from soil, climate, and crop data. The program was designed for poor farmers in arid and semi-arid regions, and creates different irrigation schedules by management conditions and calculates water supply of each scheme for varying crop patterns. Additionally, CropWat can evaluate farmers’ irrigation practices to estimate crop performance.

Any estimated water shortage from the WEAP model is fed back to the biophysical step to estimate the net effect of the shortage on irrigated crop yields. As outlined in the next chapter, there are basins in Moldova where future water shortages for agriculture are forecast, and other basins where sufficient irrigation water is forecast to be available under climate change.

The interactions between these tools are presented in figure 2.2. Note that this figure also includes an economic model that is applicable to the adaptation assessment (described below). The DSSAT, CropWat, CLIRUN, and WEAP tools are briefly described in box 2.1.

---

**Figure 2.2 Analytic Steps in Action 3: Quantitative Modeling of Adaptation Options**

- Climate data
  - Historical climate
  - GCM climate projections

- Climate scenarios

- Physical science and process models
  - Runoff model
  - Crop model
  - Water balance model

- Economic modeling
  - Economic model

*Note: GCM = global circulation model.*

Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change
http://dx.doi.org/10.1596/978-1-4648-0045-0
Box 2.1 Impact Assessment Modeling Tools

The five models used in Analytic Step 4 of this study are: DSSAT, AquaCrop, CropWat, CLIRUN, and WEAP. The characteristics of each model are as follows.

- **DSSAT.** The Decision Support System for Agrotechnology Transfer (DSSAT) is used to facilitate simulations of crop responses to climate and management. DSSAT software includes more than 20 models for the main food and fiber corps; many of the models were specifically developed for climate change impact studies with funding provided by international agencies (USAID, UNEP, and UNDP, among others) and have been calibrated and validated in a few hundred sites in all agroclimatic regions. The DSSAT models have been widely used for evaluating climate impacts in agriculture at levels ranging from individual sites to wide geographic areas.

- **AquaCrop.** The strengths of this process model are that it is simple to evaluate the impact of climate change and evaluation of adaptation strategies on crops, and it can evaluate the effects of water stress and estimate crop water demand, both key issues in several of the study countries. The model was developed and is maintained and supported by the Food and Agriculture Organization (FAO) and is the successor of the well-known CropWat package. The model is mainly parametric-oriented and therefore less data demanding than DSSAT.

- **CropWat.** CropWat was developed by FAO as simple one-dimensional crop model as a tool for use by poor farmers to plan irrigation patterns in arid to semi-arid regions. The application requires very limited input and assumes no vertical differences in soil moisture and that the soil moisture cannot exceed field capacity. CropWat simulates water stress on crops, but does not incorporate nutrient or solar stresses on a daily time-step. As a result, while it can generate both yield and water demand estimates under climate change, it cannot estimate any positive effects from longer growing seasons, and does incorporate the effects of waterlogging or daily precipitation patterns.

- **CLIRUN.** This Climate and Runoff hydrologic model can be used to estimate monthly runoff in each catchment using widely used in climate change hydrologic assessments. CLIRUN models runoff as a lumped watershed, with climate inputs and soil characteristics averaged over the watershed simulating runoff at a gauged location at the mouth of the catchment. The application can run on a daily or monthly time step. Soil water is modeled as a two-layer system (a soil layer and groundwater layer) corresponding to a quick and a slow runoff response to effective precipitation. CLIRUN can be parameterized using globally available data, but any local databases can also be used to enhance the data for the models. CLIRUN produces monthly runoff for each watershed.

- **WEAP.** The Water Evaluation and Planning System (WEAP) is a software tool for integrated water resources planning that assists rather than substitutes for the skilled planner. It provides a comprehensive, flexible, user-friendly framework for planning and policy analysis. WEAP produces a mathematical representation of the river basin encompassing the configuration box continues next page
Development of Adaptation Menu

Building on the four steps of the impact assessment, there are three additional steps necessary to develop the adaptation menu: (5) select and categorize a set of adaptation options to be considered for Moldova; (6) conduct qualitative and quantitative assessments of those options; and (7) develop a ranked order menu of adaptation options.

Step 5: Select and Categorize Adaptation Options

A set of adaptation alternatives was defined and categorized. This list was supplemented by stakeholder recommendations from the consultation workshops. The adaptation options fall into four categories:

- **Indirect.** Broad investments in programs, policies, and infrastructure that indirectly benefit agriculture (for example, road improvements)
- **Programmatic.** Investments in programs and policies that are targeted specifically at agriculture (for example, research and development, extension services)
- **Farm management.** Non-infrastructure farm management improvements aimed at improving farm productivity (for example, changing planting dates or crop varieties)
- **Infrastructure.** Infrastructure investments that improve farm productivity and/or reduce variability. These may include farm-level investments such as rainwater harvesting, or sectoral investments such as irrigation infrastructure or reservoir storage.

A list of categorized adaptation options for Moldova is provided in chapter 4.

Step 6: Conduct Adaptation Assessment

The adaptation options were evaluated based primarily on four criteria: (1) net economic benefits (quantified where possible; based on expert assessment otherwise), (2) robustness to different climate conditions, (3) potential to aid farmers with or without climate change, otherwise referred to as “win-win” potential, and...
(4) favorable evaluation by stakeholders. Because of data limitations, not all options were evaluated quantitatively. Methodologies for addressing each of the criteria are described below.

**Criterion 1: Net Economic Benefits**
The net economic benefit model evaluates a subset of the adaptation options in terms of both their net present value (NPV; total discounted benefits less discounted costs) and their benefit-cost ratio (B-C ratio; total discounted benefits divided by discounted costs) over the time period of the study. Ranking based solely on NPV would tend to favor projects with higher costs and returns; considering the B-C ratio highlights the value of smaller-scale adaptation options suitable for small-scale farming operations. The economic model used here produces the optimal timing of adaptation project implementation by maximizing NPV and the B-C ratio based on different project start years. This is of particular relevance to infrastructure adaptation options such as irrigation systems and reservoir storage, whose high initial capital expenses may not be justified until crop yields are sufficiently enhanced. Lastly, the model estimates NPV and B-C ratios for yield outputs under each dimension of the analysis, namely: (1) climate scenarios, (2) AEZs or river basins, (3) crops, (4) CO₂ fertilization, and (5) irrigated versus rainfed.

Generating these metrics requires several key pieces of information, including:

- **Crop yields** with and without the adaptation option in place—derived from DSSAT and CropWat modeling
- **Management multiplier** to convert from experimental to field yields—developed in consultation with local experts, as part of the team’s capacity building work
- **Crop prices through 2050**—using national crop price data from FAO for current conditions and price projections under two scenarios—one with constant prices and one based on an IFPRI global price change forecast
- **Exchange rate** between global and local crop prices
- **Discount rate** to estimate the present value of future revenues and costs—employing a 5 percent discount rate, consistent with recent World Bank Economics of Adaptation to Climate Change analyses
- **Capital and operations and maintenance (O&M) costs of each adaptation input** (for example, irrigation infrastructure). Local data were requested to characterize costs of adaptation options, and in some cases they were provided. However, they were often difficult to obtain or to generalize, so estimates derived from prior work were used in many cases.

The general approach for estimating the net benefits of two of the farm management options assessed (optimizing fertilizer application; and changing crop varieties) is outlined in table 2.1. More details of these analyses are provided in chapter 5. Not all options were amenable to such quantitative analysis.
### Table 2.1 Approach for Two Quantifiable Farm-Level Adaptation Options

<table>
<thead>
<tr>
<th>Adaptation option</th>
<th>Description</th>
<th>Crop modeling approach</th>
<th>Economic methodology</th>
</tr>
</thead>
</table>
| Optimize agronomic inputs              | Additional application of fertilizer may partly offset impacts of climate change on crop yields. | Redeploy DSSAT to optimize levels of fertilizer inputs and provide resulting crop yields for each of these dimensions. | 1. In the economic model, estimate the per hectare revenue increase (that is, market price times increased yield) due to implementation of the adaptation alternative, and the per hectare increase in costs, then convert these to net present value and benefit-cost ratios for each start year between 2011 and 2050.  
2. Assess whether the farm management adaptation option is net beneficial, and if so, identify the optimal start year(s). |
| Switch to more suitable crops or crop varieties | As climate conditions change, another option would be for farmers to switch to more suitable crops or crop varieties. | The economic model employs estimates of crop yields under climate change in each of the AEZs. |                                                                                       |

In addition to optimizing fertilizer application and changing crop varieties, a quantitative assessment of the following options was undertaken:

- Expanding extension services
- Expanding agricultural research and development activities
- Improving drainage capacity
- Developing new irrigation capacity
- Rehabilitating irrigation capacity
- Improving irrigation water application efficiency
- Adjusting livestock holdings in response to climate stress.

Other types of economic analyses were conducted, including break-even analyses and basin-level adaptation analyses. These are described in more detail in chapter 5.

**Criterion 2: Robustness to Different Future Climate Conditions**

All options were assessed relative to climate conditions in three alternative climate scenarios. Cost-benefit ratios and net present value calculations were developed for each of the three scenarios, both with and without the effect of carbon fertilization, providing a means for assessing robustness to future climate conditions.

**Criterion 3: “Win-Win” Potential**

The analysis also determined whether adaptation options would be beneficial even in the absence of climate change. For options amenable to economic analysis, net benefits of the adaptations can be analyzed relative to the current baseline. As a result, the benefits estimates implicitly incorporate both climate...
adaptation and non-climate related benefits of adopting the measure. For other alternatives, the win-win potential is assessed based on expert judgment.

**Criterion 4: Stakeholder Recommendations**

Adaptation alternatives that stakeholders recommended during the stakeholder consultation workshops carried significant weight in the results. Stakeholders also provided information on impacts that they had already experienced. Adaptation options that addressed those impacts, such as drainage improvements to mitigate flooding, were also given a higher priority, even if those measures were not specifically mentioned in the stakeholder workshops.

**Step 7: Develop Menu of Adaptation Options**

The menu of adaptation options presented in chapter 6 synthesizes the results of the three components of the adaptation assessment: quantitative analysis (described in chapter 5); qualitative assessment of potential net benefits to farmers (summarized in chapter 4); and farmer recommendations (also summarized in chapter 4). Tables and figures in chapter 6 provide a prioritized list of national and AEZ-level options, with a justification for the option based on these three components of the assessment. In addition, the tables identify whether the option has win-win potential.

Other components of the results include a qualitative assessment of the time needed to implement each of these adaptation options. This characteristic of the option may be a key consideration for farmers and potential investors. For example, reservoir construction requires much more time than changing crops varieties from one season to the next. This information is not used to assign priority, but instead is designed to provide guidance as to measures that could have an immediate versus delayed impact. The assessment is based on available information on each option along with expert judgment.

A key consideration in the quantitative analysis is assessing whether the option yields benefits across the range of possible future climate outcomes. These include quantitative and qualitative projections of net benefits of adaptation options across three climate change scenarios, two CO₂ fertilization scenarios, multiple crops, and four decades. For some adaptation options, robustness is assessed based on expert assessment.

**Assessing Risks to Livestock**

Although the direct effects of heat stress on livestock have not been studied extensively, warming is expected to alter the feed intake, mortality, growth, reproduction, maintenance, and production of animals. Collectively, these effects are expected to have a negative impact on livestock productivity (Thornton, et al. 2009).

In an effort to assess the effects of climate change on livestock, a broad literature review was conducted to identify existing models on the effect of climate change, particularly changing temperature, on livestock. Ideally, a “process” model...
Similar to the DSSAT crop model would be employed. A model of this type could be deployed to simulate effects on livestock for various climate scenarios, and also evaluate the impact of taking adaptive actions. The only extensive analysis of this type was a structural Ricardian model of livestock developed by Seo and Mendelsohn based on studies in 10 countries in Africa (2006). This model measures the interaction between temperature and livestock and considers the adaptive responses of farmers by evaluating which species are selected, the number of animals per farm and the net revenue per animal under changes in climate. The study relies on a survey of over 5,000 livestock farmers in 10 African countries. In this dataset, the variation in livestock productivity and expected incomes in different regions demonstrates a clear relationship to regional climate, which provides a mechanism, through spatial analogue, to statistically analyze how climate change may affect livestock incomes.

The general results of the study were that, relative to the baseline, the probability of choosing beef cattle and chickens will decline with rising temperatures, but that the probability of selecting dairy cattle, goats, and sheep will increase. Expected income per animal fell across all livestock types, but changes were most dramatic for beef cattle, goats, and chickens, which fell 19 percent, 21 percent, and 29 percent respectively with an increase in temperature of 2.5°C. Rising temperatures, in general, lead to a response to reduce the predicted number of beef cattle and chickens on each farm, but increase the number of the other livestock types.

The Mendelsohn and Seo results are consistent with other work in this area. In prior studies, beef cattle have been found to experience increases in mortality, reduced reproduction and feed intake, and other negative effects of higher temperatures (for example, Adams et al. 1999). Butt et al. (2005) found that small ruminants (that is, goats and sheep) are more resilient to rising temperatures than beef cattle. Chickens are particularly vulnerable to climate change because they can only tolerate narrow ranges of temperatures beyond which reproduction and growth are negatively affected. Furthermore, increases in temperature caused by climate change can be exacerbated within enclosed poultry housing systems.

Ultimately, however, the Mendelsohn and Seo model was not applied in the Moldovan analysis. The main reason was that the current climate, and in particular the effect of current climate on existing management practices and current livestock varieties in the 10 African countries they studied, differs markedly from those in Moldova. The Ricardian approach does not allow for a reliable adjustment for those differences. Instead, a qualitative evaluation of both the risk of climate change to livestock, and adaptive measures to consider in responding to those risks is provided.

**Uncertainty and Sensitivity Analysis**

A study of this breadth, conducted under time and data constraints, is necessarily limited. In particular, in order to look broadly across many crops, areas, and adaptation options (particularly options that may be relatively new to Moldova),
general data and characterizations of these options must be relied on in many cases. While the Team has taken care to use the best available data, and has applied state-of-the-art modeling and analytic tools, analysis of outcomes 40 years into the future, across a broad and varied landscape of complex agricultural and water resources systems, involves uncertainty. As a result, this study attempts to evaluate the sensitivity of the results to one of the most important sources of uncertainty—how future climate change will unfold across Moldova.

A potentially larger question that was not addressed by this study involves projecting the evolution and development of agricultural systems over the next 40 years, with or without climate change. The future context in which adaptation will be adopted is clearly important, but very difficult to project. Other important limitations involve the necessity of examining the efficacy of adaptation options for a “representative farm.” The results of this study should not be interpreted as in-depth analysis of options at the farm-scale. Instead, these results may be viewed as an important initial step in the process of evaluating and implementing climate adaptation options for the agricultural sector, using the current best available methods.

Notes

1. Both DSSAT and AquaCrop require daily inputs. CropWat was also used, which requires monthly data.

2. The CMI depends on average annual precipitation and average annual potential evapotranspiration (PET). If PET is greater than precipitation, the climate is considered to be dry, whereas if precipitation is greater than PET, the climate is moist. Calculated as CMI = (P/PET) - 1 {when PET>P} and CMI = 1 - (PET/P) {when P>PET}, a CMI of –1 is very arid and a CMI of +1 is very humid. As a ratio of two depth measurements, CMI is dimensionless.

3. For example, if a selected GCM projects that the change in January temperatures in the 2030s is two degrees and the earliest available station data are from 1994 to 2003, the January 1–31 temperatures for every year in the 2030s will be the temperatures during Januarys between 1994 and 2003 plus two degrees.

4. As noted in chapter 5, in most cases we found that quantitative results for adaptation options are less sensitive to uncertainties in climate forecasts than to uncertainties in future prices.

5. Because the raw data from this survey were not available, it was not possible to compare the climatic conditions observed in the Seo and Mendelsohn survey to the conditions in Moldova.
This section describes the results of the climate impact assessment for the Moldovan agriculture sector. The impact assessment is an important component of developing an adaptation plan. It reflects the impacts of forecast changes in temperature and precipitation (outlined in the section titled “Exposure of Moldova’s Agricultural Systems to Climate Change” in chapter 1) from 2010 to 2050 on crop yields and water resources available for irrigation if no actions are taken to adapt to these changes. As such, it represents a baseline from which the effects of individual adaptation options can be measured. It also provides a clear picture of the risks and opportunities presented by climate change at a detailed level by crop, AEZ, and river basin.

This chapter first reviews the forecast impacts of climate change on crops and horticulture, then summarizes the results of the screening-level assessment of the direct effects of climate change on livestock, and finally reviews the effects of climate change on water available for agricultural irrigation.

The results suggest the following:

• **Overall, the effects of climate change on crops in Moldova could be relatively modest, especially for grapes, apples, and vegetables.** There is potential for more substantial effects on maize, wheat, and pasture. To the extent irrigation infrastructure is in poor repair, water may not be available at critical times of the growing season. In that case, the severity of effects of future climate change for irrigated crops may be underestimated here.

• **The direct effect of temperature on livestock, reducing their productivity and farm revenues, could be considerable, especially for cattle and chickens.** These results, however, are based on a relatively limited literature review, as little work has been conducted to date on quantifying livestock risks in Eastern Europe, and therefore the conclusions may over or underestimate this effect.

• **Climate change will increase irrigation water demand and reduce water supply.** The modeling results indicate that higher temperatures and lower precipitation
under climate change will increase irrigation water demand and reduce river runoff during the growing season. These increases in agricultural water demand, and reductions in water supply, coupled with rising water demand in other sectors, will cause water deficits in future years, most acutely in the eastern portions of the Northern and Central AEZs.

**Climate Impacts on Crops and Horticulture**

The detailed results of the impact assessment for individual crops, for each AEZ and climate scenario, are summarized in tables 3.1 and 3.2. Table 3.1 shows the results for the medium scenario, and table 3.2 shows the range of results for the low-, medium-, and high-impact scenarios. As demonstrated in table 3.1, most crops are negatively affected by climate change, except for apples. The high-impact climate scenario has the strongest impact, with less rainfall and higher evapotranspiration due to the higher temperature projection. For the medium-climate scenario, the impact of climate change is a little less severe than the high-impact scenario, as this scenario is less pessimistic in terms of rainfall projections.

In general, the results indicate that all crop yields besides apples decline under the medium scenario. Apple yields are expected to remain relatively constant, with a slight decline for irrigated apples in the Southern AEZ and rainfed apples in the Central AEZ, and a slight increase for rainfed apples in the Southern AEZ under the medium-impact scenario. As expected, irrigation appears to moderately increase yields or reduce yield variability.

<table>
<thead>
<tr>
<th>Irrigated/rainfed</th>
<th>Crop</th>
<th>Northern</th>
<th>Central</th>
<th>Southern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigated</td>
<td>Maize</td>
<td>−8</td>
<td>−6</td>
<td>−9</td>
</tr>
<tr>
<td>Wheat</td>
<td>−14</td>
<td>−30</td>
<td>−34</td>
<td></td>
</tr>
<tr>
<td>Alfalfa</td>
<td>−7</td>
<td>−13</td>
<td>−18</td>
<td></td>
</tr>
<tr>
<td>Grapes</td>
<td>−4</td>
<td>−3</td>
<td>−5</td>
<td></td>
</tr>
<tr>
<td>Apples</td>
<td>0</td>
<td>0</td>
<td>−3</td>
<td></td>
</tr>
<tr>
<td>Vegetables</td>
<td>−5</td>
<td>−9</td>
<td>−13</td>
<td></td>
</tr>
<tr>
<td>Rainfed</td>
<td>Maize</td>
<td>−9</td>
<td>−3</td>
<td>−10</td>
</tr>
<tr>
<td>Wheat</td>
<td>−36</td>
<td>−38</td>
<td>−45</td>
<td></td>
</tr>
<tr>
<td>Pasture</td>
<td>−17</td>
<td>−22</td>
<td>−19</td>
<td></td>
</tr>
<tr>
<td>Alfalfa</td>
<td>−13</td>
<td>−18</td>
<td>−12</td>
<td></td>
</tr>
<tr>
<td>Grapes</td>
<td>−4</td>
<td>−3</td>
<td>−2</td>
<td></td>
</tr>
<tr>
<td>Apples</td>
<td>−2</td>
<td>−4</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Vegetables</td>
<td>−9</td>
<td>−13</td>
<td>−9</td>
<td></td>
</tr>
</tbody>
</table>

*Note: Results are average changes in crop yield, assuming no adaptation, no irrigation water constraints, and no effect of CO₂ fertilization, under a medium-impact scenario. Shading is darker the larger the decline in crop yield.*
The low-impact scenario shows a modest positive impact for irrigated grapes and apples, and for rainfed apples, as the plants benefit from greater water availability due to increased rainfall. The higher temperatures also result in a higher evaporative water demand, but only a part of the increased rainfall is lost through non-productive soil evaporation. Most of the crops are affected positively by the increased water availability. The high-impact scenario shows effects that are almost entirely negative for all crops and AEZs. As noted above, this results from hotter temperatures and reductions in precipitation.

The results presented above do not incorporate the effects of higher CO₂ concentrations that are expected as a byproduct of increased CO₂ emissions. Higher CO₂ concentrations can enhance growth for some crops with a photosynthesis process that can benefit from additional ambient CO₂. The effect is difficult to accurately estimate, however, because of the difficulty in designing field experiments, and the inability in most studies to account for the countervailing effects of CO₂ on competing weeds.2

Based on other work in the region, it can be expected that some of the crops studied in Moldova could experience an increase in production due to the assumed CO₂ fertilization effect. This effect compensates part of the negative impact of the increased water stress caused by the higher temperatures and evaporative demand. For other crops (for example, pasture) the overall impact of climate change would likely remain negative. Overall, for more moderate climate scenarios CO₂ fertilization is likely to be positive and could enhance yields by 5–10 percent.

For the irrigated crops, the climate impact on irrigation water demand was also assessed as a key input to the water resources analyses. In table 3.3, orange indicates an increase in crop irrigation water requirements, and darker shades of orange represent larger irrigation demand. For all scenarios, the overall trend is

---

Table 3.2 Effect of Climate Change on Crop Yields through 2040s across the Three Climate Scenarios

<table>
<thead>
<tr>
<th>% change</th>
<th>Crop</th>
<th>Northern</th>
<th>Central</th>
<th>Southern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigated/rainfed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigated</td>
<td>Maize</td>
<td>−6 to 1</td>
<td>−5 to 0</td>
<td>−4 to −2</td>
</tr>
<tr>
<td></td>
<td>Wheat</td>
<td>−6 to −1</td>
<td>−10 to −7</td>
<td>−11 to −8</td>
</tr>
<tr>
<td></td>
<td>Alfalfa</td>
<td>−5 to 0</td>
<td>−6 to −3</td>
<td>−6 to −5</td>
</tr>
<tr>
<td></td>
<td>Grapes</td>
<td>−3 to 1</td>
<td>−3 to 0</td>
<td>−2 to −1</td>
</tr>
<tr>
<td></td>
<td>Apples</td>
<td>−2 to 1</td>
<td>−1 to 0</td>
<td>−1</td>
</tr>
<tr>
<td></td>
<td>Vegetables</td>
<td>−3 to 0</td>
<td>−4 to −2</td>
<td>−4</td>
</tr>
<tr>
<td>Rainfed</td>
<td>Maize</td>
<td>−8 to −1</td>
<td>−6 to 0</td>
<td>−8 to −4</td>
</tr>
<tr>
<td></td>
<td>Wheat</td>
<td>−10 to −8</td>
<td>−13 to −12</td>
<td>−13 to −12</td>
</tr>
<tr>
<td></td>
<td>Pasture</td>
<td>−7 to −4</td>
<td>−6 to −5</td>
<td>−7 to −6</td>
</tr>
<tr>
<td></td>
<td>Alfalfa</td>
<td>−6 to −3</td>
<td>−4</td>
<td>−5</td>
</tr>
<tr>
<td></td>
<td>Grapes</td>
<td>−4 to 0</td>
<td>−2 to 0</td>
<td>−3 to −2</td>
</tr>
<tr>
<td></td>
<td>Apples</td>
<td>−1 to 0</td>
<td>0 to 1</td>
<td>0 to 1</td>
</tr>
<tr>
<td></td>
<td>Vegetables</td>
<td>−4 to −2</td>
<td>−3 to −2</td>
<td>−4 to −3</td>
</tr>
</tbody>
</table>
that more water is required to maintain the current yields. In particular, grapes, apples, and vegetables will need substantially increased amounts of water.

## Climate Impacts on Livestock

Effects on alfalfa and rainfed pasture crops summarized in the previous section present one type of climate change risk to livestock, an indirect effect. Effects of climate change on maize yields may also be linked to effects on livestock. As noted above, for the medium scenario, rainfed alfalfa and pasture yields are expected to decrease across all AEZs, where livestock makes up about one third of overall agricultural productivity. As a result, the indirect effects of climate change in areas where livestock are most important would range from negative in the worst case to relatively modest in the best case.

The direct effect of climate change on livestock is also important, and it is linked to higher than optimal temperatures for livestock, where heat can affect animal productivity and, in the case of extreme events, may lead to elevated mortality rates related to extreme heat stress. As outlined in chapter 2, there is very limited information to characterize the direct effects of climate on livestock. The currently

### Table 3.3 Irrigation Water Requirement Changes Relative to the Current Situation to 2040s under the Three Climate Scenarios, for Each Crop and AEZ (Assuming No CO₂ Fertilization)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Crop</th>
<th>Mediterranean</th>
<th>Continental</th>
<th>Alpine</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Maize</td>
<td>46</td>
<td>50</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>Wheat</td>
<td>67</td>
<td>70</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>Pasture</td>
<td>37</td>
<td>43</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>Alfalfa</td>
<td>41</td>
<td>48</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Grapes</td>
<td>83</td>
<td>85</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td>Apples</td>
<td>85</td>
<td>102</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>Vegetables</td>
<td>83</td>
<td>84</td>
<td>68</td>
</tr>
<tr>
<td>Medium</td>
<td>Maize</td>
<td>29</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Wheat</td>
<td>44</td>
<td>28</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Pasture</td>
<td>26</td>
<td>20</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Alfalfa</td>
<td>25</td>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Grapes</td>
<td>56</td>
<td>44</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>Apples</td>
<td>60</td>
<td>60</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>Vegetables</td>
<td>55</td>
<td>41</td>
<td>34</td>
</tr>
<tr>
<td>Low</td>
<td>Maize</td>
<td>13</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Wheat</td>
<td>24</td>
<td>21</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Pasture</td>
<td>15</td>
<td>14</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Alfalfa</td>
<td>8</td>
<td>8</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Grapes</td>
<td>30</td>
<td>29</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>Apples</td>
<td>21</td>
<td>27</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>Vegetables</td>
<td>28</td>
<td>25</td>
<td>34</td>
</tr>
</tbody>
</table>

Note: Shading is darker the larger the increase in irrigation water requirements.
available methodologies are far less sophisticated than the crop modeling techniques applied in the prior section, or the water resources modeling techniques in the following section, and are generally not appropriate to apply for Moldova.

A screening analysis completed for the study suggests that the direct effects of climate change on most livestock, absent adaptation, could be negative and potentially large. For many livestock type/AEZ combinations, climate change is a major risk, with potential for as much as 35 percent loss in net revenue by the 2040s, with effects on goats and sheep being less than those for chickens and cattle.

**Climate Impacts on Water Resources**

A water availability analysis was conducted at the river basin level using the WEAP, which compares forecasts of water demand for all sectors, including irrigated agriculture, with water supply results under climate change derived from the CLIRUN model. The five major river basins analyzed here are shown in map 3.1. They include, from north to south, the Upper Nistru basin, Reut basin, Lower Nistru basin, Kogilnic basin, and Prut basin. Some of these basins extend beyond Moldova’s border, indicated by the thick line on the map, but this study focuses on changes in water supply and demand within Moldova’s territory.

The remainder of this section discusses: (1) the inputs to WEAP, including basin-level water demand, supply, storage, and transboundary flows, (2) analytical results, and (3) limitations of the analysis.

In the WEAP model, irrigation water withdrawals in each river basin were estimated based on the total hectares of irrigated land in each basin, per hectare estimates of crop irrigation requirements (discussed above), and an estimate of

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**Map 3.1 River Basins in Moldova**

Sources: © Industrial Economics. Used with permission; further permission via Creative Commons Attribution 3.0 Unported license (CC BY 3.0). Country boundaries are from ESRI and used via CC BY 3.0. Basin data available from the U.S. Geological Survey Hydro1k River Basins.

Note: The numbers on the map are basin numbers from the Hydro1k River Basins database.

Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change

http://dx.doi.org/10.1596/978-1-4648-0045-0
basin-level irrigation efficiency. The distribution of irrigated hectares across the river basins was based on data provided by Moldova’s water resource management agency, Apele Moldovei; a map of this distribution across Moldova is presented in map 3.2. In total, there are currently 36,030 hectares of irrigation across the country, with 10,200 hectares in the Lower Nistru basin, another 10,200 hectares in the Reut basin, 2,810 hectares in the Lower Nistru basin, 2,390 hectares in the Kogilnic basin, and 9,900 hectares in the Prut basin. According to Apele Moldovei, the irrigated area in Moldova was 234,000 hectares in 1990, declining to a low of 3,400 hectares in 2001, and expanding ever since. Although irrigation infrastructure (for example, pumps, canals) is still in place on approximately 145,000 hectares, much of this infrastructure needs to be rehabilitated.

Crop irrigation requirements are affected by both temperature and precipitation, as water demand is directly linked to both crop yield and to
evapotranspiration. These irrigation needs are derived from the DSSAT and CropWat model results described above. Figure 3.1 compares total monthly irrigation demands for Moldova for the current baseline and under the three climate scenarios for the 2040s. Note the rise in monthly irrigation demand with climate change of up to 45 percent under the high-impact climate change scenario during the spring and summer months.

To account for potential conflicts between irrigation and other water uses, water demand forecasts for other sectors were incorporated into the WEAP model. Specifically, the team used information on existing municipal and industrial (M&I) water demands in Moldova from Apele Moldovei, coupled with World Bank forecasts of M&I per capita demand for water through 2050. According to Apele Moldovei, M&I demand currently represents over 80 percent of current water use in Moldova, the majority of which is industrial water use in Transnistria and municipal water use in Chisinau. Going forward, M&I water demand is forecast to rise from 705 million m$^3$ in 2011 to 1.4 billion m$^3$ in 2050, representing a nearly 100 percent increase in water demand in these sectors. This pattern is primarily attributable to increased industrialization in the country. (The World Bank forecasts more than a four-fold increase in GDP over this same period.)

Identifying the correct location of these M&I water uses is critical to correctly sequence the demands within the WEAP model. These demands were allocated to each basin based on information provided by Apele Moldovei; specific municipal demand locations within each basin were identified using Columbia University’s Gridded Population of the World database.
Modeling the effect of climate change on water supply was accomplished using CLIRUN. Water supply was measured based on runoff in rivers, which is the difference between precipitation and evapotranspiration; as a result, runoff is affected by both the temperature and the precipitation forecasts. CLIRUN is a two-layer, one-dimensional infiltration and runoff estimation tool that uses historic runoff as a means to estimate soil characteristics. CLIRUN was calibrated for each basin using global historical gridded runoff data from the Global Runoff Data Center (GRDC), and monthly temperature and precipitation data from Moldova’s State Hydrometeorology Service (SHS). The gridded runoff data from GRDC were checked for accuracy using historical gauged flow data from SHS. R-squared values for the CLIRUN calibration were between 0.65 and 0.81 for the five basins, and deviations between observed and modeled runoff ranging from 1–6 percent, indicating a strong relationship between observed runoff and runoff modeled from precipitation and potential evapotranspiration (PET) inputs. Once calibrated, CLIRUN uses monthly precipitation and PET projections under the three climate scenarios to project rainfall runoff in each of the five basins.

Figure 3.2 compares the mean monthly runoff in the 2040s under the baseline and three climate scenarios. Although annual runoff under the low-impact scenario is forecast to increase in the early spring, runoff during early- and mid-summer declines under all three scenarios relative to baseline conditions. These reductions occur in months when crop water demand is highest, and when DSSAT and CropWat forecast the most pronounced increase in crop water

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Figure 3.2 Estimated Climate Change Effect on Mean Monthly Runoff for All Moldovan Basins

![Figure 3.2 Estimated Climate Change Effect on Mean Monthly Runoff for All Moldovan Basins](image-url)
demand under climate change. Importantly, under all scenarios, a significant decline in river runoff is projected during the late summer and early fall months, when reservoir storage is lowest but crop water demand remains high.

Looking at changes in flow across the five basins reveals similar patterns. Map 3.3 provides the mean percentage change in runoff from the historical baseline to the 2040s under the three climate scenarios. The panel of maps on the left show the change when all months of the year are considered, and the panel on the right shows only May to September, which are the months when irrigation demands are the highest. All of the basins across all of the scenarios show reduced mean runoff during the irrigation season. In the Reut basin in particular, river flows fall over 60 percent in the high-impact scenarios relative to the historical baseline.

Map 3.3 Mean Percentage Change in Runoff, 2040s Relative to the Historical Baseline

Sources: © Industrial Economics. Used with permission; further permission via Creative Commons Attribution 3.0 Unported license (CC BY 3.0). Country boundaries are from ESRI and used via CC BY 3.0. Basin data available from the U.S. Geological Survey Hydro1k River Basins.
The WEAP model utilizes these forecasts of changing water demand and supply to estimate potential irrigation water shortages under climate change. WEAP is a software tool for integrated water resources planning that provides a mathematical representation of the river basins encompassing the configuration of the main rivers and their tributaries, the hydrology of the basin in space and time, water demands, and reservoir storage. Computations are performed on a monthly time scale between 2011 and 2050 for a base-case scenario (that is, no climate change) and the three climate change scenarios, each of which is characterized by unique inflows and changing water demand. Surface water inflows from CLIRUN were used as inflows to an aggregated river in each basin modeled in WEAP. Water supplies and demands are linked between upstream and downstream basins (for example, the Reut and Upper Nistru rivers flow into the Lower Nistru river), and reservoirs, irrigation, and municipal and industrial demand locations were sequenced consistently with respect to their actual locations.

In addition to estimating changes in water supply and demand, the WEAP model also critically depends on information for reservoir volumes and locations, transboundary flow arrangements, and assumptions about environmental flow requirements:

- **Reservoir locations and volumes** were provided by Apele Moldovei, the United Nations Economic Commission for Europe (UNECE), the Food and Agriculture Organization (FAO), and Cazac and Boian (2008), which summarize reservoir and storage pond volumes by location within Moldova. In total, they report that Moldova has 1.1 km$^3$ of storage, of which 108 million m$^3$ is in the Lower Nistru Basin, 20 million m$^3$ is in the Reut basin, 219 million m$^3$ is in the Upper Nistru basin, 41 million m$^3$ is in the Bregalnica basin, and 720 million m$^3$ in the Prut basin. For several key reservoirs, these sources also provide sedimentation information, which can be quite significant in Moldova due to significant erosion in the region. For example, the volume of the Dubasari reservoir in the Upper Nistru was 486 million m$^3$ of storage when constructed in 1954, but has since declined 56 percent to 214 million m$^3$ as sediment has been trapped behind the dam.

- **Transboundary flow agreements** are also a critical determinant of water available in Moldova, as the Prut and Nistru rivers are shared with Romania and Ukraine, respectively. Although there are no currently existing transboundary water agreements between Moldova and Romania or Ukraine, according to FAO, legislation from the former Soviet period still governs water allocation on these rivers. Under these regulations, Moldova has the right withdraw water from the Costesti reservoir on the Romania border and from the Cuciurgan reservoir on the border with Ukraine, as well as construct additional storage ponds on tributaries to the Prut and Nistru. Based on these historic sharing agreements and absent a detailed model of Romanian and Ukrainian water demands in these basins, it is assumed here that 50 percent of the mean monthly runoff from the Prut and Nistru rivers must be present in the rivers.
when they flow out of Moldova. In the WEAP model, it is assumed that these sharing arrangements hold for all months, and that any increases or decreases in available water resulting from climate change would be shared proportionally between parties.

- **Environmental flow requirements.** A minimum flow requirement of 20 percent of Moldova’s water resources is assumed to be dedicated to environmental purposes.

WEAP results indicate that although unmet irrigation water demands do not occur under the historical baseline, they begin in the 2020s and rise significantly with increasing M&I demands and climate change effects. Table 3.4 presents unmet irrigation demands for the five basins under the three climate scenarios in the 2040s. Overall unmet irrigation demands are expected to range from 0.2 percent to 5.6 percent in the 2040s under the low- and high-impact scenarios. These unmet demands are concentrated primarily in the Reut basin, which are projected to be as high as 21.5 percent in the 2040s under the high scenario. Although mean annual runoff increases in the low-impact scenario, unmet demands rise in all scenarios relative to the baseline because, as described above, irrigation demands are higher and available runoff is lower during the summer months. As a result, the majority of unmet demands occur during the high irrigation water demand months of June through August.

Overall unmet M&I demands across the basins are approximately 70 million m$^3$ annually under the high scenario in the 2040s, which is eight times larger than the total unmet irrigation demands (approximately 9 million m$^3$). The vast majority of these M&I shortfalls occur during the late fall and winter months when reservoir volumes are depleted (discussed in greater depth below), thus explaining why irrigation demands are not more severely affected by conflicts with M&I demands, which are given a higher withdrawal priority in the WEAP model.

Table 3.4 Effect of Climate Change on Forecast Annual Irrigation Water Shortfall by Basin and Climate Scenario

<table>
<thead>
<tr>
<th>Basin</th>
<th>Climate scenario (shortfall in irrigation water relative to total irrigation water demand)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low impact 2040s</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>m$^3$ thousands</td>
<td>% shortfall</td>
<td>m$^3$ thousands</td>
</tr>
<tr>
<td>Lower Nistru</td>
<td>79</td>
<td>0.2</td>
<td>62</td>
</tr>
<tr>
<td>Reut</td>
<td>213</td>
<td>0.6</td>
<td>2,000</td>
</tr>
<tr>
<td>Upper Nistru</td>
<td>26</td>
<td>0.3</td>
<td>37</td>
</tr>
<tr>
<td>Kogilnic</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Prut</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>318</td>
<td>0.2</td>
<td>2,099</td>
</tr>
</tbody>
</table>

Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change

http://dx.doi.org/10.1596/978-1-4648-0045-0
Analysis indicates that these projected future M&I shortages, which may drive future conflicts with agriculture, are caused primarily by low river flows in the summer and fall, combined with an absence of reliable storage alternatives. Figure 3.3 shows the mean monthly storage in the Dubasari reservoir (upstream of Chisinau’s diversion from the Nistru River) in the 2010s and 2040s under baseline conditions and in the 2040s under each climate change scenario. Under baseline conditions in the 2010s, mean reservoir volumes are near full pool (approximately 214 million m³) throughout the year. On the other hand, under each of the three climate scenarios in the 2040s, mean reservoir volumes over the decade drop to between less than 10 percent and 30 percent of full pool volumes by October.

It should be noted that the reservoir volumes presented in figure 3.3 are average reductions in reservoir levels. During particularly dry months in the 2040s, reservoir volumes are projected to fall to zero under all of the scenarios. Figure 3.4 provides a histogram of the percent reduction in Dubasari reservoir volumes each month of the 2010s and 2040s (i.e., out of 120 months total) for the same scenarios displayed in figure 3.3. Under the high-impact scenario in the 2040s, the reservoir has no usable storage for 20 months out of the 120 months during that decade, most of which occur between August and November.

The analysis finds that increasing irrigation demands and declining river flows under climate change, coupled with significant potential conflicts with rising M&I demands, pose serious threats to future water availability for irrigation. Potential adaptation measures, including integrated water resources management, will be discussed in chapters 4 and 5.
There are several important limitations to this analysis that if addressed, would improve the certainty of the results:

- **Groundwater use.** The WEAP model does not incorporate groundwater resources in the overall water balance, based on the assumption that these resources ultimately interact with and influence either the quantity or quality of surface water supplies. Assuming that these withdrawals are truly separable from surface water resources and that groundwater mining is not occurring, including these resources in the model would increase water availability.

- **Water quality.** Insufficient information was available to assess how water quality issues, particularly in smaller storage ponds, may affect water availability in future years. To the extent that water quality in these ponds is too poor for irrigation, water available for agriculture would decline.

- **Future irrigation and storage projects.** The analysis assumes that no new reservoirs or irrigation projects will be constructed through 2050. If the construction schedule for any such projects were known with certainty, they could be incorporated into the WEAP baseline and would affect the overall water balance.

- **Reservoir sedimentation.** Although the sedimentation that has occurred to date in some of Moldova’s larger reservoirs has been considered, it is assumed that these reported reservoir volumes remains constant in the future and that sedimentation does not cause substantial reductions in storage capacity. This assumption may overestimate storage availability over the next 40 years.
Effect of Irrigation Water Shortages on Crop Yields

As a final step in evaluating impacts of climate on agriculture, the results of the crop and water impact analyses are combined to evaluate how crop yields may be affected by reductions in basin-level water availability. To adjust mean changes in crop yields reported in tables 3.1 and 3.2 for changes in water availability projected by WEAP, information from FAO on crop sensitivity to water availability is combined with basin-level water deficits from WEAP. To do so, it is first assumed that each farm will receive the percentage of water that WEAP projects will be available at the basin level (table 3.4). For example, WEAP projects an irrigation water deficit of 5.6 percent in the Reut basin under the medium-climate scenario in the 2040s; from this it was assumed that each farm in the Reut basin receives 94.4 percent of the water necessary to meet all irrigation needs. Provided less water, an irrigator can either evenly distribute the remaining water over the field so that each crop receives less water (that is, deficit irrigation), or meet all irrigation needs of a fraction of the crops, leaving the remaining fraction unirrigated.

Determining which approach will produce higher yields depends on the sensitivity of the particular crop planted. For crops that are highly sensitive to water application, deficit irrigation would result in disproportionately lower yields relative to the irrigation deficit, so the second approach (that is, 100 percent of water to a fraction of crops) will generate higher farm-level yields, even though this approach would cause complete loss of production on a portion of the land. On the other hand, deficit irrigation will generate higher farm-level yields for crops that are relatively less sensitive to water application.

The relationship, or elasticity, between relative crop yield and relative water deficit is called the yield response factor (K_y); FAO has developed crop-specific yield response factors for each stage of the growing season. In general, the decrease in yield due to water deficit is relatively small during the vegetative period, whereas it is large during the flowering and yield formulation periods. FAO has aggregated these seasonal factors into a single coefficient for the entire growing season. For K_y values less than one, deficit irrigation causes crop yields to fall less than the water deficit, whereas K_y values greater than one result in higher yield losses relative to the water deficit. For example, if K_y for a particular crop is 0.9 and the water deficit is 10 percent, the resulting yield loss will be 9 percent (that is, 0.9*10 percent). If the K_y value for another crop is 1.1, the resulting yield loss will be 11 percent.

Table 3.5 presents the growing season K_y values for each crop from FAO’s CropWat decision support tool. Note that only grapes have an overall growing season K_y value of less than one, so deficit irrigation will reduce yield losses for only that crop. A response factor was not available for apples, but because response factors for other fruit trees were greater than one, it was assumed the factor for apples would be above one as well.

These factors are used to estimate the change in yield resulting from a reduction in water availability for each crop, unique AEZ-basin area, and climate.
scenario. At the high end of yield impacts, crops have $K_y$ values greater than one and no deficit irrigation will take place. As a result, less area will be irrigated and farm-level crop yield will fall by the water deficit percentage. At the low-end, crops have $K_y$ values less than one and crop yields fall by the water deficit percentage multiplied by the $K_y$ value. The resulting mean decadal changes in irrigated crop yields, adjusted for 2040s water availability, are presented in table 3.6.

Table 3.5 FAO Crop Response Factors

<table>
<thead>
<tr>
<th>Crop</th>
<th>$K_y$</th>
<th>FAO crop name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>1.25</td>
<td>Maize</td>
</tr>
<tr>
<td>Wheat</td>
<td>1</td>
<td>W. Wheat</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>1</td>
<td>Alfalfa 1</td>
</tr>
<tr>
<td>Grapes</td>
<td>0.85</td>
<td>Wine grapes</td>
</tr>
<tr>
<td>Apples</td>
<td>&gt;1</td>
<td>Assumed; other fruit trees are 1 or greater</td>
</tr>
<tr>
<td>Vegetables</td>
<td>1.1</td>
<td>Peppers, tomatoes &gt; 1</td>
</tr>
</tbody>
</table>


Note: $K_y$ = yield response factor (the elasticity between relative crop yield and relative water deficit).

Table 3.6 Effect of Climate Change on Crop Yield 2040–50 Relative to Current Yields for Irrigated Crops, Including Effects of Reduced Water Availability

<table>
<thead>
<tr>
<th>% change</th>
<th>AEZ/river basin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Northern</td>
</tr>
<tr>
<td></td>
<td>Reut</td>
</tr>
<tr>
<td>Low impact Maize</td>
<td>−23</td>
</tr>
<tr>
<td>Wheat</td>
<td>−6</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>−20</td>
</tr>
<tr>
<td>Grapes</td>
<td>−13</td>
</tr>
<tr>
<td>Apples</td>
<td>−7</td>
</tr>
<tr>
<td>Vegetables</td>
<td>−14</td>
</tr>
<tr>
<td>Medium impact Maize</td>
<td>−13</td>
</tr>
<tr>
<td>Wheat</td>
<td>−19</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>−12</td>
</tr>
<tr>
<td>Grapes</td>
<td>−9</td>
</tr>
<tr>
<td>Apples</td>
<td>−6</td>
</tr>
<tr>
<td>Vegetables</td>
<td>−10</td>
</tr>
<tr>
<td>High impact Maize</td>
<td>−18</td>
</tr>
<tr>
<td>Wheat</td>
<td>−39</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>−21</td>
</tr>
<tr>
<td>Grapes</td>
<td>−16</td>
</tr>
<tr>
<td>Apples</td>
<td>−18</td>
</tr>
<tr>
<td>Vegetables</td>
<td>−21</td>
</tr>
</tbody>
</table>

Note: Shading is darker the larger the decline in yield.
Notes

1. The results in tables 3.1 and 3.2 provide summary yield changes relative to current yields, expressed as average percent change per decade for the full 40-year study period. Orange indicates a decrease in yield, compared to the current situation, while green indicates an increase in yield. These percentage changes in many cases cannot be summed to reach to a total percentage over 40 years because for some crops, AEZs and scenarios, the changes do not show a linear trend.

2. A full accounting of indirect effects of climate change on crops would also incorporate the effects of higher ambient ozone, which also limits most crop yields.


5. For more information on the GRDC data, see the supporting documentation at http://www.grdc.sr.unh.edu/html/paper/index.html (accessed on January 15, 2011). Information on the Climate Research Unit can be found at http://www.cru.uea.ac.uk/.


CHAPTER 4

Identification of Adaptation Options for Managing Risk to Moldova’s Agricultural Systems

Options for Consideration

This section describes the qualitative approach to identifying and evaluating adaptation options, with a focus on those adaptation options that are not amenable to the quantitative assessment. The qualitative analyses are based on the expert judgment of three sets of individuals: (1) Moldovan in-country agricultural experts who were consulted throughout the study process; (2) farmers who shared their insights in consultation workshops; and (3) international experts engaged by the World Bank to conduct the analytical work for this study.

This section attempts to apply the same overall framework for identifying options to recommend that was used in the quantitative analyses (see chapter 5). In practice, this means the team attempted to identify options where, based on in-country and international experience, economic benefits (to farmers, primarily) seemed to exceed the costs (regardless of who bears the costs: the Moldovan government, donors, cooperatives, farmers themselves, or some combination). To the extent possible, a clear rationale and a time frame for implementing the recommended options were also identified. Finally, to the extent possible, the study attempts to be specific in its results as to the application of the options to Moldovan AEZs.

Table 4.1 provides the overall scope for the adaptation assessments in this chapter and in the quantitative analysis. The table includes four categories of options: (A) infrastructure adaptations, which are “hard” adaptation options that involve improvements to agriculture sector infrastructure, such as irrigation systems, to increase water availability; (B) programmatic adaptations, which strengthen existing programs or create new ones; (C) farm management adaptations, which are farm-level measures, and make up the largest
Table 4.1 Adaptation Options for Consideration

<table>
<thead>
<tr>
<th>Category</th>
<th>Adaptation measures and investments</th>
<th>Adaptation option reference number</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Infrastructural adaptations</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm protection</td>
<td><strong>Hail protection systems (nets)</strong></td>
<td>A.1</td>
</tr>
<tr>
<td></td>
<td>Install plant protection belts</td>
<td>A.2</td>
</tr>
<tr>
<td></td>
<td>Lime dust on greenhouses to reduce heat</td>
<td>A.3</td>
</tr>
<tr>
<td></td>
<td>Vegetative barriers, snow fences, windbreaks</td>
<td>A.4</td>
</tr>
<tr>
<td></td>
<td><strong>Move crops to greenhouses</strong></td>
<td>A.5</td>
</tr>
<tr>
<td></td>
<td>Smoke curtains to address late spring and early fall frosts</td>
<td>A.6</td>
</tr>
<tr>
<td></td>
<td>Build or rehabilitate forest belts</td>
<td>A.7</td>
</tr>
<tr>
<td>Livestock protection</td>
<td>Increase shelter and water points for animals</td>
<td>A.8</td>
</tr>
<tr>
<td></td>
<td>Windbreak planting to provide shelter for animals from extreme weather</td>
<td>A.9</td>
</tr>
<tr>
<td>Water management</td>
<td>Enhance flood plain management (for example, wetland management)</td>
<td>A.10</td>
</tr>
<tr>
<td></td>
<td>Construct levees</td>
<td>A.11</td>
</tr>
<tr>
<td></td>
<td><strong>Drainage systems</strong></td>
<td>A.12</td>
</tr>
<tr>
<td></td>
<td><strong>Irrigation systems: new, rehabilitated, or modernized (including drip irrigation, irrigation using less power, and the better use of local water sources)</strong></td>
<td>A.13</td>
</tr>
<tr>
<td></td>
<td><strong>Water harvesting and efficiency improvements</strong></td>
<td>A.14</td>
</tr>
<tr>
<td><strong>B. Programmatic adaptations</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extension and market development</td>
<td>Demonstration plots and/or knowledge sharing opportunities</td>
<td>B.1</td>
</tr>
<tr>
<td></td>
<td><strong>Education and training of farmers via extension services (new technology and knowledge-based farming practices)</strong></td>
<td>B.2</td>
</tr>
<tr>
<td></td>
<td><strong>National research and technology transfer through extension programs</strong></td>
<td>B.3</td>
</tr>
<tr>
<td></td>
<td>Private enterprises, as well as public or cooperative organizations for farm inputs (for example, seeds, machinery)</td>
<td>B.4</td>
</tr>
<tr>
<td></td>
<td>Strong linkages with local, national and international markets for agricultural goods</td>
<td>B.5</td>
</tr>
<tr>
<td>Livestock management</td>
<td>Fodder banks</td>
<td>B.6</td>
</tr>
<tr>
<td>Information systems</td>
<td>Better information on pest controls</td>
<td>B.7</td>
</tr>
<tr>
<td></td>
<td>Estimates of future crop prices</td>
<td>B.8</td>
</tr>
<tr>
<td></td>
<td>Improve monitoring, communication and distribution of information (for example, early warning system for weather events)</td>
<td>B.9</td>
</tr>
<tr>
<td></td>
<td><strong>Information about available water resources</strong></td>
<td>B.10</td>
</tr>
<tr>
<td>Insurance and subsidies</td>
<td>Crop insurance</td>
<td>B.11</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Subsidies and/or supplying modern equipment</td>
<td>B.12</td>
</tr>
<tr>
<td></td>
<td><strong>Locally relevant agricultural research in techniques and crop varieties</strong></td>
<td>B.13</td>
</tr>
<tr>
<td><strong>C. Farm management adaptations</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crop yield management</td>
<td>Change fallow and mulching practices to retain moisture and organic matter</td>
<td>C.1</td>
</tr>
<tr>
<td></td>
<td>Change in cultivation techniques</td>
<td>C.2</td>
</tr>
</tbody>
</table>

*table continues next page*
Table 4.1 Adaptation Options for Consideration (continued)

<table>
<thead>
<tr>
<th>Category</th>
<th>Adaptation measures and investments</th>
<th>Adaptation option reference number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation tillage</td>
<td>C.3</td>
<td></td>
</tr>
<tr>
<td>Crop diversification</td>
<td>C.4</td>
<td></td>
</tr>
<tr>
<td>Crop rotation</td>
<td>C.5</td>
<td></td>
</tr>
<tr>
<td>Heat- and drought-resistant crops/varieties/hybrids</td>
<td>C.6</td>
<td></td>
</tr>
<tr>
<td><strong>Increased input of agro-chemicals and/or organic matter to maintain yield</strong></td>
<td></td>
<td>C.7</td>
</tr>
<tr>
<td>Manual weeding</td>
<td>C.8</td>
<td></td>
</tr>
<tr>
<td>More turning over of the soil</td>
<td></td>
<td>C.9</td>
</tr>
<tr>
<td>Strip cropping, contour bunding (or plowing) and farming</td>
<td></td>
<td>C.10</td>
</tr>
<tr>
<td><strong>Switch to crops, varieties appropriate to temp, precipitation</strong></td>
<td></td>
<td>C.11</td>
</tr>
<tr>
<td><strong>Optimize timing of operations (planting, inputs, irrigation, harvest)</strong></td>
<td></td>
<td>C.12</td>
</tr>
<tr>
<td>Allocate fields prone to flooding from sea level rise as set-asides</td>
<td></td>
<td>C.13</td>
</tr>
<tr>
<td>Mixed farming systems (crops, livestock, and trees)</td>
<td></td>
<td>C.14</td>
</tr>
<tr>
<td>Shift crops from areas that are vulnerable to drought</td>
<td></td>
<td>C.15</td>
</tr>
<tr>
<td>Switch from field to tree crops (agro-forestry)</td>
<td></td>
<td>C.16</td>
</tr>
<tr>
<td>Livestock management</td>
<td>Livestock management (including animal breed choice, heat tolerant, change shearing patterns, change breeding patterns)</td>
<td>C.17</td>
</tr>
<tr>
<td>Match stocking densities to forage production</td>
<td></td>
<td>C.18</td>
</tr>
<tr>
<td>Pasture management (rotational grazing, etc.) and improvement</td>
<td></td>
<td>C.19</td>
</tr>
<tr>
<td>Rangeland rehabilitation and management</td>
<td></td>
<td>C.20</td>
</tr>
<tr>
<td>Supplemental feed</td>
<td>C.21</td>
<td></td>
</tr>
<tr>
<td>Vaccinate livestock</td>
<td>C.22</td>
<td></td>
</tr>
<tr>
<td><strong>Pest and fire management</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop sustainable integrated pesticide strategies</td>
<td></td>
<td>C.23</td>
</tr>
<tr>
<td>Fire management for forest and brush fires</td>
<td></td>
<td>C.24</td>
</tr>
<tr>
<td>Integrated pest management</td>
<td></td>
<td>C.25</td>
</tr>
<tr>
<td>Introduce natural predators</td>
<td></td>
<td>C.26</td>
</tr>
<tr>
<td><strong>Water management</strong></td>
<td>Intercropping to maximize use of moisture</td>
<td>C.27</td>
</tr>
<tr>
<td><strong>Optimize use of irrigation water (for example, irrigation at critical stages of crop growth, irrigating at night)</strong></td>
<td>C.28</td>
<td></td>
</tr>
<tr>
<td>Use water-efficient crop varieties</td>
<td></td>
<td>C.29</td>
</tr>
</tbody>
</table>

**D. Indirect adaptations**

<table>
<thead>
<tr>
<th>Category</th>
<th>Adaptation measures and investments</th>
<th>Adaptation option reference number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market development</td>
<td>Physical infrastructure and logistical support for storing, transporting, and distributing farm outputs</td>
<td>D.1</td>
</tr>
<tr>
<td>Education</td>
<td>Increase general education level of farmers</td>
<td>D.2</td>
</tr>
<tr>
<td>Water management</td>
<td>Improvements in water allocation laws and regulations</td>
<td>D.3</td>
</tr>
<tr>
<td></td>
<td>Institute water charging or tradable permit schemes</td>
<td>D.4</td>
</tr>
</tbody>
</table>

Note: Adaptation options in bold are those that are evaluated quantitatively in chapter 5.
Recommendations from Farmers

An important component of the study was to inform and consult stakeholders, farmers, and farmers’ associations, on the impact of climate change on agriculture and water resources. The team met with farmers for structured workshops in Balti, Chisinau, and Cahul in October 2010, for three days of stakeholder consultations. For the first day, a formal consultation was organized in Balti, in the Northern AEZ. A total of 24 participants attended the workshop including one university professor, a journalist, two other members of the Moldovan Extension Agency, ACSA, and about 20 farmers from the region. The second day, a stakeholder consultation workshop took place in Chisinau, in the Central AEZ, with 19 participants. On the final day, a stakeholder consultation workshop was organized in Cahul, in the Southern AEZ, with 24 participants.

Stakeholders were presented with projected yields of crops that are important to Moldova, and projected water supply and demand. Attendees were then asked if they have witnessed these impacts and what they have done, or would do, to mitigate their effects. All confirmed that several of the impacts have been felt on local farms. Although farmers are becoming more flexible in their response to climate events through education, their adaptive capacity is still quite limited because of poorly maintained irrigation and drainage systems, limited financial resources, and inadequate support from and access to technology, relevant know-how, weather forecasts, and extension services.

Overall Summary of Farmer Concerns and Adaptation Option Assessments

Farmers were first asked whether they had experienced the impact of climate change and whether they thought farming will be influenced, now and in the future, by this climate change. A very active discussion in each of the meetings resulted in the identification of the following topics as most relevant to the farmers in attendance:

- Drought
- High temperatures
- Frosts and hails (these are particularly a problem for orchards and vineyards)
- Temperature fluctuations, including high summer and low winter temperatures, and variations in day and night temperatures.

Information about current adaptive responses and AEZ-specific recommendations are provided below.

Current Adaptive Responses

Through conversations with stakeholders and with in-country experts, several adaptive responses that farmers are taking to climate events were conveyed. Examples are

- Irrigating
- Building reservoirs
• Harvesting rainwater
• Using local water sources for irrigation, such as creeks and groundwater
• Using protective materials, such as hail nets
• Changing planting patterns, such as crop rotation and inter-cropping
• Changing soil processes, including with chemical augmentation
• Moving vegetable production to greenhouses
• Shifting to drought-resistant varieties
• Installing plant protection belts
• Using mulch or other plant protection on soil
• Changing cultivation techniques, including no-till cultivation.

The adaptive capacity of farmers in Moldova is clearly stressed by changes in overall climate. The combination of heat waves, droughts, and intense storms is especially disruptive. On-farm adaptation responses have been numerous and partially successful, but farmers believe that larger investments in infrastructure are needed. This includes improved water storage, drainage and irrigation systems, as well as farmer training and access to information on weather related farming practices.

Summary of Discussions in Each AEZ
In the second stakeholder consultations, held April 8–11, 2011, the purpose of the meetings was three-fold: (1) to present local stakeholders with a recommended menu of adaptation options, (2) to gain feedback on those options, and (3) to elicit other climate change adaptation suggestions. The following questions were discussed in the AEZ-level workshops:

1. Which, if any, of the impacts discussed in the presentation on climate change impacts in Moldova have you observed?
2. Of these, which do you think are currently posing the greatest risk to your operations? Which do you think might pose the greatest risks in the future?
3. For those impacts that pose the greatest risk, what measures have you already taken (if any) in response?
4. What other responses do you think might be effective, and should be investigated in more detail?
5. What kind of additional information would be most helpful to you?

The outcomes of the discussions in each AEZ are summarized in the sections that follow.

Northern AEZ: Balti, April 11, 2011
The consultation at Balti included 25 farmers. Farms varied in size from less than a hectare to one of 160 hectares on which field crops were grown. Smaller farms were primarily for vegetable production, which were largely grown in greenhouses and irrigated using a drip system. The following list summarizes the group’s adaptation option rankings and scores:

Reduction of the Vulnerability of Moldova’s Agricultural Systems to Climate Change
http://dx.doi.org/10.1596/978-1-4648-0045-0
1. Construct small storage reservoirs, and improve water quality as the water currently contains high salt levels (15).
2. Conserve soil moisture: conservation tillage, mulching and plastic covering, intercropping, etc. (10).
3. Move appropriate crops to greenhouses (7).
4. Improve market infrastructure (credit, processing, storage, export; 5).
5. Rehabilitate and modernize irrigation infrastructure (4).
6. Improve insurance regime (4).
7. Improve river basin management and allocation laws (4).

**Central AEZ: Chisinau, April 9, 2011**
The session at Chisinau included 22 farmers, whose farms were relatively smaller than those in other districts, ranging in size from 350 m² to 20 hectares. Farms were more often engaged in vegetable production and utilized drip irrigation to a great degree, though some sprinkler-irrigated and rainfed crops (mostly corn and wheat) were also represented. The following is a summary of the group's top-ranked suggestions along with the scores of each:

1. Rehabilitate irrigation infrastructure (18).
2. Improve risk insurance regime (11).
3. Implement new and rehabilitated water collection and storage systems (8).
4. Improve access to more competitive credit, and private sector infrastructure would enable more adaptation investments (7).
5. Disseminate hydro-met information via cell phone texts (3).
6. Improve river basin management and allocation laws (2).

**Southern AEZ: Cahul, April 8, 2011**
Twenty-one participants were present at the meeting representing a diverse set of farming experiences. Farmers from both large and small farms were present. Some managed farms of less than two hectares, while one farmer owned a 272-hectare farm on which he had vineyards and field crops. Farmers employed all types of irrigation—drip irrigation was prevalent among those who grew vegetables such as tomatoes and cucumbers, while most of those who grew cereals and field crops did not irrigate. Two farmers of cabbage and early potatoes utilized sprinkler and surface irrigation. The following shows the ranked list of priorities, and scoring, of farmers in the Southern AEZ of Moldova:

1. Improve risk insurance regime for farmers (14).
2. Improve market infrastructure (credit, processing, storage, export; 8).
3. Expand use of moisture retention techniques, including equipment for conservation tillage (8).
4. Improve access to climate-appropriate crop and especially livestock varieties (8).
5. Promote reforestation and rehabilitate forest belts (7).
6. Rehabilitate, modernize irrigation infrastructure (5).
Concerning crops, the general conclusion of the team is that the “adaptation
deficit,” or the difference between current Moldovan yields and potential yields
for current climate, may be larger than the incremental gains that can be made
to better adapt the Moldovan agricultural system to the projected effects of cli-
mate change. Closing the adaptation deficit should be accomplished with future
climate change explicitly considered, especially for larger capital/infrastructure
projects such as irrigation infrastructure construction and/or rehabilitation. Every
large investment project should include analyses of climate change in the design
phase, because it is much less expensive to incorporate adjustments in the design
phase than as a retrofit option after the system is built.

The most critical need in Moldova, however, concerns irrigation water avail-
ability. Climate change will increase water demand for agriculture, and decrease
water supply, requiring Moldova to improve water use efficiency for on-farm
and water distribution systems. Recommended options, referring back to table
4.1, include the following:

- Optimize use of irrigation water (for example, the method of irrigating at critical
  stages of crop growth,) and optimize timing of operations (planting, inputs, irriga-
tion, and harvest) (Options C.12 and C.28). Training to enable farmers to
make better use of existing inputs is a high priority.

- Invest in irrigation systems: new, rehabilitated, or modernized (Option A.13).
The extent of the irrigation system in the recent past is extensive, though it is
not clear that irrigation can always be accomplished cost-effectively because
of the need for pumping. Nonetheless, rehabilitation is likely to be much
more cost-effective. Lining of irrigation channels to improve water use effi-
ciency is likely to have a high cost-benefit ratio.

- Improve water allocation laws and regulations (Option D.3). Currently, it ap-
ppears there are few incentives for farmers to use water efficiently. A water
allocation system that provides better signals about the importance of con-
serving scarce water would improve on-farm water use efficiency.

- Increase general education level of farmers (Options B.1, B.2, and B.3; possibly
coupled with B.14). More specifically, this option involves improving the existing
extension agency capacity overall to support better agronomic practices at
the farm level, and strategic implementation of a plan for more widespread
demonstration plots. This option could also be coupled with investment in
research focused on the testing of varieties that are better tuned for future
climate.

- Switch to crops and varieties appropriate to future climate regime (Options C.11,
C.6, and B.2). This option, assessed quantitatively in chapter 5, requires a
combination of increased knowledge at the national level and effective exten-
sion to advise farmers on those varieties best suited to the emerging tempera-
ture and precipitation trends. This option has both a medium-term and a
long-term component.
• Consider policy and/or private sector options to encourage more cooperative farming (Option B.4, as a step to more widespread adoption of all measures in Category C). Smallholders face great obstacles to investing to enhance yields. For smaller farms, these investments are difficult to justify; in larger cooperatives, there is a much greater likelihood that substantial economies of scale can be realized in implementing farm-level management improvements.

• Improve fallow and mulching practices to retain moisture and organic matter (Options C.1 and C.2). This measure is relatively low cost but could yield a substantial closure of the adaptation deficit and, in the process, improve the resiliency of the agricultural sector to climatic shifts and extremes such as drought.

• Consider strip cropping and contour bunding (plowing) (Option C.10). This option is designed to improve water management and reduce soil erosion; contour plowing in particular has been identified as an important measure to reduce soil erosion in other regional work on adapting the agriculture sector to climate change.

• Consider modifying existing crop insurance programs (Option B.11). The Moldovan Country Note prepared for this study states that Moldova began to implement a crop insurance program by subsidizing the cost of premiums to agricultural producers in an effort to cover the most vulnerable rural areas. Crop insurance, in general, is a risk-spreading instrument that provides more stable farmer income over time and across geography. If the goal in Moldova is to avoid farmers facing severe income loss and/or bankruptcy, the available options include crop insurance (which in most countries is provided by a private entity but subsidized by the government) and direct government disaster relief. The choice should be based on whether government payouts on crop insurance subsidies are lower than disaster relief payouts. The Moldova crop insurance covers risks including droughts, floods, storms, hail, and frosts. There are several problems with the current insurance programs, including coverage, cost to farmers, cost of monitoring, and the unsustainable government subsidies currently provided. The World Bank thus recommends replacing these programs with private weather insurance, based on a weather index system that does not require on-site adjusters and so is more efficient to operate (World Bank 2007) (see box 4.1).

Greenhouse Gas Mitigation Potential of Adaptation Options

Many of the adaptive measures recommended in this study for improving the climate resilience of Moldova’s agricultural sector also have the potential to mitigate the adverse effects of climate change now and in the future. Particular adaptive practices, like conservation tillage, present promising opportunities to lower greenhouse emissions by either increasing the carbon stored in agricultural soils or by reducing the greenhouse gases emitted in agricultural production processes. This section discusses the potential for greenhouse gas mitigation in
Identification of Adaptation Options for Managing Risk

Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change

Box 4.1 Index-Based Insurance

Crop insurance is one adaptation that addresses increasing occurrences of extreme weather events that are predicted with climate change. Increased losses with natural disasters have been observed globally, with economic losses from natural events increasing ten-fold from 1950 to 1999 (Munich Re 2000). Classic crop insurance, which makes up the majority of crop insurance around the world, is not optimal for rural small-scale farmers in developing countries. Traditionally, insurance requires large expenses for assessment of damages. Index-based insurance products instead use meteorological measurements to determine indemnity payments, as opposed to assessing damages at the individual farm level, allowing for a lower premium cost. Additionally index-based insurance reduces adverse selection, where those most at risk are the only ones who purchase policies, and moral hazard, where insured farmers do not try to avoid or minimize loss (Roberts 2005).

This new type of insurance is particularly useful for damages that impact areas relatively evenly. For example, weather types that can be measured to estimate monetary damages include minimum or maximum temperatures over a period of time, quantities of rainfall in a certain time period (either excess or lack of rainfall), or certain wind speeds. Payments can either be determined through temperature, precipitation and wind speed thresholds, or on a graduated scale. Certain devastating events are difficult to assess using index-based insurances such as hail and non-native pest damage. Additionally, it can be difficult to assess damages from hurricanes, as hurricanes vary in size and wind strength, and tracking a hurricane’s path is only an approximation of the actual path, which can lead to an unfair distribution of indemnity payments (Roberts 2005).

Index-based insurance is relatively new; however, implementation of both pilot and country-wide projects are fairly widespread. Two examples include crop insurance in Malawi and livestock insurance in Mongolia. Through FAO tools, effective weather-based crop yield indices for crop insurance were created for Malawi. A weather-based maize yield index for crop insurance for any point in Malawi can be determined every ten days, starting from the time of planting (FAO Data Tools). Additionally, the World Bank recommended an Index-Based Insurance Program based on livestock mortality rate by species and county in 2005 for Mongolia. The program has increased in popularity, with more than 14,000 insurance policies sold and indemnity payments made to the 2,117 herders who were eligible with livestock losses (World Bank 2010).

Moldova’s agricultural sector and highlights the specific adaptive measures that demonstrate the greatest opportunities for emissions reductions. A summary of the mitigation potential of various adaptive measures is provided in table 4.2.

The relative mitigation potential of the various adaptive measures described in table 4.2 is primarily based on each measure’s contribution to climate change as described in table 5.14 of Albania’s Second National Communication (SNC) to the Conference of Parties under the United Nations Framework Convention on Climate Change (Islami et al. 2009). The Team relied upon Albania’s SNC to

Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change
http://dx.doi.org/10.1596/978-1-4648-0045-0
### Table 4.2 Greenhouse Gas Mitigation Potential of Adaptation Options

<table>
<thead>
<tr>
<th>Adaptation measure</th>
<th>Adaptation option reference number</th>
<th>Mitigation impact</th>
<th>Mitigation potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation systems: new, rehabilitated, or modernized (including drip irrigation; use of local water sources)</td>
<td>A.13</td>
<td>Minimizes CO₂ emissions from energy used for pumping while maintaining high yields and crop-residue production.</td>
<td>✓</td>
</tr>
<tr>
<td>Change fallow and mulching practices to retain moisture and organic matter</td>
<td>C.1</td>
<td>Increases carbon inputs to soil and promotes soil carbon sequestration; Reduces energy used in transportation; Reduces energy consumption for production of agrochemicals.</td>
<td>✓✓</td>
</tr>
<tr>
<td>Conservation tillage</td>
<td>C.3</td>
<td>Minimizes the disturbance of soil and subsequent exposure of soil carbon to the air; Reduces soil decomposition and the release of CO₂ into the atmosphere; Reduces plant residue removed from soil thereby increasing carbon stored in soils; Reduces emissions from use of heavy machinery.</td>
<td>✓✓</td>
</tr>
<tr>
<td>Crop rotation</td>
<td>C.5</td>
<td>Rotation species with high residue yields help retain nutrients in soil and reduces emissions of GHG by carbon fixing and reduced soil carbon losses. Also increases carbon inputs to soil and fosters soil carbon sequestration.</td>
<td>✓✓✓</td>
</tr>
<tr>
<td>Strip cropping, contour bunding and farming</td>
<td>C.10</td>
<td>Increases carbon inputs to soil and fosters soil carbon sequestration.</td>
<td>✓✓✓</td>
</tr>
<tr>
<td>Optimize timing of operations (planting, inputs, irrigation, harvest)</td>
<td>C.12</td>
<td>More efficient fertilizer use reduces N losses, including NOₓ emissions; More efficient irrigation minimizes CO₂ emissions from energy used for pumping while maintaining high yields and crop-residue production.</td>
<td>✓✓</td>
</tr>
<tr>
<td>Allocate fields prone to flooding from sea level rise as set-asides</td>
<td>C.13</td>
<td>Increases soil carbon stocks; especially in highly degraded soils that are at risk erosion.</td>
<td>✓✓</td>
</tr>
<tr>
<td>Switch from field to tree crops (agro-forestry)</td>
<td>C.16</td>
<td>Retains nutrients in soil and reduces emissions of GHG by fixation of atmospheric N, reduction in losses of soil N, and increased carbon soil sequestration.</td>
<td>✓✓</td>
</tr>
<tr>
<td>Livestock management (including animal breed choice, heat tolerant, change shearing patterns, change breeding patterns)</td>
<td>C.17</td>
<td>Reduces CH₄ emissions.</td>
<td>✓</td>
</tr>
<tr>
<td>Match stocking densities to forage production</td>
<td>C.18</td>
<td>Reduces CH₄ emissions by speeding digestive processes.</td>
<td>✓</td>
</tr>
<tr>
<td>Pasture management (rotational grazing, etc.) and improvement</td>
<td>C.19</td>
<td>Degraded pastureland may be able to sequester additional carbon by boosting plant productivity through fertilization, irrigation, improved grazing, introduction of legumes, and/or use of improved grass species.</td>
<td>✓✓</td>
</tr>
</tbody>
</table>
Table 4.2  Greenhouse Gas Mitigation Potential of Adaptation Options (continued)

<table>
<thead>
<tr>
<th>Adaptation measure</th>
<th>Adaptation option reference number</th>
<th>Mitigation impact</th>
<th>Mitigation potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rangeland rehabilitation and management</td>
<td>C.20</td>
<td>Degraded rangeland may be able to sequester additional carbon by boosting plant productivity through fertilization, irrigation, improved grazing, introduction of legumes, and/or use of improved grass species.</td>
<td>✓✓</td>
</tr>
<tr>
<td>Intercropping to maximize use of moisture</td>
<td>C.27</td>
<td>Increases carbon inputs to soil and fosters soil carbon sequestration.</td>
<td>✓✓✓</td>
</tr>
<tr>
<td>Optimize use of irrigation water (for example, irrigation at critical stages of crop growth, irrigating at night)</td>
<td>C.28</td>
<td>Minimizes CO₂ emissions from energy used for pumping while maintaining high yields and crop-residue production.</td>
<td>✓</td>
</tr>
<tr>
<td>Use water-efficient crop varieties</td>
<td>C.29</td>
<td>Minimizes CO₂ emissions from energy used for pumping while maintaining high yields and crop-residue production.</td>
<td>✓</td>
</tr>
</tbody>
</table>

Note: CH₄ = methane, CO₂ = carbon dioxide, GHG = greenhouse gas; ✓✓✓ = high potential, ✓✓ = medium potential, ✓ = low potential.

estimate mitigation potential because Moldova’s SNC lacks a quantitative assessment of mitigation potential across adaptive practices. In particular, Albania’s SNC estimates a “score” for each adaptive measure according to its potential to reduce greenhouse gas emissions and mitigate the economic impacts of climate change. The measures were ordered by these scores and assigned a high potential (three checks in table 4.2) to the top third, a medium potential (two checks) to the middle third, and a low potential (one check) to the last third.

The adaptive practices discussed in Albania’s SNC were then mapped to those listed in table 4.2 based on similarities across qualitative descriptions. For example, Albania’s SNC estimates the mitigation potential of “Perennial crops (including agro-forestry practices), and reduced bare fallow frequency” which is here attributed to “Change fallow and mulching practices to retain moisture and organic matter” and “Switch from field to tree crops (agro-forestry)”. To supplement the analysis, a comprehensive review was also conducted of the economic and scientific literature related to the mitigating impacts of agricultural adaptation in Europe (Medina and Iglesias 2010; Paustian et al. 2006; Smith et al. 2005, 2008; Weiske 2007). The results of this review were used to corroborate the mitigation potentials identified in Albania’s SNC and to provide additional mitigation potentials for adaptive measures that were not explicitly quantified in Albania’s SNC.

Each year Moldova’s agricultural sector emits approximately 2.2 million tons of CO₂ equivalent of greenhouse gas emissions, which are generated by CO₂, nitrous oxide, and methane (Ivanov and Manful 2009). Mitigation of CO₂ emissions is primarily enabled by adaptive crop yield and cropland management practices that increase soil carbon content. Soil carbon content is augmented by either enhancing the uptake of atmospheric carbon in agricultural soils, or
by reducing carbon losses from agricultural soils. Specific adaptive practices that promote carbon soil sequestration include changing fallow season and mulching practices to retain moisture and organic matter and introducing cropping systems that promote high residue yields (that is, crop rotation, strip cropping, intercropping, cover cropping, etc.). Adaptive practices that slow rates of soil decomposition and reduce soil carbon losses include reduced till and no till farming.

Adaptive practices also have the ability to significantly reduce nitrous oxide and methane emissions. Nitrous oxide emissions are largely driven by fertilizer overuse, which increases soil nitrogen content and generates nitrous oxide losses. By improving fertilizer application techniques—specifically through more efficient allocation, timing, and placement of fertilizers—nitrous oxide emissions can be reduced while maintaining crop yields. Mitigation of methane emissions, on the other hand, is largely achieved by increasing the efficiency of livestock production. Optimizing breed choices, for example, serves to increase livestock production per animal, thereby reducing overall methane emissions. Improved feed quality quickens digestive processes and leads to reduced methane emissions. Finally, adaptive measures may also reduce the emissions associated with agricultural production processes. In particular, conservation tillage and manual weeding will reduce emissions generated by heavy machinery use. Similarly, increased irrigation efficiency reduces energy required to pump groundwater.

The potential for adaptive agricultural practices to simultaneously mitigate climate change has already garnered attention in Moldova as annual carbon losses from Moldova’s agricultural soils generate more than 1.8 million tons of CO₂ as a result of current agricultural technologies (Ivanov and Manful 2009). A recent case study undertaken in Moldova’s steppe zone assesses the mitigating impact of new agricultural technologies that focus on enhancing carbon accumulation and storage in agriculture soils (that is, conservation tillage, crop rotation, and more efficient fertilizer application). Results show that the improved agricultural technologies successfully reduced greenhouse gas emissions and suggest that Moldova could reduce emissions by more than 0.7 million tons of CO₂ if these technologies were applied to 50 percent of arable lands (Ivanov and Manful 2009).
CHAPTER 5

Cost-Benefit Analysis

Scope and Key Parameters

The quantitative cost-benefit analyses of adaptation options described in this chapter address seven of the most important adaptation options in a detailed fashion:

1. Adding new irrigation capacity
2. Rehabilitating existing irrigation infrastructure
3. Improving water use efficiency in fields
4. Adding new drainage capacity
5. Rehabilitating existing drainage infrastructure
6. Changing crop varieties and species
7. Optimizing fertilizer use.

These options may include costs for extension programs, as appropriate, if enhanced extension is necessary to achieve the full benefits of the adaptation option. This is true for two of these options: improving water use efficiency, and changing crop varieties. In the case of changing crop varieties, it is expected that farmers will incur little or no net cost from this change in farming practice. This is because the best farming practices are seemingly not pursued in Moldova at present because of incomplete research at the national level and lack of knowledge at the farm level. This has been confirmed by at least some of the farmers in the consultations. Therefore, the costs that would be incurred to enable these measures are to improve the capacity of extension services.

In addition, less detailed analyses was conducted of three other options: adding water storage capacity; installing hail nets for selected crops; and expanding the use of “plastic tunnels,” a form of greenhouse, for vegetable cultivation.

Assessments were conducted at the farm level, on a per hectare basis, and consider available estimates of the incremental cash costs for implementing the option as well as the revenue implications of increasing crop yields. All the estimates are conducted for representative “model” farms, located in each of the three Moldovan AEZs, for farms that cultivate each of the key crops. The yield
Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change

http://dx.doi.org/10.1596/978-1-4648-0045-0

benefits for adaptation options are analyzed for three crops modeled with the DSSAT system (wheat, maize, and pasture), and four crops modeled with the CropWat system (alfalfa, grapes, apples, and vegetables). Note that modeling yield changes for most adaptive measures with CropWat yielded unreliable results. As a result, yield changes for the CropWat crops were evaluated by reference to other work conducted in the region with the AquaCrop model, another FAO-supported crop model which yielded better results for the adaptation assessment. With seven crops, most of which are evaluated for both irrigated and rainfed yields, and three AEZs, there are a total of over 35 model farms in the analyses.

The results presented here are useful as a first order assessment of actions that are likely to yield positive returns for farmers. There is no conclusion in this analysis, however, regarding the farmers’ ability to pay for these measures. For example, while it may be concluded that irrigation infrastructure would increase farm-level revenue for certain crops and in certain locations, and the revenue increase would be greater than the per-hectare cost, this does not mean that it is recommended that farmers attempt to construct and pay for this infrastructure themselves. In fact, few farmers would actually be able to obtain individual farm-level irrigation infrastructure at the price per hectare used here, which reflects construction of a broader irrigation infrastructure project with potentially significant economies of scale. In many cases, national policies and/or funding are needed to enable these adaptations to occur.

While some measures (for example, additional fertilizer) could be pursued with limited or no government or donor involvement, most could be more cost-effectively pursued as sector or regional-scale programs. The results are therefore useful for decision-making at the national or regional scale, with the target decision-making audience being Moldovan government policymakers and donor communities with interest in financing agricultural sector investments.

For those options that are not amenable to quantitative cost-benefit analysis, a qualitative assessment of benefits and costs is provided based on the evaluation by the Team and summarized in chapter 4. Other costs and benefits that do not affect farm expenditures or revenues are excluded from the quantitative analysis, mainly owing to lack of available data. For example, while increasing fertilizer use may lead to social costs in terms of negative effects on nearby water quality, it is very difficult to quantify those effects without consideration of the site-specific characteristics that may be unique to individual farms. While those costs are excluded from the scope of the quantitative cost-benefit assessment, which focuses only on cash expenditures and revenues, social costs and other considerations are brought back into consideration qualitatively in the final chapter, as part of the overall results.

Figure 5.1 presents the revenue per hectare for crops, for rainfed and irrigated conditions, comparing current conditions with those with climate change in 2040s, but before adaptation actions are taken. For comparison purposes across years, the price forecasts incorporated in this figure are current prices rather than the high 2040 price forecasts. The figure indicates that the highest value crops,
now and in the future, are apples and vegetables. Among cereal crops, maize provides a higher return than wheat, although maize may not be viable in all areas of Moldova. As will be seen in the next section, adopting adaptation options has the potential for further yield and revenue enhancement, because adaptation can both address current yield deficits relative to full yield potential (closing the "adaptation deficit"), and enhance farmers abilities to both minimize risks and exploit opportunities presented by climate change.

**Results of Quantitative Analyses—Cost-Benefit Assessments**

This section presents example results for each of the options analyzed, focusing on the Central AEZ. Each adaptation option is illustrated graphically, showing B-C ratios for each crop assessed under each scenario. The dashed horizontal line in each graph shows a B-C ratio of one; bars that extend above this line represent crop/scenario/price forecast combinations where benefits exceed costs. Higher bars indicate higher cost-benefit ratios, and therefore those crop/scenario combinations, for the option examined, are more likely to be good investments. The quantitative results for each AEZ are summarized and ranked later in the chapter.
**Adding New Irrigation or Rehabilitating Existing Irrigation Infrastructure**

Figures 5.2 and 5.3 illustrate the results for adding irrigation capacity, and for rehabilitating existing irrigation capacity, respectively. The option was modeled as a switch from rainfed to irrigated for the model farms in each of the AEZs; the graph presents B-C ratios for the Central AEZ for each of the focus crops. The results in these figures indicate that B-C ratios are relatively high in this AEZ for maize and apples, and lower for alfalfa and wheat. Because rehabilitating irrigation infrastructure is less expensive than new infrastructure but the benefits are the

**Figure 5.2 Cost-Benefit Analysis for Newly Irrigated Crops in the Central AEZ**

![Cost-Benefit Analysis for Newly Irrigated Crops in the Central AEZ](image_url)
same, B-C ratios for rehabilitated infrastructure are higher than for new infrastructure, and vegetables have a B-C ratio greater than one (wheat and grapes have B-C ratios very close to one). In other AEZs, a similar pattern is seen, but in the north apples show the highest B-C ratios and in the south, maize. In all cases, B-C ratios under the high-, medium-, and low-climate scenarios are approximately equal to or higher than if the adaptation options are adopted under base climate conditions.

**Improving Water Use Efficiency in Fields**

Figure 5.4 shows the B-C ratios for improving water use efficiency in fields, for the Central AEZ. The main costs for this option are for drip irrigation, improvements to the hydrometeorological network to provide better precipitation forecasts, and enhanced extension services to build farmers’ capacity to make optimum use of existing water resources for irrigation. The results for the Central
AEZ indicate high B-C ratios for maize, but ratios well below one for alfalfa and vegetables. In general, the results across scenarios appear to be most sensitive to price projections and less sensitive to the climate scenario.

**Adding New Drainage Capacity and Rehabilitating Existing Drainage Infrastructure**

The results of the analysis on improving drainage in the Central AEZ are presented in figures 5.5 and 5.6. Figure 5.5 is for new drainage infrastructure, and Figure 5.6 is for rehabilitated drainage infrastructure.
This option involves a farm-level improvement of drainage conditions, entailing both capital and ongoing maintenance costs, estimated on a per hectare basis. Costs are higher for new drainage infrastructure than for rehabilitated infrastructure but the estimated yield increase is the same, so cost-benefit ratios are higher where it is possible to rehabilitate existing infrastructure. The yield effect in these calculations likely underestimates benefits because the modeling reflects only the continuous yield improvements, and does not reflect additional yield changes that might result from improved drainage during extreme flood events.1

Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change
http://dx.doi.org/10.1596/978-1-4648-0045-0
The results indicate that improved drainage can be most beneficial to improve yields of irrigated maize, but is also beneficial for virtually all non-fodder crops (all but alfalfa and pasture). However, although there has been some risk of floods in Moldova in recent years, farmers in Moldova (and local experts) have not mentioned a need for new or rehabilitated drainage infrastructures. It is also possible that soils in Moldova are already relatively well-drained, which would suggest the analysis overstates the benefits of this type of improvement.
Changing Crop Varieties

Figure 5.7 shows the results for changing crop varieties for the Central AEZ. For this option, the main cost is estimated to be enhanced research and development at the regional level, likely funded by national expenditures but potentially funded privately by farmer cooperatives or agribusiness concerns. For changes in crop variety, only the results for the Central AEZ are presented here, but results for other AEZs are similar. For this option the value of yield benefits is estimated for a change from current to optimal crop varieties, as feasible within the options available within the DSSAT model database of crop varieties. Note

Figure 5.7 Cost-Benefit Analysis for Optimizing Crop Varieties in the Central AEZ
that, because this option cannot be reliably evaluated within the CropWat system, results are presented only for DSSAT modeled crops.

As indicated in the figure, B-C ratios are highest for wheat, with extraordinarily high ratios of up to 200-to-1. B-C ratios for maize are lower but still significantly greater than one. In most cases, the benefits of optimizing crop varieties reflects the adaptation deficit, in that better varieties could result in substantial yield gains regardless of the change in climate. Costs for this adaptation option may however be underestimated here, as there may be additional costs to farmers for more expensive varieties, and possibly other direct costs for nutrient, pesticide, and water inputs to achieve the highest yields.

**Optimizing Fertilizer Application**

Figure 5.8 illustrates the results for optimized organic fertilizer application, relative to current use of fertilizer, for the Central AEZ. The graph shows high B-C ratios for wheat, and much lower ratios for maize. As noted above, however, the costs for fertilizer in the framework include only the direct expenditures, and do not reflect indirect costs and effects of fertilizer application for the surrounding environment, or the possibility that enhanced fertilizer application could in some cases also increase greenhouse gas emissions that contribute to climate change. As a result, while B-C ratios for this option are greater than one for maize, when other non-quantified social costs are considered it is likely the B-C ratio could drop to less than one.

**Other Economic Analyses**

In addition to the detailed economic analyses described above, analyses of the potential benefits and costs were conducted for three additional options that were of great interest to farmers, but for which data were less available: improving the hydrometeorological network; expanding extension services; and installing hail nets for selected crops. In addition, two basin level options for increasing water availability for farmers were examined: increasing basin-wide efficiency, through measures such as limiting losses in the water delivery system; and increasing basin-level storage capacity. These other economic analyses are informative for ranking options but provide less certainty than the more detailed analyses in the prior section.

**Improving the Hydrometeorological Network**

Other regional work by the World Bank has estimated the costs of improving hydrometeorological data collection and institutions in Albania, compared to the yield increases that would be necessary to achieve yield benefits equal to the estimated costs. Some of those estimates can be transferred to Moldova.

Although one of the benefits of this measure is improved timing of irrigation water application (analyzed above), it was not possible to monetize several other benefits of this alternative, some of which include flood forecasting, improved forecasting of crop life stages, and less frequent and more precise pesticide
application. Because direct comparison of costs and benefits is not possible, this option is instead evaluated by considering how much crop yields would need to increase in order to justify the costs of improving hydrometeorological capacity—this is sometime referred to as a break-even analysis. In total, it is estimated that the annualized capital and annual operation and maintenance (O&M) improvements in hydrometeorological capacity could cost 21 US cents per irrigated hectare per year. The cost would be considerably lower if rainfed hectares were included.
For the break-even analysis, the present value (over the period 2015–50) per hectare costs of hydrometeorological services is divided by the present value revenues for a typical hectare of each crop in each AEZ across each of the price and climate scenarios. This reveals the percentage increase in per hectare yields (that is, yields are linear with respect to revenues) necessary to cover the per hectare costs. Across all crops, AEZs, and scenarios, yields would need to increase an average of about less than 0.1 percent to justify the costs.

Based on these results, it can be concluded that expanding and tailoring the hydrometeorological network to agricultural needs would very likely yield benefits substantially greater than its costs. The key factor in achieving any yield increases, however, is providing relevant information to farmers in a timely fashion and in a manner in which they can readily access the information. In addition, farmers may need to be trained to make best use of this information in their farm-level decision-making for a wide range of agronomic decisions, including irrigation, nutrient application, and pest management.

**Expanding Extension Capabilities and Services**

The costs of enhanced extension services are included in B-C analyses of the optimized fertilizer application and improved irrigation water application options presented above. A break-even analysis for expanding extension services was also conducted. Information from broader regional analyses was utilized to estimate costs for an enhanced extension service. It is assumed that about 70 percent of the total number of farmland hectares in Moldova could benefit from enhanced extension, and that a reasonable program extension would cost about US$500,000 per year, so that the resulting program would have an annual cost per hectare of US$6.44. The average break-even yield increase required to justify this cost, across all crops, AEZs, and scenarios, is about 1 percent.

The yield increase required to justify the program seems plausible when compared to other estimates in the literature on the likely yield benefits of enhanced extension. For example, a meta-analysis of 294 studies of research and development rates of return (IFPRI 1998) found a 79 percent rate of return to extension services. The Inter-American Development Bank also found enhanced extension services increase yields by the lowest-producing grape farmers, and increase grape productivity (2008). Another study (Pesticide News 2007) found that farmer field schools reduced pesticide use on cotton by 34–66 percent. In a project to reform the Indian agriculture extension system, IFPRI found that Farmer Field School increased graduates’ cotton yields by 4–14 percent (2010).

**Installing Hail Nets for Apple Orchards and Other Crops**

Farmers in all three AEZs mentioned hail nets as a measure that some had already adopted in response to the threat of hail damage in the current climate. There is some emerging literature that indicates that climate change will lead to more frequent and more severe hail storms and thunderstorms (Trapp et al. 2007). Also, a recent study for Northeastern Spain estimates the costs of hail nets for apple crops relative to crop insurance; Iglesias and Alegre (2006) find slight
benefits of hail nets relative to crop insurance, but implicitly assume that crop insurance is already a wise investment, and do not evaluate the baseline risk of hail damage each year relative to insurance premiums.

Hail nets have both capital costs and yield implications; they reduce sunlight infiltration which reduces yield, but they also moderate extreme low and high temperatures to some extent, which can increase yield. Capital costs from Iglesias and Alegre and their estimates of net yield decrements from their field studies of gala apples were applied to multiple crops in all three AEZs. The result for the Central AEZ is illustrated in figure 5.9, in net present value terms. Note
that for all crops and scenarios, net present values are negative, reflecting costs in excess of benefits. The benefit-cost ratios for this measure never exceed 0.25 for any combination in any AEZ. The Iglesias and Alegre analysis provides some justification for the measure that some Moldovan farmers believe would be beneficial for their orchards, but the analysis reflecting local conditions suggests that this measure would not yield benefits in excess of costs.

**Improving Basin-Wide Water Efficiency**

A screening analysis was conducted of the benefits of improving water efficiency in three basins where the WEAP analysis finds that water shortages are likely: the Lower Nistru, the Reut, and the Upper Nistru. Unmet demands in the Reut basin are much larger than in the other two basins, as outlined in chapter 3. Improving irrigation efficiency was examined from the baseline of 50 percent (based on FAO data, but an estimate that remains highly uncertain) in 5 percent increments, up to a high of 75 percent, in both basins. The benefit is increased profit (not revenue) from additional irrigation water to bring back to cultivation additional acreage; for example, under the medium-impact climate change scenario in the Reut basin, a 5 percent increase in efficiency makes available an additional 640,000 m$^3$ of water to meet irrigation demand, reducing the unmet demand from 5.6 percent to 3.8 percent, and allows significant additional hectares to be irrigated each year by the 2040s. Costs for this measure are derived from similar irrigation efficiency improvements in other recent World Bank projects in the region.

The results are presented in figure 5.10, with one panel each for the Reut and Upper Nistru basins (results for the lower Nistru are comparable to the upper Nistru). Cost-benefit ratios are lower for the Reut basin than for the Upper and Lower Nistru basins, but in all cases cost-benefit ratios are greater than one. As a result, in all three basins it appears that the costs of substantial improvements in basin-wide water efficiency are justified by the yield-enhancing benefits of additional irrigation potential.

**Expanding Water Storage Capacity**

A screening analysis was also conducted of the costs and benefits of building new storage capacity, to provide additional water during times of low water supply. The limitations of the approach are substantial; it was not possible to conduct detailed studies of basin dynamics, and there is no analysis undertaken of the implications of storage for transboundary flows and compliance with international water treaties. The estimated costs of constructing storage are from Ward et al. (2010), and are between 12 and 30 US cents per cubic meter, varying based on the size of storage structure and the average slope of the basin.

The benefits of storage are in reducing unmet irrigation water demand, and therefore providing additional net revenues of cultivating crops. The value of additional crop cultivation is net revenue from a mix of crops identical to those currently cultivated in the basin. In practice this may overstate benefits because, as water shortages manifest, water might be diverted to higher value crops.
Figure 5.10  Impact of Improving Basin-Wide Irrigation Efficiency

a. Reut basin

b. Upper Nistru basin
Estimating benefits for Moldova, however, is complicated by the competition for water supplies from M&I demand. As described in more detail in chapter 3, the projections used for M&I demand suggest that, as incomes in Moldova grow through 2050, M&I demand could increase substantially. As a result, increased basin yields from additional storage are at best shared with agricultural demands. However, because of the higher value of water for M&I, are mostly allocated to M&I. For this reason, cost-benefit ratios for irrigation uses in both the upper and lower Nistru basins are extremely low, with benefits equal to zero in many cases because all the storage water yield goes to meet M&I demand.

Another important factor in Moldova is that the terrain does not lend itself to large-scale storage projects. Smaller-scale storage is more feasible, but in general the moderate terrain makes storage projects more expensive as well as difficult to site.

Figure 5.11 illustrates the range of B-C results for the Reut basin. Cost-benefit ratios for storage vary substantially by the amount of storage, along the horizontal axis, and the climate scenario, represented by the individual bars, with storage generally showing cost-benefit ratios much less than one for almost all scenarios.

Figure 5.11 Preliminary Analysis of the Benefits and Costs of Water Storage in the Reut Basin

Note: mcm = million cubic meters.
Only more modest storage increases yield cost-benefit ratios greater than one for any scenario, and then only the high-price, high-impact scenario.

These results should be considered with caution, however, as they reflect only a zero-order analysis of the viability of storage across the basin, at a very coarse resolution, without the benefit of detailed study of the feasibility of constructing additional water storage. With water shortages forecast in Moldova as a result of multi-sector demand and supply reductions from climate change, if water storage options are to be considered further an integrated water management approach that incorporates demands from all sectors would appear to be necessary to achieve a goal of increasing water for agricultural irrigation purposes.

**Sensitivity Analyses**

As indicated above, the sensitivity of the B-C ratio and present value of benefits were examined across 12 (3×2×2) scenarios, including the three climate scenarios (low-, medium-, and high-impact), two carbon dioxide fertilization assumptions (no effect and full effect), and two price projections (low forecast, which holds prices constant, and high forecast, which incorporates a gradual upward trend in prices based on IFPRI published projections). The results in general are most sensitive to the price projections, which yield relatively larger changes in revenues in later years of the period of analysis, near 2050, though some of those differences are tempered by application of a 5 percent discount rate.

The effect on the results of using a 10 percent rather than 5 percent discount and cost-of-capital rate was also considered. Overall, use of a higher discount rate results in present value benefits of the adaptation options falling by about a factor of two (across crops, AEZs, and climate/crop price scenarios). The effect on present values varies and depends on relative magnitudes of the costs and benefits. In a small number of instances, about 2 percent, the use of a 10 percent discount rate causes NPVs of the adaptation options to change signs. The changes are from positive NPVs to negative NPVs, and occur under adaptation scenarios where the NPVs are already near zero. Because only options with B-C ratios much greater than one or NPVs much greater than zero are recommended here, the higher discount rate does not alter the results of the priority ranking.

More detailed sensitivity analyses are possible, including analysis of the optimal start date for specific options for each crop and AEZ, as illustrated in figures 5.12 and 5.13. Figure 5.12 shows that, under all scenarios and start dates, changes in irrigated maize varieties in the Central AEZ have a B-C ratio greater than one. Figure 5.13, for the same measure in the same AEZ, but for rainfed maize, shows a different pattern, where under the low-impact climate scenario, for later start dates, B-C are less than one. In this case, climate is clearly more important than price in determining the B-C ratios. One conclusion from figure 5.13 might be that, rather than ruling out implementation of this measure, it would be prudent to wait to implement this option, and to monitor how climate scenarios unfold over time.
Analysis of Livestock Sector Adaptation

In the absence of a process model that can simulate the effects of climate change and adaptation measures on livestock productivity, it is difficult to evaluate livestock sector adaptation options. As a result, the livestock sector options are based on the literature review and qualitative analysis. These include options such as providing better protection for livestock during heat waves (ranging from better shade to air-conditioned barn space) and transitioning livestock varieties. Chapter 6 recommends a national policy to devote greater attention to evaluating the suitability of gradually introducing heat-tolerant breeds for stocking Moldovan herds.
Summary of Quantitative Results in AEZs

The previous section highlights selected results for cost-benefit ratios for the Central AEZ. Cost-benefit ratios are useful, but another useful measure is net present value benefits, which indicates the per hectare benefits minus the per hectare costs over the full period of analysis, starting in 2015 and ending in 2050. Ranges of results reflect variation across climate and price scenarios.

Tables 5.1 through 5.3 summarize the net benefit estimates for the three Moldovan AEZs. The tables list the adaptation measures with the highest overall net benefits. Note that only those crops with a positive net benefit are listed; for
all other crops not listed in the table, a negative or very near zero net benefit is estimated for the measure.

The ranking of benefits also considers that some benefit and cost estimates are incomplete, as indicated in the “Notes” column. For example, the estimated costs for optimizing fertilizer application include only the costs for the fertilizer input and extension service to advise farmers and leave out the potentially very significant environmental costs to surface and ground water quality, as well as potential

<table>
<thead>
<tr>
<th>Description of recommended adaptation measure</th>
<th>Crop focus for Northern AEZ</th>
<th>Illustrative present value economic results per hectare (000 2009$)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Improve varieties</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigated maize</td>
<td>$4 to 9</td>
<td>$0.35</td>
<td>$3 to 9</td>
</tr>
<tr>
<td>Rainfed maize</td>
<td>$4 to 8</td>
<td>$3 to 7</td>
<td></td>
</tr>
<tr>
<td>Irrigated wheat</td>
<td>$5 to 10</td>
<td>$4 to 9</td>
<td></td>
</tr>
<tr>
<td>Rainfed wheat</td>
<td>$3 to 6</td>
<td>$3 to 5</td>
<td></td>
</tr>
<tr>
<td>2) Use irrigation water more efficiently</td>
<td>Irrigated maize</td>
<td>$17 to 25</td>
<td>$10 to 19</td>
</tr>
<tr>
<td>Irrigated vegetables</td>
<td>$27 to 38</td>
<td>$21 to 32</td>
<td></td>
</tr>
<tr>
<td>3) Rehabilitate existing drainage infrastructure</td>
<td>Irrigated alfalfa</td>
<td>$0.5 to 0.7</td>
<td>$0.2 to 0.4</td>
</tr>
<tr>
<td>Rainfed alfalfa</td>
<td>$0.4 to 0.5</td>
<td>$0.07 to 0.2</td>
<td></td>
</tr>
<tr>
<td>Irrigated grapes</td>
<td>$9 to 13</td>
<td>$8 to 12</td>
<td></td>
</tr>
<tr>
<td>Rainfed grapes</td>
<td>$8 to 11</td>
<td>$7 to 11</td>
<td></td>
</tr>
<tr>
<td>Irrigated maize</td>
<td>$20 to 30</td>
<td>$19 to 30</td>
<td></td>
</tr>
<tr>
<td>Rainfed maize</td>
<td>$16 to 23</td>
<td>$15 to 23</td>
<td></td>
</tr>
<tr>
<td>Pasture</td>
<td>$0.4 to 0.6</td>
<td>$0.1 to 0.3</td>
<td></td>
</tr>
<tr>
<td>4) Install new drainage infrastructure</td>
<td>Irrigated grapes</td>
<td>$9 to 13</td>
<td>$8 to 12</td>
</tr>
<tr>
<td>Rainfed grapes</td>
<td>$8 to 11</td>
<td>$7 to 9</td>
<td></td>
</tr>
<tr>
<td>Irrigated maize</td>
<td>$20 to 30</td>
<td>$19 to 29</td>
<td></td>
</tr>
<tr>
<td>Rainfed maize</td>
<td>$16 to 23</td>
<td>$15 to 29</td>
<td></td>
</tr>
<tr>
<td>5) Rehabilitate existing irrigation infrastructure</td>
<td>Rainfed apples</td>
<td>$21 to 32</td>
<td>$17 to 28</td>
</tr>
<tr>
<td>Rainfed maize</td>
<td>$7 to 16</td>
<td>$3 to 12</td>
<td></td>
</tr>
<tr>
<td>6) Install new irrigation infrastructure</td>
<td>Rainfed apples</td>
<td>$21 to 32</td>
<td>$10 to 21</td>
</tr>
<tr>
<td>Rainfed maize</td>
<td>$2 to 5</td>
<td>$0.4 to 3</td>
<td></td>
</tr>
<tr>
<td>7) Optimize fertilizer application</td>
<td>Irrigated maize</td>
<td>$2 to 5</td>
<td>$1 to 2</td>
</tr>
<tr>
<td>Rainfed maize</td>
<td>$2 to 3</td>
<td>$1 to 2</td>
<td></td>
</tr>
</tbody>
</table>
Table 5.2 Adaptation Measures with High Net Benefits: Central AEZ

<table>
<thead>
<tr>
<th>Description of recommended adaptation measure</th>
<th>Crop focus for Central AEZ</th>
<th>Illustrative present value economic results per hectare (000 2009$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Estimated revenue gain</td>
</tr>
<tr>
<td>1) Improve varieties</td>
<td>Irrigated maize</td>
<td>$4 to 10</td>
</tr>
<tr>
<td></td>
<td>Rainfed maize</td>
<td>$1 to 6</td>
</tr>
<tr>
<td></td>
<td>Irrigated wheat</td>
<td>$16 to 26</td>
</tr>
<tr>
<td></td>
<td>Rainfed wheat</td>
<td>$7 to 9</td>
</tr>
<tr>
<td>2) Use irrigation water more efficiently</td>
<td>Irrigated maize</td>
<td>$16 to 24</td>
</tr>
<tr>
<td>3) Rehabilitate existing drainage infrastructure</td>
<td>Irrigated alfalfa</td>
<td>$0.5 to 0.7</td>
</tr>
<tr>
<td></td>
<td>Rainfed alfalfa</td>
<td>$0.4 to 0.6</td>
</tr>
<tr>
<td></td>
<td>Irrigated grapes</td>
<td>$8 to 13</td>
</tr>
<tr>
<td></td>
<td>Rainfed grapes</td>
<td>$7 to 10</td>
</tr>
<tr>
<td></td>
<td>Irrigated maize</td>
<td>$19 to 29</td>
</tr>
<tr>
<td></td>
<td>Rainfed maize</td>
<td>$11 to 18</td>
</tr>
<tr>
<td></td>
<td>Pasture</td>
<td>$0.5 to 0.7</td>
</tr>
<tr>
<td></td>
<td>Irrigated vegetables</td>
<td>$4 to 6</td>
</tr>
<tr>
<td></td>
<td>Rainfed vegetables</td>
<td>$4 to 5</td>
</tr>
<tr>
<td></td>
<td>Irrigated wheat</td>
<td>$4 to 6</td>
</tr>
<tr>
<td></td>
<td>Rainfed wheat</td>
<td>$3 to 4</td>
</tr>
<tr>
<td>4) Install new drainage infrastructure</td>
<td>Irrigated grapes</td>
<td>$9 to 13</td>
</tr>
<tr>
<td></td>
<td>Rainfed grapes</td>
<td>$7 to 10</td>
</tr>
<tr>
<td></td>
<td>Irrigated maize</td>
<td>$19 to 29</td>
</tr>
<tr>
<td></td>
<td>Rainfed maize</td>
<td>$11 to 18</td>
</tr>
<tr>
<td></td>
<td>Irrigated vegetables</td>
<td>$4 to 6</td>
</tr>
<tr>
<td></td>
<td>Rainfed vegetables</td>
<td>$4 to 5</td>
</tr>
<tr>
<td></td>
<td>Irrigated wheat</td>
<td>$4 to 6</td>
</tr>
<tr>
<td></td>
<td>Rainfed wheat</td>
<td>$3 to 4</td>
</tr>
<tr>
<td>5) Rehabilitate existing irrigation infrastructure</td>
<td>Irrigated apples</td>
<td>$9 to 19</td>
</tr>
<tr>
<td></td>
<td>Rainfed maize</td>
<td>$14 to 26</td>
</tr>
<tr>
<td></td>
<td>Rainfed vegetables</td>
<td>$7 to 13</td>
</tr>
<tr>
<td>6) Install new irrigation infrastructure</td>
<td>Rainfed maize</td>
<td>$14 to 26</td>
</tr>
<tr>
<td>7) Optimize fertilizer application</td>
<td>Irrigated maize</td>
<td>$2 to 5</td>
</tr>
<tr>
<td></td>
<td>Rainfed maize</td>
<td>$2 to 3</td>
</tr>
<tr>
<td></td>
<td>Irrigated wheat</td>
<td>$4 to 6</td>
</tr>
<tr>
<td></td>
<td>Rainfed wheat</td>
<td>$2 to 3</td>
</tr>
</tbody>
</table>

greenhouse gas emissions, which could result from added fertilizer loads on fields. In part for this reason, but also because the estimated benefits are low, fertilizer application is the lowest-ranked of the options listed here.

This ranking of measures by their net benefits is carried through to the next chapter, where results of the quantitative and qualitative evaluations are combined to arrive at an overall set of recommended climate adaptation options for Moldovan agriculture.
Table 5.3 Adaptation Measures with High Net Benefits: Southern AEZ

<table>
<thead>
<tr>
<th>Description of recommended adaptation measure</th>
<th>Crop focus for Southern AEZ</th>
<th>Estimated revenue gain (000 2009$)</th>
<th>Estimated costs (000 2009$)</th>
<th>Net revenues (000 2009$)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Improve varieties</td>
<td>Irrigated maize</td>
<td>$5 to 12</td>
<td>$0.35</td>
<td>$5 to 12</td>
<td>Costs are for R&amp;D</td>
</tr>
<tr>
<td></td>
<td>Rainfed maize</td>
<td>$3 to 6</td>
<td></td>
<td>$2 to 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Irrigated wheat</td>
<td>$17 to 29</td>
<td></td>
<td>$17 to 28</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rainfed wheat</td>
<td>$7 to 12</td>
<td></td>
<td>$7 to 12</td>
<td></td>
</tr>
<tr>
<td>2) Use irrigation water more efficiently</td>
<td>Irrigated maize</td>
<td>$10 to 14</td>
<td>$6.1</td>
<td>$4 to 8</td>
<td>Costs are drip irrigation, extension &amp; hydromet</td>
</tr>
<tr>
<td></td>
<td>Irrigated vegetables</td>
<td>$15 to 20</td>
<td></td>
<td>$8 to 14</td>
<td></td>
</tr>
<tr>
<td>3) Rehabilitate existing drainage infrastructure</td>
<td>Irrigated alfalfa</td>
<td>$0.4 to 0.6</td>
<td>$0.31</td>
<td>$0.1 to 0.3</td>
<td>Benefits do not reflect increased risk of floods with climate change</td>
</tr>
<tr>
<td></td>
<td>Rainfed alfalfa</td>
<td>$0.4 to 0.6</td>
<td></td>
<td>$0.1 to 0.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Irrigated grapes</td>
<td>$8 to 12</td>
<td></td>
<td>$8 to 11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rainfed grapes</td>
<td>$7 to 10</td>
<td></td>
<td>$7 to 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Irrigated maize</td>
<td>$18 to 26</td>
<td></td>
<td>$18 to 26</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rainfed maize</td>
<td>$10 to 17</td>
<td></td>
<td>$10 to 17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pasture</td>
<td>$0.4 to 0.7</td>
<td></td>
<td>$0.1 to 0.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Irrigated vegetables</td>
<td>$4 to 6</td>
<td></td>
<td>$4 to 5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rainfed vegetables</td>
<td>$4 to 5</td>
<td></td>
<td>$4 to 5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Irrigated wheat</td>
<td>$4 to 6</td>
<td></td>
<td>$4 to 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rainfed wheat</td>
<td>$3 to 4</td>
<td></td>
<td>$2 to 3</td>
<td></td>
</tr>
<tr>
<td>4) Install new drainage infrastructure</td>
<td>Irrigated grapes</td>
<td>$8 to 12</td>
<td>$1.0</td>
<td>$7 to 11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rainfed grapes</td>
<td>$7 to 10</td>
<td></td>
<td>$6 to 9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Irrigated maize</td>
<td>$18 to 26</td>
<td></td>
<td>$17 to 25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rainfed maize</td>
<td>$10 to 17</td>
<td></td>
<td>$9 to 16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Irrigated vegetables</td>
<td>$4 to 6</td>
<td></td>
<td>$3 to 4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rainfed vegetables</td>
<td>$4 to 5</td>
<td></td>
<td>$2 to 4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Irrigated wheat</td>
<td>$4 to 6</td>
<td></td>
<td>$3 to 5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rainfed wheat</td>
<td>$3 to 4</td>
<td></td>
<td>$2 to 3</td>
<td></td>
</tr>
<tr>
<td>5) Rehabilitate existing irrigation infrastructure</td>
<td>Rainfed maize</td>
<td>$12 to 22</td>
<td>$4</td>
<td>$8 to 18</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rainfed wheat</td>
<td>$5 to 7</td>
<td></td>
<td>$1 to 3</td>
<td></td>
</tr>
<tr>
<td>6) Install new irrigation infrastructure</td>
<td>Rainfed maize</td>
<td>$12 to 22</td>
<td>$11</td>
<td>$1 to 12</td>
<td></td>
</tr>
<tr>
<td>7) Optimize fertilizer application</td>
<td>Irrigated maize</td>
<td>$3 to 6</td>
<td>$1.2</td>
<td>$2 to 5</td>
<td>Costs do not include environ. damages</td>
</tr>
<tr>
<td></td>
<td>Rainfed maize</td>
<td>$2 to 4</td>
<td></td>
<td>$1 to 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Irrigated wheat</td>
<td>$5 to 7</td>
<td></td>
<td>$3 to 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rainfed wheat</td>
<td>$2 to 4</td>
<td></td>
<td>$1 to 3</td>
<td></td>
</tr>
</tbody>
</table>
Notes

1. Note that it was not possible to estimate yield effects of this option with the DSSAT model. Instead, the AquaCrop model from the Albanian analysis was used to illustrate the potential yield benefits for improving drainage.

2. Cost-benefit ratios over time, however, are influenced by an inability to estimate benefits after 2050. In many cases, benefits of options that have a continued useful life after 2050, and may have higher benefits as climate changes accelerate after 2050, may be underestimated.
This chapter combines the review of current adaptive capacity (chapter 1), the identification of the risk of climate change to agriculture (chapter 3), the results of the farmer and World Bank evaluation of adaptation options in (chapter 4), the quantitative evaluation of adaptation measures in (chapter 5), and the results of the National Dissemination and Consensus Building Conference held in Chisinau on April 12, 2011, to arrive at an overall set of high-priority policy, institutional capacity building, and investment measures to improve the resilience of Moldovan agriculture to climate change.1

Below is a summary of the high-priority options identified at the national level, followed by recommendations specific to each AEZ. The discussions below include summaries of the ranked lists developed at the National Conference.

Options at the National Level

Based on the analysis in the study, four measures for adoption at the national level were identified. The basis for the ranking of these options in most cases is the qualitative analysis of potential net benefits, combined with support from the farmer consultations. These national-level options are the following:

1. *Increase the access of farmers to technology and information through farmer education, both generally and for adapting to climate change.* The capacity of the existing extension agency be improved in two areas: (1) to support better agronomic practices at the farm level, including implementation of more widespread demonstration plots and access to better information on the availability and best management practices of high-yield crop varieties, with a particular focus on drought- and pest-resistant varieties; and (2) to support the same measures but with a focus on maintaining yields during extreme water stress periods that are likely be more frequent with climate change. The first part of this option is a short-term measure to close the adaptation deficit,
Options to Improve Climate Resilience

Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change

http://dx.doi.org/10.1596/978-1-4648-0045-0

and the second part is a long-term measure to ensure yield gains are not undermined by future climate change. Investing in extension has a high cost-benefit ratio in the quantitative analysis. Building better links between research and on-farm outcomes is also a part of this measure.

2. Improve the dissemination of hydrometeorological information to farmers. In every farmer meeting held, participants noted a need for better weather information, focused on better warning for extreme events. While the current lead hydrometeorological institution in Moldova is a highly capable organization that has access to good equipment, additional capacity is needed to better disseminate climatological information, to support better farm-level decisionmaking. The economic analysis of the costs and benefits of a relatively modest hydrometeorological investment, which includes training and annual operating costs, suggests that benefits of such a program are very likely to exceed costs.

3. Investigate options for crop insurance, particularly for drought. The Moldovan Country Note observes that crop insurance, while presently available in Moldova, is not viable for the vast majority of agricultural producers. This conclusion was supported in the farmer workshops, and farmers remain eager to explore insurance options. The Country Note also suggests that a possible way to expand coverage could be via the piloting of a privately run index-based weather insurance program. This approach has many potential advantages over traditional multiple-peril crop insurance, including simplification of the product, standardized claim payments to farmers in a district based on the index, avoidance of individual farmer field assessment, lower administrative costs, more timely claim payments after loss, and easier accommodation of small farms within the program. The program may be particularly suitable for Moldova, where the institutional hydrometeorological capacity is relatively sophisticated and could support an index-based approach. The drawback of an index-based approach may be the inability to readily insure coverage of damage from pests. Overall, an effort is needed at the national level to fully investigate these options, because insurance systems need to be carefully designed to maintain incentives for farmers to continue to invest in drought damage mitigation and resilience, such as through better water use efficiency.

4. Encourage private sector measures to most efficiently adapt to climate change. There may be a tendency to assume that adaptation to climate change is necessarily a public sector function, but as the economic analysis in chapter 5 has demonstrated, there is strong private sector incentive with economic benefits greatly exceeding costs for measures that will improve the resiliency of Moldovan agriculture to climate change. The national government should focus on putting in place policies that enable the private sector to effectively assist in adaptation. For example, conducting testing of seed and livestock varieties for their suitability for Moldovan climate, terrain, and soil conditions, and making recommendations through extension of the best varieties, but allowing the private sector to provide those varieties. In addition, farmers noted the need for better market information, including crop price information.
At the National Conference, the national breakout group developed the following ranked list of adaptation options:

1. Promote farmer access to drought, heat and pest tolerant plant varieties available from national and international sources, soil conservation technology, and improved water use efficiency.
2. Extend farmers’ access to financial resources and create incentives to adopt adaptive measures, with a focus on soil conservation technologies and drought-tolerant horticultural crops, and improve crop insurance affordability for adverse climatic events such as hail storms.
3. Implement the national policy on the development of market infrastructure for agro-food production including promotion of the wholesale market in Chisinau and four regional markets.
4. Support hydro-met, mass media and private sector information providers to provide necessary and timely information.

These options are summarized in table 6.1, where options in italics indicate overlap between these options and the National Conference recommendations (all options overlap).

Combining the above priorities with the options emerging from the National Conference generates an overall set of adaptation measures at the national level. Figure 6.1 links the climate change exposures to impacts, and then these impacts

<table>
<thead>
<tr>
<th>Adaptation measure</th>
<th>Specific focus areas</th>
<th>Net economic benefit</th>
<th>Expert assessment</th>
<th>Potential to aid farmers with or without climate change</th>
<th>Evaluation by local farmers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improve access to technology, financial resources and information</td>
<td>Seed varieties; more efficient use of water</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Improve dissemination of hydrometeorological information</td>
<td>Extreme event forecasts, drought forecasts</td>
<td>High (based on &quot;break-even&quot; analyses)</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Improve crop insurance affordability and streamline implementation</td>
<td>Drought damage</td>
<td>Not evaluated</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Encourage private sector adaptation and market infrastructure</td>
<td>Seeds, livestock breed research; agri. market information provision</td>
<td>Not evaluated</td>
<td>Potentially High</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

Note: Rows in italics indicate measures that were prioritized both by the expert analysis and by the stakeholders participating in the National Conference.
to the national-level adaptation options. Measures shaded in darker green represent options that were recommended by both the consultants’ assessment and the National Conference group.

**Options at the AEZ Level**

The results of the adaptation modeling (chapter 5), qualitative analysis, and farmer consultations (chapter 4) form the basis for overall ranked options to improve the resilience of Moldova’s agricultural sector to climate change. Those results are presented in tables 6.2 through 6.4, for each AEZ. Each table reflects four ranking criteria and an assessment of the measure on a five-point scale for net economic benefits, with all measures on that scale representing a favorable economic evaluation. The scale provides a rank order; and a three-point scale (high, medium, or low) for other criteria:

- Net economic benefits (benefits minus costs).
- Expert assessment of ranking for those options that cannot be evaluated in economic terms.
- “Win-win” potential. A measure with a high potential for increasing the welfare of Moldovan farmers, with or without climate change.

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**Figure 6.1 Adaptation Measures at the National Level Based on Team and National Conference Assessment**

<table>
<thead>
<tr>
<th>Climate hazard</th>
<th>Impact</th>
<th>Adaptation</th>
</tr>
</thead>
</table>
| • Decreased and more variable precipitation  
  • Higher temperatures  
  • Reduced river runoff | Reduced, less certain, and lower quality crop and livestock yields | Encourage private sector involvement to improve agricultural productivity |
| • Increased frequency and severity of extreme events | Crop failure | Implement national policy on development of market infrastructure |
| | | Improve farmer access to technologies, crop varieties, and information |
| | | Improve dissemination of hydromet information to farmers |
| | | Extend farmers' access to financial resources and create incentives to adapt |
| | | Investigate options for crop insurance |

High priority | Medium priority
Table 6.2 Adaptation Options for the Northern AEZ

<table>
<thead>
<tr>
<th>Adaptation measure</th>
<th>Crop and livestock focus</th>
<th>Ranking criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Net economic benefit: ranking in quantitative analysis</td>
</tr>
<tr>
<td>Improve crop varieties</td>
<td>Wheat, Maize</td>
<td>1</td>
</tr>
<tr>
<td>Improve farm-level irrigation water efficiency</td>
<td>Maize, Vegetables</td>
<td>2</td>
</tr>
<tr>
<td>Rehabilitate irrigation infrastructure, increase basin-wide irrigation efficiency</td>
<td>All crops</td>
<td>3</td>
</tr>
<tr>
<td>Research and improve livestock management, nutrition, and health</td>
<td>Beef cattle, Chickens</td>
<td>Unknown</td>
</tr>
<tr>
<td>Optimize agronomic practices</td>
<td>Maize</td>
<td>7</td>
</tr>
</tbody>
</table>

Note: Rows in italics indicate measures that were prioritized both by the expert analysis and by the stakeholders participating in the National Conference. The measure not in italics was prioritized only by the expert analysis.

- Favorable evaluation by the local farming community. These results are based on the results of two stakeholder consultations at the AEZ level, with farmers and local agriculture sector experts.

In addition, the sections below summarize the results of the individual, AEZ-specific small groups that met at the National Conference on April 12, 2011. The purpose of those groups was to rank adaptation options most advantageous for each AEZ. To the extent possible, the results of those ranking exercises have been incorporated in the summary tables presented below. The synthesized menus of high- and medium-priority adaptation options for each AEZ are summarized in figures 6.2 through 6.4.

**Northern AEZ**

At the National Conference, the Northern AEZ breakout group developed the following ranked list of adaptation options:

1. Promote soil moisture conservation technologies such minimum tillage, mulching, efficient use of fertilizers, and plastic mulching.
2. Improve access to higher-yield and drought-tolerant crop varieties and livestock breeds and management systems, developed locally and internationally.
3. Improve and enhance access to information and training of farmers for wide-scale adoption of technologies.
4. Improve water quality for irrigation water.
5. Enhance water use efficiency at the farm level.
6. Promote forestry and agroforestry in areas prone to soil erosion and degradation.
7. Promote agricultural produce under greenhouses and plastic tunnels.

Five options emerge from the quantitative, qualitative, and farmer evaluations of measures as most advantageous for adapting to climate change in the Northern AEZ. Where these options overlap with recommendations from the National Conference, they are italicized in table 6.2.

- ** Improve access to higher-yield and drought-resistant crop varieties.** The team evaluated yield increases possible by changing varieties in the short term to higher-yield alternatives. To achieve the higher yields, experts note that this measure needs to be combined with extension on management practices; this analysis also reflects those costs. These measures represent some of the potentially most cost-effective measures to improve resiliency, they provide benefits both with and without climate change, and they were strongly supported by Northern AEZ farmers.

- **Enhance irrigation water efficiency.** Improving irrigation water efficiency is a farm-level measure that includes drip irrigation, extension to support good decision-making about the use of this technology, and provision of better hydromet information to farmers. This suite of measures represents a high priority for farmers and the Team, and shows high economic benefits as well.

- **Research and improve livestock management, health, and nutrition.** The team assessed the benefits of a program to improve livestock management techniques (for example breeding), health, and nutrition (for example, improved forage and silage) as a means of increasing productivity of livestock. The World Bank team assessment ranked this measure as a medium priority. Farmers did not mention this as a high priority, but the National Conference stakeholder group felt it should be a high priority.

- **Repair irrigation infrastructure and increase basin-wide irrigation efficiency.** Repairing irrigation infrastructure that is in disrepair can also improve its effective capacity. Farmers were in favor of enhancing the irrigation system. Analysis of a measure to repair irrigation infrastructure also finds a very high B-C ratio, providing further support for this measure. Although the basin-wide irrigation efficiency measure was not ranked, the WEAP analysis and supplemental economic analysis suggest that there is high potential for investments in basin-wide irrigation system efficiency, especially in the Reut Basin.

- **Optimize agronomic practices.** High to very high B-C ratios were found for optimizing fertilizer application, based on the enhanced yields indicated by crop modeling. When combined with the omission of other costs of fertilizer application, such as reduced water quality, however, there is a significant potential that a full cost analysis could yield costs in excess of yield benefits. Although the quantitative analysis only covered fertilizer practices, farmers supported a broader level of support for improved agronomic practices in general. The sensitivity analysis suggests that yield benefits associated with
this measure do not necessarily change with climate change. Thus, this is a “close the adaptation deficit” option, particularly when coupled with the national measure, discussed above, to enhance extension and localized weather forecasting capacity.

Figure 6.2 presents an overall set of prioritized adaptation options based on the National Conference recommendations and the options considered by the team. Measures shaded in darker green represent options that were recommended by both the team assessment and the National Conference groups.

**Central AEZ**

Many of the most highly ranked measures in the Central AEZ are similar to those in the Northern AEZ. Note that switching to existing, higher-yield varieties has greatest value where there is already irrigation and that there is less impact from the higher-yield varieties when the crop is rainfed, because water application cannot be timed to achieve the best results from these varieties. Farmers in this AEZ also advocated for support for improved employment of drought-resistant varieties, which currently have limited availability and so are difficult to evaluate quantitatively. These varieties would be beneficial for both irrigated and rainfed crops, but have their greatest effect over time and for the lower precipitation scenarios. As a result, a phased approach to this variant of the “improve varieties”...
option may be called for. The Central AEZ breakout group at the National Conference developed the following ranked list of adaptation options:

1. Encourage specific crop, livestock or horticultural production systems based on compatibility with natural resources.
2. Improve access to higher yield and drought-tolerant plant varieties and livestock breeds and management systems, developed locally and internationally.
3. Rehabilitate irrigation infrastructure and improve water collection ponds.
4. Train farmers on improved on-farm water use efficiency and soil moisture conservation technologies.

Where these National Conference recommendations overlap with the original consultant team priorities in table 6.3, they are listed in italics.

Merging the above priorities with the options from the National Conference generates an overall menu of adaptation measures for the Central AEZ. Figure 6.3 summarizes exposures, impacts, and adaptation options, where measures shaded in darker green represent options that were recommended by both the Bank assessment and the National Conference groups.

**Southern AEZ**

Table 6.4 summarizes highly ranked adaptation measures for the Southern AEZ. Crop modeling suggests that crops in the Southern AEZ may face the greatest

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**Table 6.3 Adaptation Options for the Central AEZ**

<table>
<thead>
<tr>
<th>Adaptation measure</th>
<th>Crop and livestock focus</th>
<th>Ranking criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Net economic benefit: ranking in quantitative analysis</td>
</tr>
<tr>
<td>Improve crop varieties</td>
<td>Wheat, Maize</td>
<td>1</td>
</tr>
<tr>
<td>Improve irrigation water efficiency</td>
<td>Maize</td>
<td>2</td>
</tr>
<tr>
<td>Rehabilitate irrigation capacity</td>
<td>Apples, Maize, Vegetables</td>
<td>3</td>
</tr>
<tr>
<td>Build new small-scale water storage</td>
<td>All crops, but especially in the Reut basin</td>
<td>Moderate for the Reut basin</td>
</tr>
<tr>
<td>Research and improve livestock management, nutrition, and health</td>
<td>Beef cattle, Chickens</td>
<td>Unknown</td>
</tr>
<tr>
<td>Optimize agronomic practices</td>
<td>Wheat, Maize</td>
<td>7</td>
</tr>
</tbody>
</table>

Note: Rows in italics indicate measures that were prioritized both by the expert analysis and by the stakeholders participating in the National Conference. The measures not in italics were prioritized only by the expert analysis.
Figure 6.3 Adaptation Measures for the Central AEZ Based on Team and National Conference Assessment

<table>
<thead>
<tr>
<th>Climate hazard</th>
<th>Impact</th>
<th>Adaptation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreased and more variable precipitation, Higher temperatures, Reduced river runoff</td>
<td>Reduced, less certain, and lower quality crop and livestock yields</td>
<td>Improve livestock varieties, management, nutrition, and health</td>
</tr>
<tr>
<td>Increased frequency and severity of extreme events</td>
<td>Crop failure</td>
<td>Optimize agronomic inputs: fertilizer application and soil moisture conservation</td>
</tr>
</tbody>
</table>

Table 6.4 Adaptation Options for the Southern AEZ

<table>
<thead>
<tr>
<th>Adaptation measure</th>
<th>Crop and livestock focus</th>
<th>Net economic benefit: ranking in quantitative analysis</th>
<th>Net economic benefit: expert assessment</th>
<th>Potential to aid farmers with or without climate change</th>
<th>Ranking by local farmers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improve varieties for higher yield and drought resistance</td>
<td>Wheat, Maize</td>
<td>1</td>
<td>High</td>
<td>High</td>
<td>4</td>
</tr>
<tr>
<td>Improve on-farm water use efficiency</td>
<td>Maize, Vegetables</td>
<td>2</td>
<td>High</td>
<td>High</td>
<td>3</td>
</tr>
<tr>
<td>Rehabilitate existing irrigation infrastructure, build small-scale water storage</td>
<td>All crops</td>
<td>5</td>
<td>High</td>
<td>High</td>
<td>6</td>
</tr>
<tr>
<td>Research and improve livestock management, nutrition, and health</td>
<td>Beef cattle, Chickens</td>
<td>Unknown</td>
<td>High</td>
<td>Low</td>
<td>4</td>
</tr>
<tr>
<td>Optimize agronomic practices</td>
<td>Maize, Wheat</td>
<td>7</td>
<td>Not mentioned</td>
<td>High</td>
<td>3</td>
</tr>
</tbody>
</table>

Note: Rows in italics indicate measures that were prioritized both by the expert analysis and by the stakeholders participating in the National Conference. The measure not in italics was prioritized only by the expert analysis.
risks from changes in temperature and precipitation. Irrigation water may be particularly scarce in this region, owing to the flatter terrain (which is less amenable to surface storage) and to the higher current use of groundwater resources, which can be of variable quality and quantity. As a result, improving on-farm water use efficiency and developing drought-resistant varieties are of high importance in the Southern AEZ.

The Southern AEZ representatives at the National Conference developed a list of adaptation options, ranked as follows:

1. Improve collection and storage of good quality rain and river water.
2. Train farmers on improved on-farm water use efficiency.
3. Support access to improved varieties of crops that are tolerant to biotic and abiotic hazards, particularly for almonds, walnuts, grapes, peaches, apricots, and forest nuts.
4. Promote adoption of locally-adapted livestock and their nutrition and management.
5. Rehabilitate and restore wetlands along the Prut River.
6. Encourage specific farming systems such as crops, livestock or horticultural based production systems based on the compatibility of natural resources.
7. Promote silvi-pastoral practices on degraded lands.

Where these National Conference recommendations overlap with the original team priorities in table 6.4, they are listed in italics.

Figure 6.4 summarizes exposures, impacts, and adaptation options for the Southern AEZ, where measures shaded in darker green represent options that were recommended by both the Bank assessment and the National Conference groups.

Categorization of Short-, Medium-, and Long-Term Options

The measures outlined in the previous section will need to be implemented over differing time scales to ensure they have maximum effect and cost-effectiveness. As part of the quantitative analysis undertaken in this study, several sensitivity tests were conducted to assess whether, as climate changes, certain of the options analyzed might be more effectively implemented (on a cost basis) at a certain point in time. For all the options analyzed, however, it was found that time was not an important factor in determining B-C ratios. In other words, options with B-C ratios greater than one exhibited positive net benefits from the start of the simulations (in 2015), and exhibited continued net benefits throughout the period of analysis (through 2050), regardless of the simulated start date. The opposite was also true: options with B-C ratios less than one exhibited those low B-C ratio values for all simulated start dates.

As a result, categorization of short-, medium-, and long-term options is mainly based on qualitative assessment. For this purpose, short-term options are those
most appropriate for implementation in 1–3 years; medium-term options would be implemented in 4–10 years; and long-term options in 10 years or more.

**Short-Term Options**
The following should be implemented or at least initiated within 1–3 years of the completion of the study:

- Improve on-farm water use efficiency.
- Improve dissemination of weather forecasts.
- Improve access to new varieties, technology, and know-how, including demonstration plots, farmer field schools, and forums for cooperative learning.
- Optimize agronomic inputs, including fertilizer application and soil moisture conservation.
- Evaluate crop insurance reform options.

**Medium-Term Options**
The following should be implemented or at least initiated within 4–10 years of the completion of the study. These measures will require lead time to ensure they are designed with consideration of the effects of future climate change on the potential for episodic flooding, for example. Prior to implementing these options, therefore, more detailed engineering feasibility
studies will be needed for these long-term investments, but those studies must consider the effects of climate change. However, these measures are not long-term options, because they clearly will yield benefits based on current climate conditions, even before the climate changes significantly:

- Evaluate small-scale water storage options.
- Improve basin-level irrigation efficiency.

**Long-Term Options**

The following options require long lead time to implement, and also are best pursued as climate scenarios unfold:

- Research and develop new drought-tolerant varieties.
- Transition to more heat-tolerant livestock systems, with attention to management, nutrition, and health.

A study with this broad scope necessarily involves significant limitations. These include the need to make assumptions about many important aspects of agricultural and livestock production in Moldova, the limits of simulation modeling techniques for forecasting crop yields and water resources, and time and resource constraints. Some of the options will require more detailed examination and analysis than could be accomplished within the scope of this study to ensure that specific adaptation measures are implemented in a manner that maximizes their value to Moldovan agriculture.

It is hoped, however, that the awareness of climate risks and the analytic capacities built through the course of this study provide not only a greater understanding among Moldovan agricultural institutions of the basis of the results presented here, but also an enhanced capability to conduct the required, more detailed, assessment that will be needed to further pursue the most promising adaptation measures.

**Note**

1. The National Conference was structured so that participants could first learn more about the work presented in this report, and then work in small groups to develop AEZ-level rankings of options identified here, determine if some of the options were infeasible or not needed, and add new options for consideration. Ultimately, each of the small breakout groups, one for each AEZ, made a specific recommendation to the conference with a ranked list of adaptation options, including in some cases national-level policy and institutional strengthening needed to successfully implement those options.
Glossary

The source of these definitions is the IPCC AR4 Working Group II report, Appendix I: Glossary, unless otherwise noted. Italics indicate that the term is also contained in this glossary.

**Adaptation.** Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory, autonomous, and planned adaptation:

- **Anticipatory adaptation**—Adaptation that takes place before impacts of climate change are observed. Also referred to as proactive adaptation.
- **Autonomous adaptation**—Adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in human systems. Also referred to as spontaneous adaptation.
- **Planned adaptation**—Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state.

**Adaptation assessment.** The practice of identifying options to adapt to climate change and evaluating them in terms of criteria such as availability, benefits, costs, effectiveness, efficiency, and feasibility.

**Adaptation—“hard” vs. “soft”.** “Hard” adaptation measures usually imply the use of specific technologies and actions involving capital goods, such as dikes, seawalls and reinforced buildings, whereas “soft” adaptation measures focus on information, capacity building, policy and strategy development, and institutional arrangements. (World Bank 2011)

**Adaptive capacity (in relation to climate change impacts).** The ability of a system to adjust to climate change (including climate variability and extreme to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

**Agroforestry.** A dynamic, ecologically based, natural resources management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels (World Agroforestry Centre 2011).
**Aquaculture.** The managed cultivation of aquatic plants or animals, such as salmon or shellfish, held in captivity for the purpose of harvesting.

**Arid region.** A land region of low rainfall, where “low” is widely accepted to be less than 250 millimeters precipitation per year.

**Baseline/reference.** The baseline (or reference) is the state against which change is measured. It might be a “current baseline,” in which case it represents observable, present-day conditions. It might also be a “future baseline,” which is a projected future set of conditions excluding the driving factor of interest. Alternative interpretations of the reference conditions can give rise to multiple baselines. Economic baselines reflect current conditions, and climate baselines reflect the decade 2000–2009.

**Basin.** The drainage area of a stream, river, or lake.

**Benefits of adaptation.** The avoided damage costs or the accrued benefits following the adoption and implementation of adaptation measures.

**Biophysical model.** Biophysical modeling applies physical science to biological problems, for example, in understanding how living things interact with their environment. In this report, biophysical modeling is used in conjunction with economic modeling.

**Capacity building.** In the context of climate change, capacity building is developing the technical skills and institutional capabilities in developing countries and economies in transition to enable their participation in all aspects of adaptation to, mitigation of, and research on climate change, and in the implementation of the Kyoto Mechanisms.

**Carbon dioxide (CO$_2$).** A naturally occurring gas fixed by photosynthesis into organic matter. A by-product of fossil fuel combustion and biomass burning, it is also emitted from land-use changes and other industrial processes. It is the principal anthropogenic greenhouse gas that affects the Earth’s radiative balance. It is the reference gas against which other greenhouse gases are measured, thus having a Global Warming Potential of 1.

**Carbon dioxide fertilization.** The stimulation of plant photosynthesis due to elevated CO$_2$ concentrations, leading to either enhanced productivity and/or efficiency of primary production. In general, C$_3$ plants show a larger response to elevated CO$_2$ than C$_4$ plants.

**Catchment.** An area that collects and drains water.

**Climate.** Climate in a narrow sense is usually defined as the “average weather,” or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system. The classical period of time is 30 years, as defined by the World Meteorological Organization (WMO).
Climate change. Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), which defines climate change as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.” See also climate variability.

Climate model. A numerical representation of the climate system based on the physical, chemical, and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties. The climate system can be represented by models of varying complexity (that is, for any one component or combination of components a hierarchy of models can be identified, differing in such aspects as the number of spatial dimensions; the extent to which physical, chemical, or biological processes are explicitly represented; or the level at which empirical parameterizations are involved. Coupled atmosphere/ocean/sea-ice General Circulation Models (AOGCMs) provide a comprehensive representation of the climate system. More complex models include active chemistry and biology. Climate models are applied, as a research tool, to study and simulate the climate, but also for operational purposes, including monthly, seasonal, and interannual climate predictions.

Climate Moisture Index (CMI). CMI is a measure of aridity that is based on the combined effect of temperature and precipitation. The CMI depends on average annual precipitation and average annual potential evapotranspiration (PET). If PET is greater than precipitation, the climate is considered to be dry, whereas if precipitation is greater than PET, the climate is moist. Calculated as \( CMI = (P/PET) - 1 \) (when \( PET > P \)) and \( CMI = 1 - (PET/P) \) (when \( P > PET \)), a CMI of –1 is very arid and a CMI of +1 is very humid. As a ratio of two depth measurements, CMI is dimensionless.

Climate projection. The calculated response of the climate system to emissions or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based on simulations by climate models. Climate projections are distinguished from climate predictions, in that the former critically depend on the emissions/concentrations/radiative forcing scenarios used, and therefore on highly uncertain assumptions of future socio-economic and technological development.

Climate risk. Denotes the result of the interaction of physically defined hazards with the properties of the exposed systems - i.e., their sensitivity or social vulnerability. Risk can also be considered as the combination of an event, its likelihood and its consequences - i.e., risk equals the probability of climate hazard multiplied by a given system’s vulnerability (UNDP 2005).

Climate (change) scenario. A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships and assumptions of radiative forcing, typically constructed for
explicit use as input to climate change impact models. A “climate change scenario” is the difference between a climate scenario and the current climate.

**Climate variability.** Climate variability refers to variations in the mean state and other statistics (such as standard deviation, statistics of extremes, and so on) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variation in natural or anthropogenic external forcing (external variability). See also climate change.

**Costs of adaptation.** Costs of planning, preparing for, facilitating, and implementing adaptation measures, including transition costs.

**Crop modeling.** Determines characteristics of crops such as yield and irrigation water requirements. Examples of inputs to crop models include changes in conditions, such as soil type, soil moisture, precipitation levels, and temperature, and changes in inputs, such as fertilizer and irrigation levels.

**Deficit irrigation.** A type of irrigation meant to maximize water-use efficiency (WUE) for higher yields per unit of irrigation water applied: the crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing season. The expectation is that any yield reduction will be insignificant compared with the benefits gained through diverting the saved water to irrigate other crops. The grower must have prior knowledge of crop yield responses to deficit irrigate (Kirda 2000).

**Desert.** A region of very low rainfall, where “very low” is widely accepted to be less than 100 millimeters per year.

**Discount rate.** The degree to which consumption now is preferred to consumption one year from now, with prices held constant, but average incomes rising in line with GDP per capita.

**Drought.** The phenomenon that exists when precipitation is significantly below normal recorded levels, causing serious hydrological imbalances that often adversely affect land resources and production systems.

**Evaporation.** The transition process from liquid to gaseous state.

**Evapotranspiration.** The combined process of water evaporation from the Earth’s surface and transpiration from vegetation.

**Exposure.** A description of the current climate risk within the priority system, that is, the probability of a climate hazard combined with the system’s current vulnerability (UNDP 2005).

**Extreme weather event.** An event that is rare within its statistical reference distribution at a particular place. Definitions of “rare” vary, but an extreme weather event would normally be as rare or rarer than the 10th or 90th percentile. By definition, the characteristics of what is called “extreme weather” may vary from place to place. Extreme weather events typically include floods and droughts.

**Food security.** A situation that exists when people have secure access to sufficient amounts of safe and nutritious food for normal growth, development, and an
active and healthy life. Food insecurity may be caused by the unavailability of food, insufficient purchasing power, inappropriate distribution, or inadequate use of food at the household level.

**Forecast.** See climate projection.

**Global circulation model (GCM).** Computer model designed to help understand and simulate global and regional climate, in particular the climatic response to changing concentrations of greenhouse gases. GCMs aim to include mathematical descriptions of important physical and chemical processes governing climate, including the role of the atmosphere, land, oceans, and biological processes. The ability to simulate subregional climate is determined by the resolution of the model.

**Greenhouse gas (GHG).** Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth’s surface, the atmosphere, and clouds. This property causes the greenhouse effect. Water vapor (H2O), carbon dioxide (CO2), nitrous oxide (N2O), methane (CH4), and ozone (O3) are the primary greenhouse gases in the Earth’s atmosphere. As well as CO2, N2O, and CH4, the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride (SF6), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs).

**Hydrometeorological data.** Information on the transfer of water between land surfaces and the lower atmosphere, especially in the form of precipitation. This type of data can provide insight on effects on agriculture, water supply, flood control, and more.

**(Climate change) Impact assessment.** The practice of identifying and evaluating, in monetary and/or non-monetary terms, the effects of climate change on natural and human systems.

**(Climate change) Impacts.** The effects of climate change on natural and human systems. Depending on the consideration of adaptation, one can distinguish between potential impacts and residual impacts:

- **Potential impacts**—all impacts that may occur given a project change in climate, without considering adaptation.
- **Residual impacts**—the impacts of climate change that would occur after adaptation.

**Index-based insurance.** A type of crop insurance that uses meteorological measurements to determine indemnity payments, as opposed to assessing damage at the individual farm level, allowing for a lower premium cost. This type of insurance is particularly useful for damages that affect areas relatively uniformly (Roberts 2005).

**Infrastructure.** The basic equipment, utilities, productive enterprises, installations, and services essential for the development, operation, and growth of an organization, city, or nation.
**Integrated water resources management (IWRM).** The prevailing concept for water management which, however, has not been defined unambiguously. IWRM is based on four principles that were formulated by the International Conference on Water and Environment in Dublin in 1992: (1) Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment; (2) Water development and management should be based on a participatory approach, involving users, planners, and policy makers at all levels; (3) Women play a central part in the provision, management, and safeguarding of water; and (4) Water has an economic value in all its competing uses and should be recognized as an economic good.

**Irrigation water-use efficiency.** Irrigation water-use efficiency is the amount of biomass or seed yield produced per unit of irrigation water applied, typically about 1 tonne of dry matter per 100 millimeters water applied.

**Mitigation.** An anthropogenic intervention to reduce the anthropogenic forcing of the climate system; it includes strategies to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks.

**Multiple-peril crop insurance (MPCI).** A type of insurance that is geared toward a level of expected yield, rather than to the damage that is measured after a defined loss event. MPCI policies are best suited to perils where individual contribution to a crop loss are difficult to measure and peril impacts last over a long period of time. Yield shortfall may be determined on either an area or individual farmer basis (Roberts 2005).

**Net present value (NPV).** Total discounted benefits less discounted costs.

**Projection.** The potential evolution of a quality or set of quantities, often computed with the aid of a model. Projections are distinguished from predictions in order to emphasize that projections involve assumptions—concerning, for example, future socioeconomic and technological developments, that may or may not be realized—and are therefore subject to substantial uncertainty.

**Rangeland.** Unmanaged grasslands, shrublands, savannas, and tundra.

**Reservoir.** A component of the climate system, other than the atmosphere, that has the capacity to store, accumulate, or release a substance of concern (for example, carbon or greenhouse gas). Oceans, soils, and forests are examples of carbon reservoirs. The term also means an artificial or natural storage place for water, such as a lake, pond, or aquifer, from which the water may be withdrawn for such purposes as irrigation or water supply.

**Resilience.** The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the capacity to adapt to stress and change.

**Runoff.** That part of precipitation that does not evaporate and is not transpired.

**Scenario.** A plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from
projections, but are often based on additional information from other sources, sometimes combined with a “narrative storyline.” See also (climate change) scenario.

**Sector.** A part or division, as of the economy (for example, the manufacturing sector, the services sector) or the environment (for example, water resources, forestry) (UNDP 2005).

**Semi-arid regions.** Regions of moderately low rainfall, which are not highly productive and are usually classified as rangelands. “Moderately low” is widely accepted as 100–250 millimeters precipitation per year. See also arid region.

**Sensitivity.** Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (for example, a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (for example, damages caused by an increase in the frequency of coastal flooding due to sea-level rise).

**Silviculture.** Cultivation, development, and care of forests.

**Special Report on Emissions Scenarios (SRES).** The storylines and associated population, GDP, and emissions scenarios associated with the Special Report on Emissions Scenarios (SRES; Nakicenovic et al. 2000), and the resulting climate change and sea-level rise scenarios. Four families of socioeconomic scenarios—A1, A2, B1, and B2—represent different world futures in two distinct dimensions: a focus on economic versus environmental concerns and global versus regional development patterns.

**Stakeholder.** A person or organization that has a legitimate interest in a project or entity or would be affected by a particular action or policy.

**United Nations Framework Convention on Climate Change (UNFCCC).** The convention was adopted in 1992 in New York and signed at the 1992 Earth Summit in Rio de Janeiro by more than 150 countries and the European Community; it entered in force in March 1994. Its ultimate objective is the “stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.” It contains commitments for all “parties, which under the convention, are those entities included in Annex I that aim to return greenhouse gas emissions not controlled by the Montreal Protocol to 1990 levels by the year 2000.

**Vulnerability.** Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.

**Water stress.** A country is water-stressed if the available freshwater supply relative to water withdrawals acts as an important constraint on development. Withdrawals exceeding 20 percent of renewable water supply have been used as an indicator of water stress. A crop is water-stressed if soil-available water,
and thus actual evapotranspiration, is less than potential evapotranspiration demands.

**Water-use efficiency (WUE).** Carbon gain in photosynthesis per unit water lost in evapotranspiration. It can be expressed on a short-term basis as the ratio of photosynthetic carbon gain per unit transpirational water loss or on a seasonal basis as the ratio of net primary production or agricultural yield to the amount of available water.

**Win-win options.** "Win-win" options are measures that contribute to both climate change mitigation and adaptation and wider development objectives; for example, business opportunities from energy efficiency measures, sustainable soil, and water management, among others. They constitute adaptation measures that would be justifiable even in the absence of climate change. Many measures that deal with climate variability (for example, long-term weather forecasting and early warning systems) may fall into this category (World Bank 2011).

**Win-win-win options.** “Win-win-win” options are measures that contribute to climate change mitigation, development objectives, and adaptation to climate change.
Acvaproject Institute. Water Management Concern Apele Moldova.


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Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change: Impact Assessment and Adaptation Options is part of the World Bank Studies series. These papers are published to communicate the results of the Bank’s ongoing research and to stimulate public discussion.

Agriculture is one of the most climate-sensitive of all economic sectors. Moldova is one of the many countries where the majority of the rural population depends on agriculture—directly or indirectly—for their livelihood. The risks associated with climate change pose an immediate and fundamental problem in the country.

The study proposes a clear and comprehensive plan for aligning agricultural policies with climate change; developing the capabilities of key agricultural institutions; and making needed investments in infrastructure, support services, and on-farm improvements. Developing such a plan ideally involves a combination of quality quantitative analysis; consultation with key stakeholders, particularly farmers and local agricultural experts; and investments in both human and physical capital. The experience of Moldova, highlighted in this work, shows that it is possible to develop an initiative to meet these objectives, one that is comprehensive and empirically driven as well as consultative and quick to develop.

The approach of the study is predicated on strong country ownership and participation, and is defined by its emphasis on “win-win” or “no regrets” solutions to the multiple challenges posed by climate change for farmers in Moldova. The solutions are measures that increase resilience to future climate change, boost current productivity despite the greater climate variability already occurring, and limit greenhouse gas emissions—also known as “climate-smart agriculture.”

Reducing the Vulnerability of Moldova’s Agricultural Systems to Climate Change: Impact Assessment and Adaptation Options applies this approach to Moldova with the goal of helping the country mainstream climate change adaptation into its agricultural policies, programs, and investments. The study projects impacts of climate change on agriculture across Moldova’s three agro-ecological zones through forecast variations in temperature and rainfall patterns so crucial to farming. It offers a map for navigating the risks and realizing the opportunities, outlined through a series of consultations with local farmers. A detailed explanation of the approach is provided for those who want to implement similar programs in other countries of Europe, Central Asia, and anywhere else in the world.

The study is one of four produced under the World Bank program “Reducing Vulnerability to Climate Change in European and Central Asian Agricultural Systems.” The other countries included in this series are Albania, the former Yugoslav Republic of Macedonia, and Uzbekistan. The results from the four studies are consolidated in the book Looking Beyond the Horizon: How Climate Change Impacts and Adaptation Responses Will Reshape Agriculture in Eastern Europe and Central Asia.

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