1 Introduction

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This book focuses on the impact of climate change on agriculture and how agriculture is able to adapt to such change. It explores what many disciplines can tell us about two questions: what will be the impending impact of such change? and what mechanisms can be implemented to help mitigate the resulting impacts? Climate change is expected to affect human livelihood, to different extents, at different locations. However, the impact on agriculture and its ability to adapt varies a great deal between regions (Mendelsohn and Dinar, 2009a). For example, some countries in Africa already face extreme climatic conditions, whereas some countries in Latin America appear to be the most vulnerable to climate change scenarios (Mendelsohn and Dinar, 2009a). Agriculture is the most important climate-sensitive sector in the economy, contributing 5 per cent of GDP (US CIA, 2011). At present, nearly one third of the earth's land is utilized for growing both crops and pasture (FAO, 2006). Furthermore, farming provides the livelihood of hundreds of millions of people. Three-quarters of the rural poor in developing countries depend on agriculture as their main source of livelihood (IPCC, 2007).

Agricultural and agro-ecological systems in many low-latitude countries are particularly vulnerable for several reasons. (a) climates in many low-latitude countries are already too hot and often too dry; (b) water supplies in these countries are limited and variable; (c) soil quality is often low and degraded; and (d) there is lack of adaptive capacity because these regions are relatively poor, have low levels of technology and R&D as well as weak government institutions.

Therefore it is no wonder that there has been a nexus of agriculture and climate change studies in recent years (e.g. FAO, 2007; Dinar et al., 2008; Nelson et al., 2009; Mendelsohn and Dinar 2009a, b; and Hillel and Rosenzweig, 2011). The FAO (2007) study assembles information and results from many previous studies to arrive at a consolidated assessment of impacts, data and analytical needs, and prescribed directions of policy work. Dinar et al. (2008) apply two methodologies to a set of countries in Africa, namely the production function and the Ricardian methodologies, in order to assess the impact of climate change and adaptation strategies at the country and regional levels. This work focuses on economic and simple agronomic tools. Nelson et al. (2009) deal with cropped agriculture, using a crop growth model in combination with a global agricultural production decision model. The work is focused on normative assumptions and does not explain the relationships between climate change and agricultural impacts. Mendelsohn and Dinar (2009a) combine science and economics to provide a very detailed set of applications of the Ricardian method to crops and livestock in 22 countries. Hillel and Rosenzweig (2011) provide a very comprehensive set of works that focus on the science of climate change and agro-ecosystems. Their study is a nice supplement to this *Handbook on Climate Change and Agriculture* in that it provides valuable scientific background to help understand the complicated interactions between climate change and agricultural production.

So, why do we need another study on climate change and agriculture? The *Handbook* extends previous work by adding the economic and policy context to agronomic and hydrologic analyses. It also demonstrates various methodologies and approaches used by scholars to estimate impacts and adaptation options.

AGRONOMIC STUDIES OF CLIMATE IMPACTS AND ADAPTATION

This part of the book introduces readers to the scientific background that links climate and crops and livestock, crop modeling and drought studies. Ziska (Chapter 2) addresses several challenges that climate change poses for field crops. He also emphasizes potential adaptations to these challenges by addressing the options in biodiversity, agronomic practices and biofuels that could allow agriculture to adapt or mitigate climate change impacts on crop production. Uncertainties are discussed, including uncertainties in field experiments and in modeling, as well as climate predictions. The chapter illustrates potential changes that could maintain or increase productivity in an uncertain climate.

Mader and Gaughan (Chapter 3) summarize research on the effects of climate change on domestic livestock. The chapter explains the mechanisms by which increased climate stress affects animal metabolism, productivity and health. These mechanisms may cause domesticated livestock to face severe impacts due to climate change. The impact of climate change on animal production is quantified using indices of animal comfort and well-being. Alternatively, one could measure climate change impacts on livestock using economic measures such as net revenue (Mendelsohn and Dinar, 2009a). Specific strategies for minimizing the effects of adverse weather on livestock production are suggested. Finally, the chapter suggests that the carbon footprint of livestock be measured to capture the impact of livestock on greenhouse gas emissions.

Iglesias et al. (Chapter 4) provide a thorough review of the most common methods, models and tools currently applied to assess crop productivity and production changes due to climate change. This comparison is important because these tools and models vary in terms of their data requirements and the variables they take into consideration. In particular, the chapter focuses on those models used to assess impacts on crop production as well as those that estimate the economic impacts of climate change. Examples of the application of the models in diverse agricultural regions are given, from highly developed regions of Europe to poverty-stricken regions in Africa. The chapter also discusses several hurdles that researchers confront when modeling crop production; namely, changes in spatial scale, sources of uncertainty and variability.

Hayes et al. (Chapter 5) investigate the connections between climate change, drought and agricultural production. Some of the most obvious and damaging economic, environmental and social impacts from climate change/drought occur in the agricultural sector. These impacts include not only primary impacts on agricultural production, but also indirect and induced impacts on agribusinesses and on local and regional economies. The chapter describes these threats based on the current state of knowledge and presents examples that illustrate efforts to reduce the potential impacts of drought and climate change on agriculture.

ECONOMIC STUDIES OF CLIMATE IMPACTS ON AGRICULTURE

This part of the book examines economic studies of climate impacts on agriculture, utilizing various approaches, including mathematical programming, farm production models, intertemporal weather models and the Ricardian approach.

Peck and Adams (Chapter 6) use firm-level mathematical programming to discuss the underpinnings of mathematical programming techniques, and how they may be used to represent economic decision making in agriculture. The chapter then reviews the use of techniques involving climate change with a special emphasis on uncertainty, and discusses the limitations and the opportunities of these studies. Finally, the chapter provides guidance on the appropriate use of these techniques in addressing future climate change.

Deschenes and Greenstone (Chapter 7) demonstrate the use of panel-data models of interannual changes in weather across the USA to estimate the economic impacts of weather on agricultural production. The chapter presents the key theoretical and empirical issues in using panel-data methods for this purpose. Then it reviews and interprets recent literature based on panel data using data from the US Census of Agriculture.

Masseti and Mendelsohn (Chapter 8) demonstrate the use of repeated cross-sections to estimate Ricardian models. Ricardian models generally rely on data from a single year. By using multiple years of data, the authors show that a more robust measure can be obtained. However, in conducting such an analysis it is important to include critical control variables, accurate climate data, all relevant observations and the correct functional form. Using the repeat cross-sectional analysis on US data, the authors estimate the impact of climate change on US agriculture.

AGRICULTURAL IMPACTS ON THE ECONOMY

Because the agricultural sector is a significant part of the economy in many countries, what happens in this sector has wide-ranging effects. This part of the book explores macroeconomic models, trade and integrated assessment models as tools for explaining the role of agriculture in these larger issues.

Calzadilla et al. (Chapter 9) develop an economy-wide model to estimate how climate change impacts on agriculture affect the economy. The model incorporates international markets and other sectors as well as agriculture. The authors use IMPACT, a global partial equilibrium agricultural sector model combined with a water simulation model and GTAP-W, a global general equilibrium model including water resources. The methodology combines advantages of a partial equilibrium approach, considering detailed water and agriculture linkages, with a general equilibrium approach, which takes into account linkages between agriculture and non-agricultural sectors and includes a full treatment of factor markets.

Leimbach et al. (Chapter 10) discuss how agriculture is depicted in climate change integrated assessment models (IAMs). The IAMs are used to evaluate the interaction between mitigation and impacts. As such, agriculture is modeled as a source of greenhouse gases, a substitute energy source for fossil fuels as well as a damaged sector from climate change. The chapter discusses how carefully agriculture is modeled in each of the

major IAMs and then discusses the results of relying on biomass as a substitute for fossil fuels using the REMIND–MAGPIE–LPJmL.

The role of trade is explored by Reilly (Chapter 11). The starting point of the chapter is the observation that climate will have a range of effects across regions of the world. The global impact will depend upon how much trade is allowed from regions with more production to regions with less. The chapter uses a simple graphical analysis of the effects of trade on consumer and producer surplus to review basic economic trade results. Trade and agricultural impacts are discussed, given growing global incomes, changing food demands, multiple environmental impacts, competing demands for land, effects of carbon dioxide (CO₂) and tropospheric ozone and biofuels.

AGRICULTURAL MITIGATION

This part of the *Handbook* discusses the role that agriculture may play in greenhouse gas mitigation. Hochman et al. (Chapter 12) analyze the effects of increased investment in, as well as subsidization of, biofuels on the economy. The authors expect that future mandates requiring adoption of biofuels are likely to result in further substitution away from fossil fuels and a reduction in greenhouse gas emissions. However, the introduction of biofuels may contribute indirectly to greenhouse gas emissions through expansion of farming and resulting deforestation. The chapter compares the impact on social benefits from a carbon tax, a cap-and-trade system and renewable fuel standards, all of which are in the present policy discourse. In searching for policies to enhance adoption of biofuel and the resulting reduction in greenhouse gas emissions, the authors evaluate the effectiveness of less strict regulation of biotechnology that will allow increased agricultural productivity.

Larson et al. (Chapter 13) observe that while agriculture is one of the most vulnerable climate sensitive sectors, agricultural activities can act both as a carbon source, exacerbating greenhouse gas pollution, as well as a carbon sink, for agricultural soils possess great capacity to store CO₂. The chapter examines the use of JI (Joint Implementation) and CDM (Clean Development Mechanism) to encourage agricultural mitigation projects. The chapter contrasts the potential and the actual investments in this sector. It then explores the policy reasons for the resulting discrepancy between the actual outcome using JI and CDM and its potential.

ADAPTATION TO AGRICULTURAL IMPACTS

The final part of the *Handbook* explores the potential of adaptation as a response to climate change in agriculture. Sources of adaptation include research and development (R&D), improving the effectiveness of institutions, insurance, irrigation and crop and livestock switching. Aisabokhae et al. (Chapter 14) discuss the promise and challenges of using adaptation to address climate change in the agricultural sector. The chapter relies on a literature review, the results of the authors' own research and an econometric investigation of the implications of climate change for research returns. The chapter reviews data to assess the extent to which climate change damages can be mitigated by changing

crop varieties and shifting planting dates. A mathematical programming model of US agriculture is used to investigate the economic value of crop mix migration, varietal adaptation, livestock mix change, irrigation change and research investment.

Medellin-Azuara et al. (Chapter 15) develop a hydro-economic model to assess climate impacts and adaptation in Californian agriculture in the year 2050. The effect of larger populations and urbanization is taken into account. Warm-dry forms of climate change are likely to reduce surface water and could reduce agricultural production throughout California. The study explores the merits of reallocating water, technological change and alternative water sources as adaptations.

Fleischer and Kurukulasuriya (Chapter 16) examine the interaction of crop and irrigation technology choice as climate changes across agro-ecological zones. Using a cross-section of household-level data from Africa and Israel, the chapter examines the determinants of irrigation technology selection given particular crop choices. The results are used to project the implications of climate change and irrigation technologies on farm incomes. Israel and Africa reflect a technological and income spectrum when it comes to the role of technology and infrastructure.

Gollin (Chapter 17) discusses the prospects for adaptation via R&D. The chapter explores some of the emerging climate-linked challenges faced by breeders and draws on empirical evidence to suggest likely directions for crop and livestock research. The chapter also discusses the importance of continued management improvements and increased input.

Thornton et al. (Chapter 18) address adaptation to climate change in mixed crop-livestock farming systems. The chapter argues that crop-livestock systems serve as robust approaches for poor farmers to cope with climate variation. However, mixed crop-livestock farms tend to have low intensity and will face increasing pressure in the future from human population growth and competition for land and water. The chapter reviews what is known about the impacts of climate change on mixed systems, particularly in developing countries. It then discusses adaptation options at the level of the household, community and landscape that can help mixed crop-livestock farmers improve livelihoods and food security in the face of global change.

Garrido et al. (Chapter 19) examine insurance as an adaptation to climate variability in agriculture. The chapter begins by reviewing alternative modalities of agricultural insurance as they are found around the world. It then addresses the challenges that insurance faces as climate changes. Numerical examples are used to illustrate to what extent insurance can provide feasible adaptation strategies. The chapter also reviews the technical, institutional and financial requirements that are needed to promote agricultural insurance in developed and developing countries as an adaptation measure to climate change.

Seo (Chapter 20) models the choice of livestock species in Africa and Latin America as an adaptation to climate change. He relies on agro-ecological zones to extend a limited sample to all of Africa. The chapter applies a multinomial logit model to estimate the probability that farmers in each agro-ecological zone in Africa and Latin America select each type of livestock. The comparison between Africa and Latin America allows the author to verify whether or not farmers in both continents have similar behavior.

Saleth et al. (Chapter 21) provide an analytical framework to assess the effectiveness of institutions and infrastructure in encouraging adaptation of the agricultural sector to

climate change. The chapter applies a methodology that measures the critical linkages between the success of adaptation options and strategies, and the effectiveness of their underlying institutions and their performances. The chapter covers agricultural, rural, and water institutions. The methodology focuses on the individual and joint impact of these multiple institutions.

CONCLUSION

Finally, Mendelsohn and Dinar (Chapter 22) in the concluding chapter provide a summary of all the chapters. The conclusion examines the contributions of each chapter and brings out the common insights. It also identifies future research needs to understand the impacts of climate change on agriculture, how agricultural actors may adapt and what role agriculture may play in mitigation. The conclusion identifies the role of individuals and the role of institutions in finding effective solutions.

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