David Lobell
Marshall Burke
Editors

ADVANCES IN GLOBAL CHANGE RESEARCH 37

Climate Change and Food Security

Adapting Agriculture to a Warmer World

Springer

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Part I

Chapter 1
Introduction

David Lobell and Marshall Burke

1.1 Why Read This Book?

The Earth is clearly warming. Mounting evidence from around the globe has removed virtually any serious doubt over this fact, and also over whether the main culprit is human emissions of heat-trapping gases such as carbon dioxide (CO_2). These emissions have been the product of a march towards better economic living standards, and for much of the world this march has led people out of a life of hunger and poverty and into one of relative comfort and security. But many have been left behind, and roughly 1 billion people continue to live under poverty and with insecure access to food. In an average day, more than 20,000 children die from hunger related causes.

A large majority of the world's poor continue to live in rural areas and depend on agriculture for their livelihoods. Given that agriculture everywhere remains dependent on weather, changes in climate have the potential to disproportionally affect these poor populations. But what, precisely, will human-induced climate changes mean for the globe's billion poor? How will climate change interact with the many other factors that affect the future of food production and food security?

There are no easy answers to these questions. That fact, of course, does not stop people from making simple predictions based on ideology, such as that innovation and free market responses will avoid any damages, or that climate change will wreak havoc on humans. Theory alone cannot refute either of these extreme positions, as there are no obvious reasons why that the pace of climate change caused by human activity should or should not match the pace with which we are able to adapt food production systems. Rather, the issue at hand is an empirical one, and finding answers will require a cadre of scientists capable of collecting and analyzing the relevant data, and policy makers and citizens capable of understanding their implications.

This book aims to foster these capabilities in students, researchers, and policy-makers in the field, by providing an accessible introduction into the fundamental

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science needed to address the potential effects of climate change on food security. To accomplish this, our approach in the book has five main features that we feel distinguish it from other texts on this subject.

The first is the style of presentation: we offer non-technical descriptions of the fundamental data and science underlying models of agricultural impacts, descriptions that should be comprehensible without prior knowledge of the subject. We hope this will prove useful not only for students, but also for inter-disciplinary researchers and policy makers who wish to understand in more detail the output from models in disciplines with which they commonly interact. Accordingly, we have not attempted an exhaustive review of recent applications in any of the chapters – results that in any case are likely to change quickly – but rather present enough examples to explain important concepts.

The second feature is a focus on the full suite of interactions between climate change and food security, which moves beyond the traditional narrower focus on the potential climate effects on the production of a few cereal crops. Although the main cereal crops (rice, wheat, maize) do contribute the majority of calories consumed globally, in many parts of the developing world they play a more minor role, warranting increased attention to the myriad other crops of importance to the poor. Furthermore, the majority of poor households are both producers and consumers of agricultural commodities, suggesting that a narrow focus on production might miss the effects of climate change on other important aspects of food security, such as incomes and health.

A third related feature of the book is our focus on the inherent uncertainties associated with any assessment of the effects of climate on food security, uncertainties that are often not clearly quantified elsewhere in the literature. In each chapter we focus on the types of uncertainties that exist and the ways that researchers attempt to measure them. We feel this reflects a broader trend in the community to move away from simple "best guess" estimates and provide a more probabilistic view of the future.

The fourth feature of the book is an embrace of the diversity of approaches and perspectives necessary for a complete assessment of the linkages between climate and food security. Because a complete assessment requires the integration of tools from often diverse fields, the book presents a broad range of perspectives from various experts. Thus, for example, the presentation does not focus on a single approach to estimating crop responses to climate change but covers the strengths and weaknesses of the various methods employed by researchers on this particular topic.

Finally, the book discusses extensively the adaptation options available to agriculture in order to cope with climate change over the next few decades. This contrasts with many studies that have focused instead on the longer time frame of 2080 or 2100. In our opinion, this choice reflects a broader trend in the global change community to focus not only on questions of mitigation (i.e. whether and how to reduce greenhouse gas emissions) but increasingly also on how to adapt to the changes we can expect regardless of emissions reductions.

1.2 The Strength and Limits of Models

In order to provide quantitative measures of climate change impacts, we will rely heavily on numerical models of various pieces of the puzzle, including climate, agricultural, and economic systems (Fig. 1.1). Models are needed because it is rarely possible to perform controlled experiments where one or two factors are changed while others are held constant, particularly for the time scales and spatial scales of interest. One cannot measure, for example, global crop production with climate change and compare it to a world without. Instead, one must perform the controlled experiments in the simplified world of computer models, which can be run at any scale.

However, it is important to remember that models are only simplified representations of reality, tools that can be used to estimate things that often cannot be directly measured. When their output is compared to things that can be measured, they almost always contain some error. In the case of predicting the future, this error arises both from not knowing perfectly how the climate and agricultural systems currently behave, and not knowing the future decisions that humans will make (both on the mitigation and adaptation side) that will influence the result.

The goal of modeling must therefore be to estimate not only a "best-guess", but also a probability distribution function (pdf), which describes the probability that the true value will take on each possible value. Often of interest is the chance that a particular threshold will be exceeded, such as 500 ppm atmospheric CO_2, 2°C global average annual temperature, or 1 billion food insecure people. For these purposes, a single best guess of impacts is essentially useless. While nearly everyone acknowledges that treating a single output of a model as a firm "prediction" can be foolish, there appears a strong and persistent desire in humans to ignore uncertainties and overstate confidence in predictions.

Of course, the alternative of throwing up our hands and claiming no knowledge about the future is equally unattractive. Instead, we seek to clearly distinguish between those aspects of the future we know well and those that we do not – a task that can only be achieved by tracking uncertainties. The job is made somewhat easier by the fact that the goal is often not to actually predict the future, but instead to predict the difference between two outcomes. For example, impacts on wheat in China versus India; impacts on corn versus rice; impacts for low versus high CO_2 emissions; or impacts for low versus high investments in a certain adaptation technology. In these cases, errors that are similar for each individual projection will tend to cancel out when looking at differences. It is thus often helpful to remember that while we would love to be able to predict everything about the future, our actual goals (and certainly our abilities!) are often much more modest.

Fig. 1.1 The cascade of models needed to evaluate the impacts of climate change on food security

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1.3 The Importance of Time Scales

Two main types of interventions are often discussed as ways to reduce the impacts of climate change on society: mitigation and adaptation. Mitigation is a reduction in greenhouse gas emissions, which leads (eventually) to a reduction in climate change. Adaptation refers to changes made to a system impacted by climate, in this case some aspect of the food economy, that improve the outcome of climate change relative to no adaptation. Adaptations can include both changes that either reduce negative outcomes or enhance positive outcomes.

The effectiveness of an intervention can be extremely dependent on the time scale of interest (Fig. 1.2). For example, investments in adaptation are the only real way of reducing impacts for the next 30–40 years, because the benefits of mitigation are realized with a lag of roughly this length (see Chapter 2). However, nearly all assessments agree that adaptations are less effective than mitigation for reducing impacts by 2100.

Much of this book will focus on time scales of the next few decades, rather than the end of the century. There are several pragmatic reasons for this choice. First, growth in food demand is expected to be faster before 2050 than after, because global population growth will likely decelerate. According to the United Nations' medium growth rate scenario, for instance, population will increase by 2.8 billion people between 2000 and 2050 but only by 0.2 billion between 2050 and 2100 (Table 1.1). The challenges to food security of rising global demand are therefore

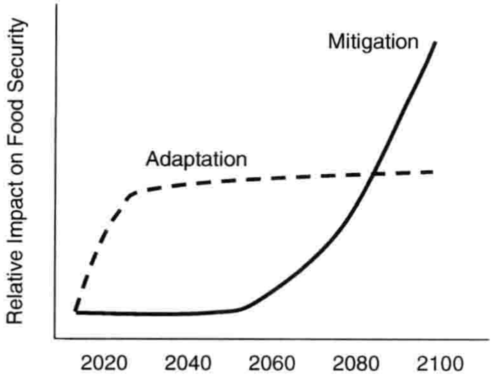

Fig. 1.2 A schematic view of the effectiveness of adaptation and mitigation as a function of time

Table 1.1 Projections of global population (billions of people) to 2050 and 2100 for different growth scenarios (data source: United Nations Population Division 2004)

Year	Low variant	Medium variant	High variant
2000	6.1	6.1	6.1
2050	7.4	8.9	10.6
2100	5.5	9.1	14.0

likely to be greatest in the near-term. Put differently, the challenge of the next few decades is to foster a tremendous growth in agricultural production in the face of climate change in order to improve food security, while after 2050 lies the more modest challenge of maintaining existing production levels in a warming world.

A second and no less important reason is that uncertainties in projections beyond 2050 are far greater than those of the next few decades. That is, it makes sense to focus on the aspects of the problem where projections are most likely to be accurate. Beyond 2050, agricultural technologies may be completely different from the current ones, and temperatures at a given location will often be beyond anything currently experienced (Chapter 2), making projections of climate impacts on agriculture very difficult.

Third, our experience is that most decisions, whether made in public or private sectors, do not account for time scales beyond a few decades. Therefore, scientific assessments of the near-term are likely to have a greater impact on societal choices than are those focused on the end of the twenty-first century, even if the latter would play a greater role in an ideal world.

Finally, and perhaps most importantly, is the fact that food security impacts of climate change in the next few decades may be severe in some locations. There is tremendous need for science that supports effective adaptations, especially when considering that most investments in agriculture take over a decade to provide substantial returns. Efforts to adapt to climate in 2020 or 2030 must therefore begin soon. There are obviously larger potential impacts as one looks beyond 2050, but one need look no further than the next 20 years to find a major scientific and societal challenge.

Although we believe these reasons are compelling enough to justify a focus on the short-term, we recognize that a view of the longer term is also needed, if only for the critical job of assessing the eventual benefits of mitigation. We therefore also include many references to assessments of 2080–2100, although none to our knowledge extend beyond this time.

1.4 Overview of Book

This book is organized to cover the major topics that, in our opinion, are needed to address this interdisciplinary subject. Part 1 of the book includes essential background information on food security and trends in the climate system. Chapter 2 presents an overview of food security and the potential ways that it can be influenced by climate changes. Chapter 3 presents an overview of climate models and how they are used to assess uncertainties in the future of climate.

Part 2 delves into the links between climate and crop yields, with a focus on how and how well scientists attempt to quantify these links with models and experiments. Chapter 4 describes the process-based ecophysiological crop models that underlie many assessments of yield impacts, while Chapters 5 and 6 discuss statistical approaches that model yields based on relationships gleaned from historical yield variations across time and space. Chapter 7 focuses on crop responses to elevated CO_2, a critical factor for projecting future yield impacts.

Part 3 provides an in-depth look at different adaptation options that may play a key role in minimizing impacts over the next few decades. Chapter 8 reviews market-mediated adaptations through trade, as well as on-farm agronomic adaptations such as shifts in planting dates or crop varieties. Chapter 9 discusses the key role that crop development can play in generating new seeds that can better thrive in a new climate.

Finally, Part 4 takes a snapshot of current research, with Chapter 10 summarizing results from recent regional and global assessments and Chapter 11 focusing on major lessons from past work and suggestions for future research.

1.5 Missing Pieces

Editors must inevitably choose to draw the line somewhere in order to balance the scope and focus of a book. The decisions made here reflect partly the expertise and interests of the authors involved, and partly our own biases on the most relevant and scientifically mature topics. However, we wish to point out many less mature topics that may prove important in the final analysis. For instructors who plan to use this book as a text, we encourage instructors planning to use this book as a text to supplement it with current papers on these topics.

Water Resources for Irrigation Impact assessments for irrigated regions often assume that water supply will be unaffected by climate change. Although this is a reasonable starting point (in order to focus first on the more direct effects of temperature and precipitation on crops), indirect effects through changes in regional water resources may be important. Studies that do link regional hydrology models to crop models, in order to simultaneously treat both supply and demand for irrigation water, have shown that local impacts and adaptation responses can be constrained by water supplies (Thomson et al. 2005).

Irrigation is currently practiced on roughly 17% of global cropland, with these systems contributing 40% of global food production (FAO 2002). Most of global irrigation water is applied in Asia, and therefore it is in this region that consideration of changes in water resources is most urgently needed. For example, it is widely acknowledged that much of the irrigation water in India and Pakistan originates as meltwater from Himalayan glaciers, that these glaciers are rapidly melting, and that summer streamflow may be significantly reduced within a few decades (Singh and Bengtsson 2004; Barnett et al. 2005; Rees and Collins 2006). Yet the implications of these limited water supplies on agriculture in general, and on the ability to adapt to climate change in particular, have to our knowledge only been superficially addressed.

Sea Level Rise Little work has considered the direct impacts of rising sea levels on agricultural production. Increases over the next few decades will likely be too small to have a major impact on agricultural production, but increases of more than 1 m, which are possible by the end of the century (Rahmstorf 2007), could result in the inundation of large tracts of low-lying coastal agriculture throughout Asia. Even smaller rises in the near-term could have strong local effects related to saltwater intrusion, with three particularly vulnerable sectors suggested in a recent FAO report: vegetable production, which tends to be irrigated in coastal regions, low lying aquaculture, and coastal fisheries (Bruinsma 2003).

Pest and Pathogens Farmers are constantly faced with the prospects of yield losses from weeds, animal pests, fungal and bacterial pathogens, and viruses. By one estimate, roughly 30–40% of global production for the major food crops is lost to these factors each year (Oerke 2005). Although climate change will undoubtedly modify pest dynamics, current understanding of these changes is quite limited (Easterling et al. 2007). With a few exceptions (Aggarwal et al. 2006), crop models in common use today do not include treatment of weeds, pests, or pathogens. Approaches to modeling responses to climate change include models that explicitly simulate weed competition or predator–prey interaction as well as simpler projections that use thresholds to define pest ranges. Nearly always the effects of temperature and CO_2 changes have been considered separately, although interactions between the two may prove important (Fuhrer 2003). Pests and pathogens can not only impact yields, but also the nutritional quality and health impacts of many crops. For example, carcinogenic aflatoxins are commonly found in maize and groundnuts and are most prevalent in hot and dry conditions (Chauhan et al. 2008).

Livestock and Fisheries This book focuses mainly on food crops, but meat, poultry, dairy, and fish are important sources of calories, protein, and income for many, including the food insecure. Livestock is a particularly important means of risk management (i.e. mixed crop–livestock systems) and adaptation to drought throughout much of the tropics (Thornton et al. 2007). Livestock systems broadly fit into two classes: those fed on grains or managed pasture grasses, such as in intensive feedlot systems common in developed countries, and those based mainly on grazing of wild grasses such as those common in poor countries with large malnourished populations. For the former, the main effects of climate change may be via crop yield and price changes discussed in this book, though higher temperatures will also present a challenge to management of heat stress and disease among animal populations. In pasture and rangeland systems, direct effects of heat on animals will be complemented by effects on forage quantity and quality. Pasture grasses in many temperate locations show yield increases for moderate warming, but also exhibit significant declines in nutrient content with higher CO_2 (Easterling et al. 2007).

In fisheries, interannual climatic variations, most notably related to the El Niño Southern Oscillation, lead to wide fluctuations in fish stocks. However, the net effects of future climate changes on fisheries are currently very uncertain, aside from a likely northward shift of many fish populations (Brander 2007). In addition to effects of warming, aquatic food webs could be as or more impacted by increased acidity resulting from oceanic CO_2 uptake (Easterling et al. 2007).

Mitigation in Agriculture Though this book focuses on the impacts of climate change on agriculture and food security, the role of agriculture in mitigating climate change is an important related topic. It has long been recognized that agriculture is a significant contributor to global greenhouse gas emissions, in terms of CO_2 and especially methane and nitrous oxide (Rosenzweig and Hillel 1998). Major reductions in emissions of these gases from agricultural activities could thus contribute to climate mitigation, and a myriad of technologies offer promise in this respect. For more information, a good starting point is the periodic reports of the Intergovernmental Panel on Climate Change.

Mitigation could even present an opportunity to adapt to climate impacts. For example, the prospect of a global emissions trading market will make it possible to generate rural income from either reducing emissions or providing renewable fuels. Such income, for example through biofuel production in poor oil-importing nations, may be an important means of income generation and represent a possible adaptation to declining staple crop production. Other synergies between adaptation and mitigation have been argued in the literature, such as the potential of conservation tillage practices to both sequester carbon in the soil and improve soil moisture needed in dry years (Lal 2004).

Policy Responses Despite the many uncertainties in physical and biological aspects of food security response to climate change, much of the inability to project future impacts relates to the simple fact that we cannot predict how humans will respond. Put differently, the severity of future impacts will depend in large measure on whether humans can effectively adapt. This book deals extensively with models of how rational farmers and regional economies might respond to climate change, but it should be clear that, like most other assessments, we implicitly assume that government policies that influence these behaviors remain fairly stable.

Any significant shifts in policy could dramatically affect the capacity of economies to cope with climate change, either for better or worse. One particularly important set of policies relates to long-term investments in the types of institutions and technologies that are needed to adapt to climate change, such as agricultural research or extension activities and emergency relief organizations. Funding for these activities has fluctuated in recent years and it is difficult to predict the future trajectory of overall policy support for agricultural development. Although many have argued convincingly that these investments offer high returns even in current climate (Alston et al. 2000), it can be difficult to prioritize long-term investments in public goods, particularly in poor countries.

Standing as a complement to these decisions about longer-term institutional investments are policies that deal with the short-term supply shocks that occur in years of bad harvests, shocks that may become more frequent and widespread with climate change. The recent experience with rapid price changes in 2008 provides a clear example. Many governments instituted new policies aimed at stabilizing local markets, including price controls, import tariffs, and export restrictions (FAO 2008). Yet the effect of these inward looking policies was often to destabilize global markets even further, causing rapid spikes in food prices and declines in food access in many rice importing countries.

How will governments respond if a year with extreme heat waves reduces global cereal harvests by 10% in 2020? Will they preserve existing policies and increase support of famine relief organizations, or will they embark on politically popular but potentially harmful protectionist policies? Though the recent experience of 2008 provides a cautionary note, perhaps it was a good learning experience that will lead to improved coordination during a future crisis.

There are many difficulties in predicting the future course of human decisions, not the least of which is that human behavior is not necessarily rational. As Bertrand Russell wrote: "It has been said that man is a rational animal. All my life I have been searching for evidence which could support this." Progress in anticipating future policy responses will therefore likely be slow.

The only certainty is perhaps that good policies, or the absence of bad policies, will be critical to maintaining food security in a changing climate. Identifying what these particular policies should be, and how to implement them, is beyond the scope of our book, but a topic that surely deserves much study in years ahead.

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