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Cambodian Agriculture

Adaptation to Climate Change Impact

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ABSTRACT

Cambodia has been identified as one of the most vulnerable countries to climate change, given the predicted changes in temperature and precipitation, the share of labor in agriculture, and the country's low adaptive capacity due to widespread poverty. In this study, we use climate data from four general circulation models (GCMs) to evaluate the impact of climate change on agriculture in Cambodia by 2050.

We used the Decision Support System for Agrotechnology Transfer crop modeling software to evaluate crop yields, first for the 1950–2000 period (actual climate) and then for the climates given by the four GCMs for 2050. We evaluated crop yields for eight different crops at 2,162 points in Cambodia, using a grid of 10-kilometer squares, for 2000 and 2050. For each crop, we searched for the best cultivar (variety) in each square, rather than assuming the same cultivar to be used in all locations. We also searched for the best planting month in each square.

We explored potential gains from changing fertilizer levels and from using irrigation to compensate for rainfall changes. This analysis indicates that when practiced together, using improved cultivars better suited for the changing climate conditions and adjusting planting dates can lessen the impact of climate change on yields, including for both wet- and dry-season rice. In addition, the analysis shows that losses in yield due to climate change can be compensated for—for many crops—by increasing the availability of nitrogen in the soil.

To provide context to the modeling analysis, a survey of 45 communes was conducted using focus group discussions to solicit information on agricultural practices. Questions were asked about fertilizer, irrigation, seeds, tillage, and pest management, as well as about natural disasters and how farmers respond. Key results indicate that in response to extreme weather, only 7 to 16 percent of farmers report changing crop variety and only 20 percent of farmers report changing planting dates. Since the modeling results indicate that adaptation to climate change by changing crop variety and planting dates will be critical in order to avoid yield losses over the next 40 years, it is recommended that farmers expand their capacity to adapt in this way. In addition, every commune reported using some type of chemical fertilizer; however, in a typical commune, only 50 percent of the farmers were using any chemical fertilizer. This indicates that there is room to increase the use of chemical fertilizers.

Finally, focus group participants were asked to name the top three natural disasters of concern. Drought was the most cited, reported in 44 of the 45 communes (98 percent), while flooding was cited in 67 percent of the communes surveyed. Despite this, in fully 58 percent of the communes, farmers reported taking no action in response to floods. In response to drought, farmers reported switching to other crops in 16 percent of the communes, and changed planting dates in 19 percent, while only 7 percent of the communes reported no adaptation in farming practices. These findings indicate the need for intervention to help farmers deal with floods in particular, and to determine whether strategies for adapting to drought are the best suited to mitigate crop loss.

Keywords: climate change, IMPACT model, GCM, Cambodia, adaptation, agriculture

ABBREVIATIONS AND ACRONYMS

AR4	Fourth Assessment Report
ASSDP	Agricultural Sector Strategic Development Plan
DSSAT	Decision Support System for Agrotechnology Transfer
FGD	focus group discussion
GCM	general circulation model
GDP	gross domestic product
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IPCC	Intergovernmental Panel on Climate Change
IR	imidazolinone-resistant
MAFF	Ministry of Agriculture, Fisheries, and Forestry
MOWRAM	Ministry of Water Resources and Meteorology
NAPA	National Adaptation Programme of Action to Climate Change
NGO	nongovernmental organization
NPRS	National Poverty Reduction Strategy
NSDP	National Strategic Development Plan
RS	Rectangular Strategy
SRES	Special Report on Emissions Scenarios
SEDP	Socio-economic Development Plan
SAW	Strategy for Agriculture and Water
TWGAW	Technical Working Group on Agriculture and Water

1. INTRODUCTION

Some observers are concerned that the combination of climate change and population growth in many developing countries might be the coming *perfect storm*. A combination of supply reduction, due to climate change effects on agriculture, and demand increase, from still-growing populations, might at last validate Malthus's fears and result in food shortages and widespread hunger.

Yet despite food crises in recent years that resulted in riots in many cities around the globe, it is not clear that these fears are warranted. Technological growth in the agricultural sector, including the Green Revolution of recent decades, along with some expansion of agricultural land, has generally managed to supply the world's population with sufficient food, despite explosive population growth in the last century. Clearly, large portions of the global population still struggle to gain access to sufficient nutrition, but these struggles seem to be the result not of insufficient production of food but of constraints in access to the food due to poverty, as well as of distribution failures.

Climate change, by definition, will alter temperature and rainfall patterns. Since agriculture is dependent on weather, and crops are known to suffer yield losses when temperatures are too high, many experts are concerned that warming caused by climate change will lower crop yields. Changes in rainfall might also cause reductions in yields, though at least in some places, changes in rainfall could lead to increased yields. Finally, rising seas may result in inundation and soil salinization, causing loss of currently productive agricultural land.

Many studies of the impact of climate change on agriculture have already been conducted. Hertel and Rosch (2010) review a number of these, as do Tubiello and Rosenzweig (2008). Hertel and Rosch highlight three major approaches to assessing the impacts: crop growth simulation models, estimating statistical relationships between crop yields and climate variables (precipitation and temperature), and the use of hedonic or Ricardian models. The approach we take here is to use crop modeling. A large number of studies have already been performed using this approach; White et al. (2011) review 221 papers from the literature on the use of crop models to assess the impact of climate change on agriculture.

ADB and IFPRI (2009) studied the impact of climate change on agriculture in the countries of Asia and the Pacific and concluded that that "a combination of indicator values representing exposure (change in temperature and precipitation), sensitivity (share of labor in agriculture), and adaptive capacity (poverty) identifies Afghanistan, Bangladesh, Cambodia, India, Lao PDR, Myanmar, and Nepal as the countries most vulnerable to climate change" (2009, 9). They go on to suggest:

> Required public agricultural research, irrigation, and rural road expenditures are estimated to be \$3.0–\$3.8 billion annually during 2010–2050, above and beyond projected baseline investments. In addition, these agricultural investments require complementary investments in education and health, estimated at \$1.2 billion annually up to 2050. (ADB and IFPRI 2009, 20)

The ADB and IFPRI (2009) study is a regional study that used a methodology very similar to some published global studies, such as Nelson et al. (2009); Nelson, Rosegrant, Koo, et al. (2010); and Nelson, Rosegrant, Palazzo, et al. (2010). Our study takes a more detailed look at the impact of climate change on agriculture in Cambodia, using a similar approach to that of ADB and IFPRI but extending it in many important ways: (1) Instead of restricting the modeling analysis to areas currently believed to be planted in a given crop, we examine the potential future growth of the crop on all land areas. This allows us to consider the feasibility of expanding a crop into new areas, or bringing in a new crop not currently grown. (2) We examine the potential yields for every variety of a given crop available within the Decision Support System for Agrotechnology Transfer (DSSAT), while other studies considered a single variety (or two, in the case of rice). (3) We allow the planting date to move freely (or within a specified period, when examining crops that are specifically wet-season or dry-season crops). By allowing the planting date to shift radically, we consider wider adaptation options than do other studies. (4) We consider a wider range of crops. (5) We consider more fertilizer application options. (6) We use newer climate models than those used in ADB and IFPRI (2009), Nelson et al. (2009), and Nelson, Rosegrant, Palazzo, et al. (2010); it is the same model used by Nelson, Rosegrant, Koo, et al. (2010). (7) Our spatial resolution is much finer than that of the other studies. The three studies using the older climate models have roughly 60-kilometer spatial resolution, while Nelson, Rosegrant, Koo, et al. (2010) have roughly 30-kilometer spatial resolution; we use 10-kilometer spatial resolution. (8) We take a more comprehensive look at the national context, including detailed background on agriculture, the environment, and overall economic development, as well as a keener focus on the policy environment.

Masutomi et al. (2009) use DSSAT, the same crop model software that we use, applied along with 19 general circulation models (GCMs) in a study of the impact of climate change on rice cultivation in Asia. The advantage of their analysis was using a wider collection of GCMs (19 rather than 4) and emission scenarios (three rather than one), as well as a more varied time frame that includes estimates for 2030 and 2080 (rather than only 2050). One disadvantage of the Masutomi study is that the spatial resolution was 144 times lower than ours—12 times in both the horizontal and vertical directions, at a 1-degree resolution. The researchers also limited their selection of varieties of rice to two (though they considered different growing periods), and they did not allow for adaptation by selecting a variety different from what was used in the pre–climate change environment. They did allow for some adaptation by permitting the planting date to be shifted.

Cambodia is located in the southern portion of the Indochina Peninsula and shares borders with Vietnam, Laos, and Thailand. In 2010, its population was 14.3 million in an area covering more than 180,000 square kilometers (km^2). Gross domestic product (GDP) in 2010 was \$11.2 billion, with GDP per capita around \$790.[1] Cambodia's economy has grown substantially in recent years, with average annual GDP growth approaching 9.5 percent for the 10-year period ending in 2008 (Theng and Koy 2010). Agriculture remains a very important economic sector for Cambodia, representing more than 30 percent of GDP (ADB 2011).

According to the 2008 Census, 81.7 percent of the households in Cambodia live in rural areas (RGC, NIS 2009). With such a large rural population, most families are highly dependent on agriculture. The agricultural sector provides employment for more than 70 percent of people who are employed (ADB 2011). Most rural household incomes are low, leading to food insecurity. Eleven percent of the population lives in the plateau/mountain region, which previously had limited access. However, major infrastructure development since 2003 has improved national roads, and village roads are now better connected to major urban centers.

The Royal Government of Cambodia has prioritized agriculture in all its major development strategies, as the main sector to alleviate poverty in the country. In 2010, the government released a policy on the promotion of rice production and milled rice export, with the goal of exporting one million metric tons of milled rice by 2015. The vision is to bring Cambodia into the world market as a key milled rice–exporting country (RGC, Prime Minister 2010).

Cambodia has a monsoon climate, with a six-month wet season and a six-month dry season. The southwest monsoon brings the rainy season, which extends from mid-May to mid-September or early October. With the northeast monsoon comes drier, cooler air, from early November to March.

Two geophysical features that must be mentioned are the Mekong River and Tonle Sap Lake. The Mekong River and its tributaries flow across the country from north to south, where they converge to form the Mekong Delta on the South China Sea. The Mekong River fills and swells Tonle Sap Lake during flooding season. This hydrological cycle, involving the filling and draining of the lake along with the inundation of adjacent forest areas, causes the lake's depth to range from 1 or 2 meters at its lowest to 10 meters during flooded times; its surface area ranges from 3,000 km^2 to between 10,000 and 14,000 km^2 (Thuok 2009). For a period of one to four months, the lowlands around Tonle Sap Lake and the Upper and Lower Mekong areas are inundated with water. This area is not only the *food basket* of the country (producing rice and fish) but is also the richest wetland ecosystem in the world (Neou 2001).

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[1] All dollar figures are US dollars.

This lowland area has played a very important role in the spectacular increase in rice production in Cambodia in the last decade, roughly doubling between 2000 and 2010. (FAOSTAT [FAO 2011], using three-year averages to smooth out year-to-year variation, reports doubling between 1999 and 2009.) This report, in endeavoring to make recommendations for the way forward to 2050 under the impact of climate change, will point to areas that will require strengthening. Those recommendations in no way imply that the agricultural sector has been neglected or mismanaged. Rather, the impressive growth of the last decade indicates successes that need to be acknowledged—evidence that leaders have made some good decisions about investing in the expansion of agriculture.

These targeted investments in agriculture have included the expansion of the harvested area, both through increasing the cropping intensity and expanding some of the physical area; increasing the irrigated area by adding or repairing irrigation infrastructure; increasing the use of fertilizer; and using improved seeds.

Model

In a simple way of thinking about crop growth, we might say that yield from a given piece of land is a function of just a few things: seed variety (*V*), soil characteristics (*N*) including nutrients, water availability (*H*), temperature (*T*), and sunshine (*S*). Except for seed variety, which is fixed once it is chosen, the other elements can vary moment by moment. We could write a simple yield function as

$$y(N, H, T, S; V). \qquad (1)$$

The variety impacts how all the other inputs affect yield, so we treated it differently by putting it after the semicolon.

There is a time dimension to yield: the number of days that pass between the time the seed (or seedling) is planted and the time the crop is harvested. Because yield is affected by nutrients, water, temperature, and sunshine over the whole period from planting to harvesting, it would be more accurate to include as inputs multiple temperatures (as well as multiple levels of nutrients, water, and sunshine)—perhaps even a different temperature for every hour over that period. Indeed, crop growth is sensitive to temperature, and growing rates change markedly throughout the day depending on the temperature.

Crops can be sensitive to both high and low temperatures. There are a few measures a farmer can take in some instances to modify the impact of temperatures (such as covering plants in the cold to prevent them from freezing, as is sometimes done in the case of high-value crops), but generally when it comes to field crops, there are no economically viable temperature interventions.

In regard to temperature, the main decisions the farmer makes relate to planting date, *d*, and harvest date, h. If the farmer were able to predict the weather (including the temperature profile) of the entire year, he or she would be able to choose the ideal planting and harvest dates to maximize yield. The farmer would also be able to choose a more ideal variety to plant. For example, if the year ahead promised many days with high temperatures during the growing season, the farmer might choose a variety that was heat tolerant, meaning that its growth was not hindered by heat as much as standard varieties of the crop. We might write this temperature function as

$$T(t; d, h), \qquad (2)$$

where *t* is time.

Unfortunately, in reality the farmer cannot know temperature cycles in advance, so he or she instead forms expectations based on knowledge of the local long-term climate conditions, *C*. That knowledge includes an awareness of the typical temperature ranges of each month of the year (and perhaps even of each week), as well as of unusual temperature variations in past years.

Science continues to develop in terms of the accuracy of shorter-term predictions of weather. Longer-term, seasonal predictions (four to six months in advance) are becoming more accurate for many regions of the world, based on, among other things, the El Niño Southern Oscillation. Weather forecasts, C_7, and weather outlooks, C_{120}—while not 100 percent accurate—influence the farmer's expectations for weather, often improving the predictive accuracy of those expectations. The weather outlook might help the farmer better choose the variety of seed to plant, and perhaps influence other crop husbandry decisions. The weather forecast of a week or so in advance can help the farmer choose planting and harvest dates, particularly to avoid overly water-saturated fields and to determine times when the crop can be harvested and dried in the field.

This allows us to write the temperature function now as

$$E[T(t; d, h); C, C_7, C_{120}], \tag{3}$$

where E is the expectation operator. When we write the function this way, we are looking at the problem from the farmer's perspective. The previous temperature function, for actual temperature rather than expected temperature, was from the crop modeler's perspective.

We can write an identical set of functions for sunshine. For water availability, however, the set of functions will be a bit more complicated. Note that temperature and sunshine cannot be modified by the farmer (except with regard to the choice of planting and harvest dates). Water availability, in some circumstances, can be modified by the farmer through water application; that is, in addition to depending on rainfall, R, the farmer in some cases can use irrigation, I, which will express as a function of time, because water can be applied at specific dates in specific quantities:

$$H(R(t), I(t); d, h). \tag{4}$$

Soil nutrients might be considered as either a function of rainfall or a function of time, or both. More intensive rainfall can sometimes make some nutrients unavailable to crops, by causing them to either run off (if fertilizer has been used) or go deeper than the roots can access. And over the time period of a growing season, the plant itself will use nutrients, so they will no longer remain in the soil. Nutrient uptake will also vary based on the crop type and variety (V). Furthermore, as crop growth is affected by many nutrients, N should be thought of as a vector of nutrients. Soil type, D, helps determine the amount of nutrients the soil can absorb, as well as the rate of loss of those nutrients. Finally, soil nutrients can be modified through application of organic fertilizers (compost or manure) and inorganic fertilizers, F, just as water availability was modified through irrigation. (Other soil amendments, such as gypsum to adjust pH, or rhizobia to enhance nitrogen fixation, can be incorporated into F, which is best thought of as a vector: fertilizers can amend nitrogen, phosphorous, potassium, sulfur, and various micronutrients.)

We might write the nutrient function as

$$N\big(t, F(t); d, h, V, D, R(t)\big). \tag{5}$$

We can omit, for simplification, other major soil- and crop-related issues, merely indicating here how they might be accounted for. The issue of weeds might be modeled similarly to soil nutrients, because weeds can be reduced either through herbicides or through weeding (mechanical processes). Similarly, the impact of insects and other pests on yield can be modified through insecticides and other interventions. Thinking more broadly about soil nutrients as the entire soil- and plant-supporting environment, we could then fold weeds and pests into the vector for soil nutrients (while allowing for the fact that more weeds and pests lead to worse yields, while more nutrients lead to better yields). The full range of interventions—herbicides, pesticides, and weeding—could then be folded into a vector that was previously reserved for fertilizer application. For simplicity, however, we will not further address weeds and pests in the modeling section of the paper.

The yield function has in any case become much more complicated:

$$y\Big(N\big(t, F(t); d, h, V, D, R(t)\big), H(R(t), I(t); d, h), T(t; d, h), S(t; d, h); V\Big). \tag{6}$$

A reduced form of this would be

$$y\big(d,h,V,F(t),I(t);D,R(t),T(t),S(t)\big). \tag{7}$$

Essentially, this separates out the variables selected by the farmer (or modeler), which are those before the semicolon, from the variables that are out of the farmer's (and modeler's) control, which are soil type and weather.

In practice, the farmer must choose the planting date, *d*, and the seed variety, *V*, before beginning cultivation. Other variables—harvest date, *h*; fertilizer application, *F*; and irrigation, *I*—can be chosen later, although starter fertilizer and starter irrigation would normally be chosen ahead of time.

In terms of the modeling in this report, h will choose itself, because we can tell the program to harvest when the crop is mature (not unlike how a farmer decides). This would reduce the yield function further to

$$y\big(d,V,F(t),I(t);D,R(t),T(t),S(t)\big). \tag{8}$$

The other variables must be set before running the program: planting date; crop variety; and whether, how much, and when to apply fertilizer and irrigation. The soil type at each point of analysis is inserted, along with climate variables that allow the program to simulate daily values of rainfall, temperature, and solar radiation.

In terms of an economic model, the profit-maximizing, market-integrated farmer would choose d, V, F(t), and I(t) to optimize the profit function,

$$\Pi = E[p;V] * y(d,V,F(t),I(t);D,E[R(t)],E[T(t)],E[S(t)]) - E[r_F]\int F(t) - E[r_I]\int I(t) - E[r_L], \tag{9}$$

where r_L is the cost of land preparation, harvesting, seed purchasing, weeding, and other field operations. (We could have made this a function of yield and crop type, but chose rather to keep it simple.) We use p for the farmgate price of the crop (the market price minus transport cost), r_F for the farmgate cost of fertilizer (the market price plus the cost of transport), and r_I for the cost of irrigation. We have neglected labor in this model, which should be more fully included in profitability studies. We might say that this model assumes only household labor, with zero opportunity costs (as might be the case if there were no alternative uses of that labor).

If we were able to specify values for each of these price and cost parameters, we could use yield output from the crop models to compute not only the most profitable crop *variety* for a given crop but also the most profitable crop *type* to plant on a given piece of land. These would be heroic accomplishments, for several reasons. First, it is notoriously difficult to predict, apart from surveying farmers themselves, what the true farmgate price is (because it is difficult know the real transport costs of goods). Second, in modeling for the future, predicting appropriate market prices and costs is challenging. Third, in choosing the best option we would be comparing two different values, both highly uncertain; and differencing two highly uncertain values generally increases the level of uncertainty (the variance of a difference is equal to the sum of the two variances minus twice the covariance)—although, if they are highly correlated, differencing could reduce the variance. Furthermore, many crops are grown for home consumption, and for this purpose, people generally select the foods (crop, varieties) that they are familiar with.

By focusing on yields, however, we can still compare the performance of different crop varieties. We assume for simplicity that the prices and costs would be approximately the same for each crop variety of a specific type of crop (for example, we treat all rice varieties as if they brought the same market price). The crop model can then help us pick the highest-yielding crop variety for each crop type, at a given level of fertilizer and irrigation. This is the approach we take in this study, to look at yield responsiveness to fertilizer, irrigation, and, especially, climate change.

Referring back to equation (8), for a given fertilizing and irrigating plan we run the crop model over 12 different planting dates (one per month, to cover the entire year) and over the different varieties (for rice, there are 51 varieties pre-coded in the DSSAT crop modeling software). We select the best planting month and variety for the soil type and climate information for the year 2000. It may be that the farmer is actually using a suboptimal variety, perhaps because of limited knowledge of varieties or because of market constraints (only some varieties will be available for the farmer). It may be that the farmer is using a suboptimal planting date as well. But our starting point in this analysis will be the variety and planting date that the model shows is optimal.

Using the same fertilizing and irrigating plan, we then rerun the crop models, this time for one of the sets of climate statistics predicted for 2050. We can see what the yield would be if we force the crop variety and planting month to remain the same as in 2000 (the “no adaptation” case) and compare it to the yield if the crop variety and planting month were optimal for the climate of 2050 (the “adaptation” case).

All these exercises can be repeated for different fertilizing and irrigation schemes, thus giving us a large amount of data on the value of adaptation to climate change and on crop responsiveness to fertilizer and irrigation.

Layout of Report

Section 2 provides an overview of the agricultural sector in Cambodia and includes a review of studies of the impact of climate change and household responses to weather shocks and climate change. Section 3 presents the main results from the models used to investigate the impact of climate change on yield, after reviewing the climate projections being used in the analysis. Section 4 presents the findings from a small commune-level survey conducted for this research project. The final section concludes with some policy implications and recommendations resulting from the analysis.

2. OVERVIEW OF AGRICULTURE AND CLIMATE CHANGE ADAPTATION IN CAMBODIA

This section provides an overview of the agricultural sector in Cambodia, including a description of the rural population and the institutions and legal frameworks guiding agricultural development. In addition an important household survey dealing with climate change and adaptation is reviewed. In Section 4, details of the commune survey conducted by this team of researchers are given to augment and update these existing survey results.

Overview of Cambodia's Rural Population and Agricultural Sector

Cambodia's Rural Population

Of the 2.8 million households recorded in the 2008 Census, 81.7 percent live in rural areas. The 2008 Census puts Cambodia's total population at 13.4 million (51.5 percent female, 48.5 percent male), with an estimated growth rate of 1.54 percent per year and an average population density of 75 persons per km^2 (RGC, NIS 2009). The lowest population density is in the plateau/highland areas in the northeast, where about 30 percent of the populace lives below the poverty line.[2] The average household size is four to five persons, except in the plateau/mountain area, where average household size is five to six persons (RGC, NIS 2008).

With the majority of Cambodians living in rural areas, livelihoods are heavily dependent on agriculture. Most Cambodians earn approximately $30 per month, which is not enough to ensure household food security, and many face hunger. Approximately 52 percent of the population lives in the plains region, 30 percent in the Tonle Sap Plains, and about 7 percent in the coastal area. The remaining 11 percent live in the plateau/mountain region, which covers 38 percent of the total land area. Prior to 2000, access to this area was difficult. However, major infrastructure development since 2003 has improved national roads, and village roads are better connected to major areas.

The Agricultural Sector

Agriculture has been the top priority of the government's development strategies since 1993. In addition to rice, most rural people grow cash crops such as cassava, cashew, maize, and beans, as well as raising poultry (chickens, ducks) and livestock to supplement daily subsistence and household income. Mechanization in the form of modern farming equipment is being introduced into the agricultural sector; animal power is gradually being replaced by two-wheel (hand) tractors, tractors, harvesters, and threshers. Yet, traditional agricultural techniques and seeds are still widely used. Farming is predominantly rainfall dependent, and most farmers grow only one crop a year. Four major ecosystems allow the production of four types of rice: rainfed lowland rice, rainfed upland rice, floating rice and recession rice,[3] and dry-season irrigated rice.

Forests and fisheries also make important contributions to agricultural development and economic growth. Forest resources are valuable to forest dwellers and communities close to forested areas. Subforest areas and forests provide many products for local subsistence, especially timber, construction materials, bamboo, rattan, wild vegetables, traditional medicine, and other nontimber forest products. Before 1960, forests covered 73 percent (13.23 million hectares [ha]) of the country's total land area, including mangroves in the coastal areas extending about 83,700 ha (RGC, MoE and Danida 2007). The current extent of forest cover is estimated at about 59.09 percent of total land area (TWGFE 2007). The fisheries subsector is considered the second most important after rice, and fish consumption

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[2] Representative of Plan International in an interview with Radio Free Asia, www.rfa.org (accessed February 24, 2011).

[3] USDA website, "Cambodia: Future Growth Rate of Rice Production Uncertain," www.pecad.fas.usda.gov/highlights/2010/01/cambodia/ (accessed January 26, 2010).

contributes around 70–75 percent of the protein in the national diet. Nevertheless, these resources have been increasingly degraded in terms of ecosystem services. Both fisheries and forests are under threat. Important wetland habitats, including coastal mudflat and mangrove, sea grass meadow, and coral reef, have been degraded.

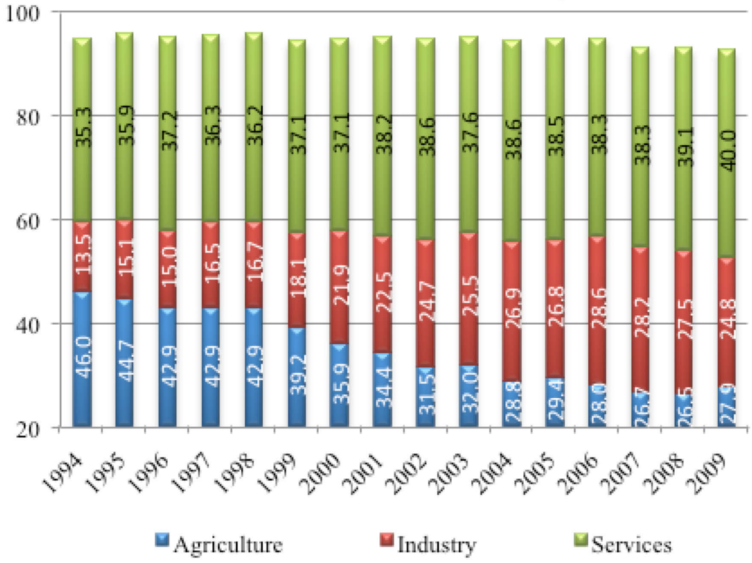
The expansion of agricultural activities, including rice farming and agroindustrial crops such as rubber and cassava, is seen as important to improving production. Such development, which is critical for food security and poverty alleviation, is likely to result in increased water use and demand. This is of growing significance, particularly since the rainfall pattern has become increasingly irregular, leading most farmers to choose new seed varieties for cultivation, particularly new strains of 90-day rice. Water shortage is a major constraint to improving productivity. Efforts to develop irrigation infrastructure have partly eased the situation in some areas, but only about 30 percent of irrigation structures had been rehabilitated at the time of study. In addition, most irrigation schemes are designed to provide supplementary irrigation water for wet-season rice farming. There are, however, certain medium- and large-scale irrigation schemes that can supply sufficient water for dry-season rice farming.

Agriculture's Contribution to GDP

Cambodia's economy has grown substantially since its integration into the global market economy. Average annual GDP growth was 9.5 percent for the period 1999 to 2008, peaking at 13.3 percent in 2005 (Theng and Koy 2010). However, this growth was narrowly based and largely dependent on four key sectors: garments, tourism, construction, and agriculture. Various sources give slightly different figures for the agricultural sector's contribution to GDP: Chao (2009) reports that the sector contributed 34.5 percent, while Wokker et al. (2011) report 33 percent.

According to International Monetary Fund (IMF 2009) data, as of 2009 agriculture's share of GDP had gradually declined to around 28 percent, from 46 percent in 1994 (Figure 2.1). Rice production is central to this sector: not only do the majority of Cambodian farmers depend directly and indirectly on the success of the rice crop each year, but because rice is the staple food, its production is a critical factor in the national effort to promote food security. Other major crops (maize, cassava, soybeans, and other cash crops) have recently emerged as marketable produce that can improve livelihoods and generate revenue and savings.

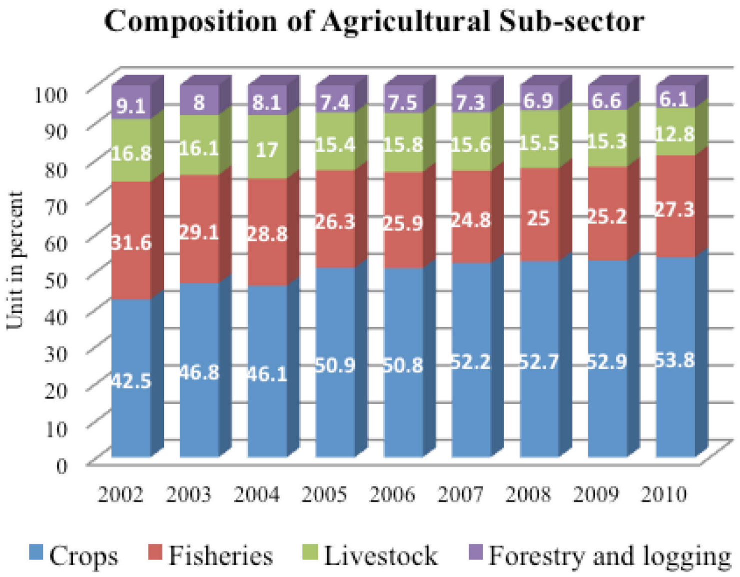
Figure 2.1—Percentage share of GDP (constant 2000 prices), 1994–2009



Source: IMF (2009).

Crop production contributes the highest share to the agricultural sector, followed by fisheries, livestock, and forestry, in that order (Figure 2.2). Rice has contributed significantly over the last decades. Its share of GDP increased from 6.7 percent in 2002 to 8.6 percent (29 percent of the agricultural sector's total GDP share) in 2007, at 2000 prices (RGC, NIS 2009).

Figure 2.2—Composition of agricultural subsectors, 2002–2010



Source: RGC, MAFF (2007, 2010a, 2011).

In terms of the fisheries and forest subsectors' GDP contribution, any further increase seems unlikely unless legal frameworks and law enforcement are strengthened. These resources will come under increasing threat due to population growth as well as agricultural expansion. Increased loss of fishery and forest resources might pose significant constraints on the rural poor in particular. Strengthening law enforcement can ensure sustainability of these resources.

Policies, Legal Framework, and Institutional Arrangements

Cambodia has prioritized agriculture as the main sector to alleviate poverty in the country. The government's national development strategies for the period 1993–2011 have been set out in a number of policy documents: Socio-economic Development Plan I (SEDP I) 1995–2000 and SEDP II 2001–2005; the National Poverty Reduction Strategy (NPRS) 2003–2005; Rectangular Strategy (RS), Phase I (2004) and II (2008); the National Strategic Development Plan (NSDP) 2006–2010; and the NSDP-Update 2010–2013. The NSDP is a comprehensive strategy to synthesize various policy documents (RGC 2006), with agriculture as the government's first priority in improving productivity and diversification, in addition to land reform, mine clearance, and fisheries and forestry reforms (RGC 2008). Agriculture is also viewed as the main vehicle for achieving the government's strategic goals (RGC 2010). In 2010, with a view to increasing rice exports, the government released a policy on the promotion of rice production and milled rice exportation, with the goal of exporting one million metric tons of milled rice by 2015. The vision is to bring Cambodia into the world market as a key milled rice–exporting country. With the government's commitment to removing all barriers to milled rice export, measures related to rice production, collection and processing, logistics, and marketing have been set. The policy clearly assigns specific responsibilities to all government agencies concerned (RGC 2010).

Two other sector-level strategies specifically aim at improving agriculture and water management: the Agricultural Sector Strategic Development Plan (ASSDP) 2006–2010 and the Strategy for Agriculture and Water (SAW) 2006–2010. SAW has recently been updated and extended to cover 2010–2013. The ASSDP 2006–2010 is a specialized policy on agriculture, fisheries, and forestry that captures relevant elements from the RS and NSDP. The overall objective of this strategy is to improve agricultural productivity and diversification, mostly in the rice subsector. It has five programs: enhancement of agricultural productivity and diversification; increased market access for agricultural products; strengthening the institutional and legislative framework and human resource development; sustainable fisheries resources management; and sustainable forestry resource management (RGC, MAFF 2005).

SAW is similar to the ASSDP in that it aims to enhance agricultural sector growth through rehabilitation and construction of physical infrastructure. According to the Asian Development Bank (ADB 2008), farmers' access to irrigation water is still limited. The irrigated area in 2008 was 1,064,263 ha (Cambodia, MOWRAM 2009), around 28 percent of the total cultivated area, made up of 2,403 irrigation schemes. The Ministry of Water Resources and Meteorology (MOWRAM) set its vision in the RS to increase the irrigated area.

Five programs are identified in the strategy: (1) institutional capacity building and management support for agriculture and water; (2) food security; (3) agriculture and agribusiness (value chain) support; (4) water resources, irrigation management, and land; and (5) agricultural and water resource research, education, and extension. The Ministry of Agriculture, Fisheries, and Forestry (MAFF) and MOWRAM are responsible for leading SAW, which is implemented by the Technical Working Group on Agriculture and Water (TWGAW).

The following section examines public perceptions of global warming, household vulnerability, and traditional coping mechanisms.

Findings of Rural Household Survey on Vulnerability and Adaptation (2004)

There have been two field surveys of the Cambodian population with regards to climate change: the 2004 survey of rural households on vulnerability and adaptation to climate change and climate hazards (RGC, MoE 2005) and the 2010 survey of public perceptions in Cambodia (RGC, MoE and BBC World Services Trust 2011). These constitute primary sources of information on the experiences and perceptions of local communities and the general public, on which government papers and other studies have relied. The first survey, which is reviewed below, focuses solely on adaptation in the agricultural sector.

Background

The survey was conducted as part of the formulation of Cambodia's National Adaptation Programme of Action to Climate Change (NAPA). The goal of NAPA was to identify and prioritize activities to adapt to current climate variability, climate extremes, and climate change. Since there had been no systematic survey of rural communities regarding climate change and adaptation issues, the Climate Change Department decided to allocate part of the project's Global Environmental Fund funding toward field surveys that would provide the basis for designing the proposed NAPA project activities for the rural population. Whereas other least developed countries relied primarily on expert judgment and policymakers for the formulation of their NAPAs, Cambodia conducted a range of consultations, from the grassroots to policymakers at the provincial and national levels.

Methodology

A total of six different questionnaires were used. The surveys aimed to (1) understand the main characteristics of climate hazards in Cambodia (flood, drought, windstorm, high tide, salt water intrusion, and malaria) and (2) understand coping mechanisms at the grassroots level. Coping mechanisms were broadly divided into health and nonhealth hazards, and by type of stakeholders (households, local nongovernmental organizations [NGOs], local communities, or informal leaders). The health questionnaires examined vulnerability and adaptation to malaria, while the nonhealth questionnaires covered flood, drought, windstorm, high tide, and seawater intrusion. During fieldwork, the NAPA team consulted with local authorities in each province to determine the most vulnerable areas at the commune and village level for field surveys. The surveys were administered from May 12 to June 10, 2004, in 17 hazard-prone provinces and 42 communes. A total of 684 households participated in the nonhealth questionnaire. About 95 percent of the households stated that farming was their main source of income (RGC, MoE 2005).

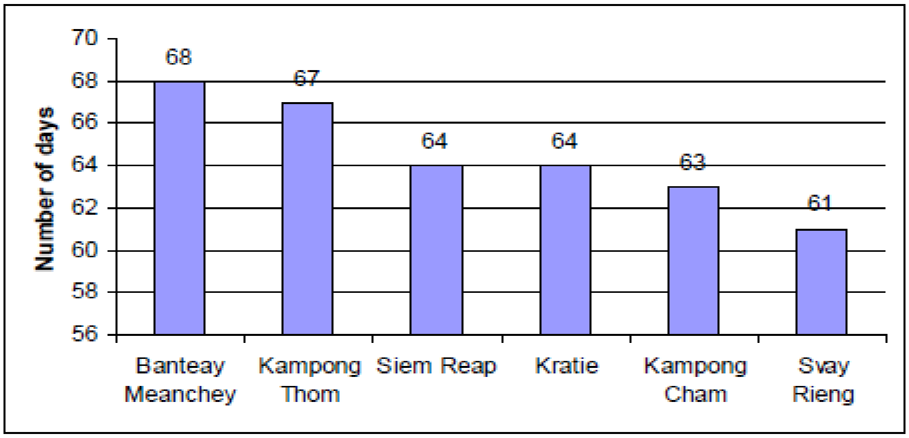
Key Findings

This section summarizes the key findings of the NAPA rural household survey for nonmalaria climatic hazards. All 17 provinces typically experience both flood and drought. Fifteen provinces also experience windstorms. There is little information on windstorms, as they are more rarely reported than flood and drought. All coastal provinces experience seawater intrusion.

In the areas surveyed, flood durations vary from two days to about 180 days (Figure 2.3). All provinces experience at least two floods a year, and seven provinces experience at least four floods a year. The depths of floods around dwellings may exceed 2 meters in Koh Kong and Kratie Provinces. Floods in agricultural fields are estimated to exceed 5 meters for Kratie and 3 meters for Koh Kong and Kandal. Traditional adaptation measures include building elevated enclosures for livestock, stocking up on food and feedstock for animals, and preparing boats. However, almost 20 percent of villagers interviewed said they do not usually make any preparations for seasonal floods. For example, an insignificant number of households have moved (temporarily) to safer ground in anticipation of floods.

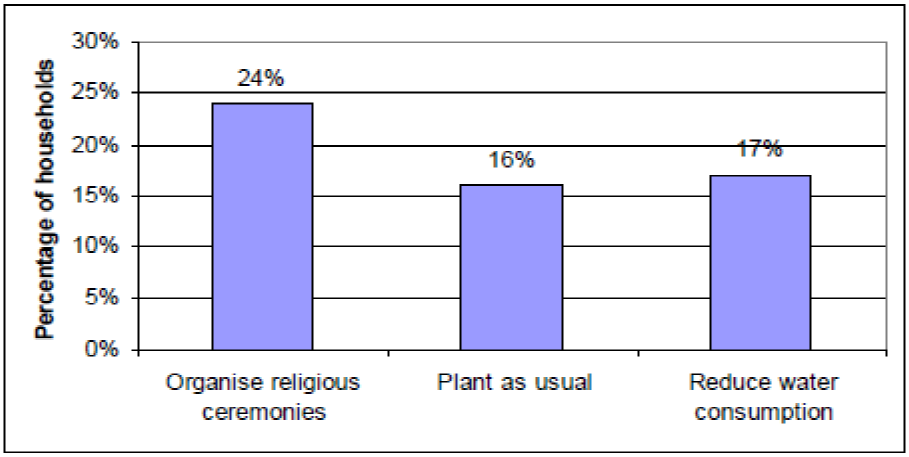
The villagers interviewed consider drought as severe a climate hazard as flood. Water shortages are a common occurrence all year round. About 80 percent of households interviewed suffered from water shortages for agricultural uses, while more than half suffered from water shortages for personal uses. Their coping capacity in drought appears limited: about a quarter of interviewees have organized religious ceremonies to bring rain, while others may grow crops as usual, hoping that there will be enough rainfall for plants (Figure 2.4). In periods of drought, households are forced to drastically reduce water consumption, which is restricted to human and livestock consumption. For instance, bathing and washing would not be considered priorities. Almost a third of villagers suggested solutions to help them adapt to drought: digging wells for household water consumption, constructing ponds and reservoirs for dry-season storage, and building canals to irrigate agricultural land. The most cited obstacle to implementation was the lack of financial resources.

Figure 2.3—Longest flood durations



Source: RGC, MoE (2005).

Figure 2.4—Household adaptation to drought



Source: RGC, MoE (2005).

According to the surveyors and authors of the report, local people have a high understanding of climatic hazards and of their causes. Villagers have noticed changes in drought and flood frequencies in recent years. About 58 percent of villagers have seen an increase in the frequency of floods, while 71 percent cite an increase in the frequency of droughts. The preparedness of villagers for extreme climate events is generally low. Villagers are aware of possible coping and adaptation activities, such as rehabilitating water storage structures and irrigation canals, or building dikes and water control structures. However, the lack of financial resources has generally prevented local people from implementing these projects.

Conclusions

Cambodian farmers may not have a scientific understanding of climate change, but they have already suffered from dramatic changes in seasonal patterns. Rural communities are ill prepared for climate change because of lack of information and lack of resources. Villagers are aware of possible coping and adaptation activities, such as rehabilitating water storage structures and irrigation canals, building dikes and water control structures, and the like. However, the lack of financial resources has prevented local people from implementing these projects. Cambodians understand climate change in the context of localized changes in weather and their experiences of extreme climate events. Preparing rural communities for climate change is key to food security and poverty alleviation.

3. USING CROP MODELS TO DETERMINE THE IMPACT OF CLIMATE CHANGE ON AGRICULTURE

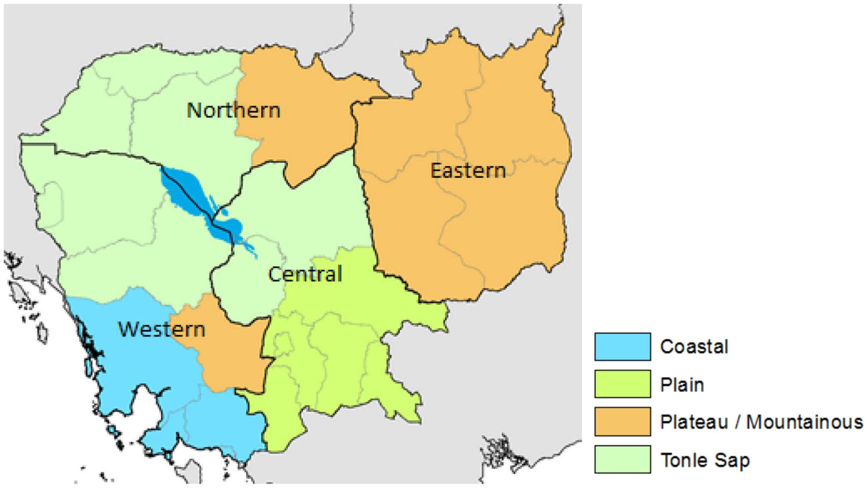
Climate Projections

In this study, we use climate data from four GCMs to evaluate the impact of climate change on agriculture in Cambodia by 2050. These GCMs were among the 23 recognized by the Intergovernmental Panel on Climate Change (IPCC) for the Fourth Assessment Report (AR4).[4] The IPCC data included results for three Special Reports on Emissions Scenarios (SRESs). In this study we wanted to limit the scenarios to just one, since with four GCMs, using multiple scenarios might overcomplicate comparisons. We chose to use the A1B scenario, which was very similar to the A2 scenario through 2050. Both of these scenarios assumed higher emission levels than the B1 scenario, which seems overly optimistic about the speed at which the nations of the world can lower emissions.

Because the GCM data are presented on a grid of at least 1.9 degrees (approximately 210 km at the equator), and because we wanted higher spatial resolution, we used downscaled data from Jones, Thornton, and Heinke (2009). They used inverse distance squared weighting on the nearest nine cells to downscale data spatially to 5 arc minutes (at the equator, around 9.3 km). (Those data consisted of monthly data for normal high and low temperatures, rainfall, solar radiation, and number of rainy days.)

To make our exposition easier, we have grouped the regions in two different ways: one grouping based on the country's four agroecological zones (Tonle Sap Plain, Mekong Plain, the plateau/mountain region, and the coastal area) and another grouping using contiguous regions (Figure 3.1). The Central zone is located in the center in an east-west orientation, extending south; it consists of the Mekong Plain as well as part of Tonle Sap. The Northern zone—north of Central—includes the northern part of Tonle Sap and the westernmost part of the mountains and plateau of the east. The Western zone covers the coastal area, some of the mountainous area west of the Mekong Plain, and the area west of Tonle Sap. Finally, the Eastern zone represents the mountainous and plateau area in the eastern and northeastern part of the country.

Figure 3.1—Regions used for aggregations



Source: Authors, using GADM 1.0.

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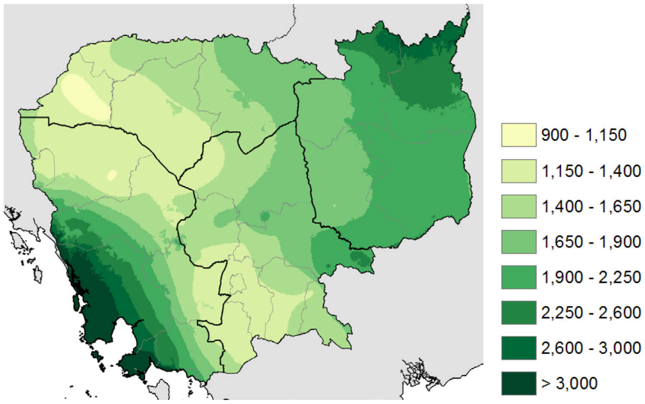
[4] GCMs are listed at www.ipcc-data.org/ar4/gcm_data.html.

Figure 3.2 shows the baseline (1950–2000) annual rainfall for Cambodia. We note a large variation across the country, with less than 1,150 millimeters (mm) annually in part of the north and more than 3,000 mm along the coast, as well as another area of high rainfall (2,600–3,000 mm/year) in the extreme northeastern part of the country.

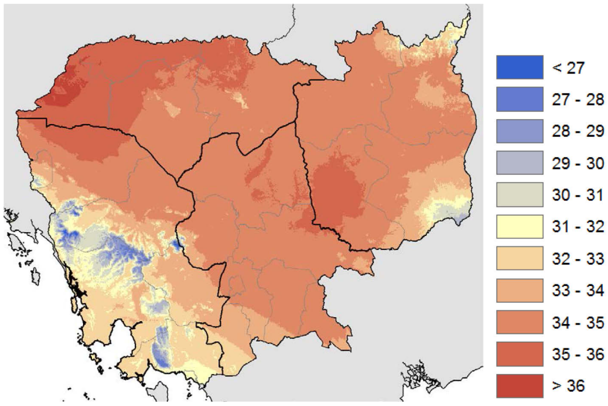
Figure 3.2—Annual rainfall, millimeters, 1950–2000 (baseline)



Source: WorldClim 1.4 (Hijmans et al. 2005).

Figure 3.3 shows the baseline (1950–2000) annual high temperature for Cambodia.[5] We focus on this value because high temperatures are known to limit crop yields, and climate change will in most cases result in higher temperatures. Normal high temperatures range from a low of less than 27 degrees Celsius in the high elevation areas of the Western region to a high of more than 36 degrees Celsius in the northwestern portion of the Northern region.

Figure 3.3—Annual high temperature, degrees Celsius, 1950–2000 (baseline)



Source: WorldClim 1.4 (Hijmans et al. 2005).
Note: Shows the average daily high temperature for the warmest month.

The GCMs were far from unanimous in their projections of future climate, differing on overall temperature and rainfall changes as well as the distribution of these changes geographically. Figures 3.4 through 3.7 show changes in annual precipitation, precipitation in the wettest three months (the actual months vary depending on location and year), and warmest annual temperatures, for each of the four GCMs.

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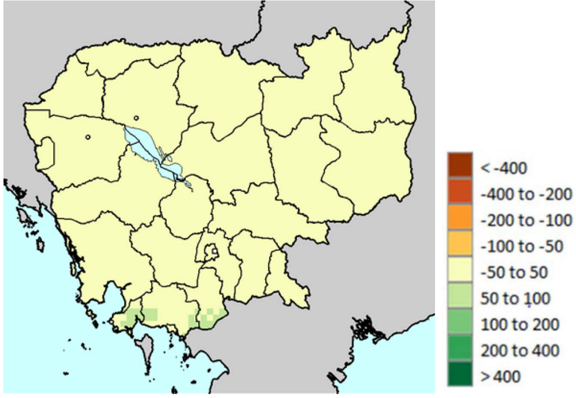
[5] This is actually the average daily high temperature for the warmest month.

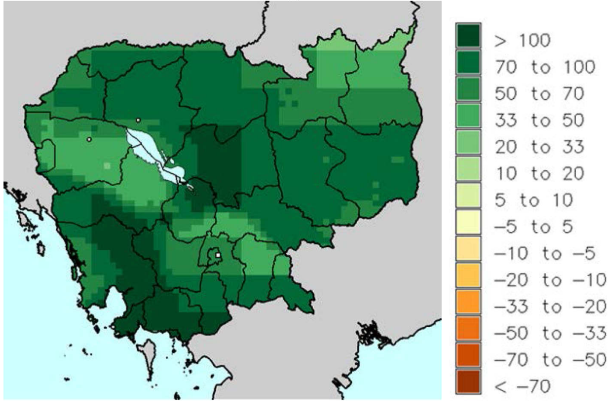
Figure 3.4a shows that there is little or no change in annual rainfall in CNRM (the GCM from the French National Center for Meteorological Research), though also it shows a substantially wetter rainy season (Figure 3.4b). Temperatures are projected to be much hotter, with the highest increases just east and south of Tonle Sap (Figure 3.4c).

Figure 3.4—Changes in important climate indicators, 2000–2050, for CNRM-CM3 GCM, A1B scenario

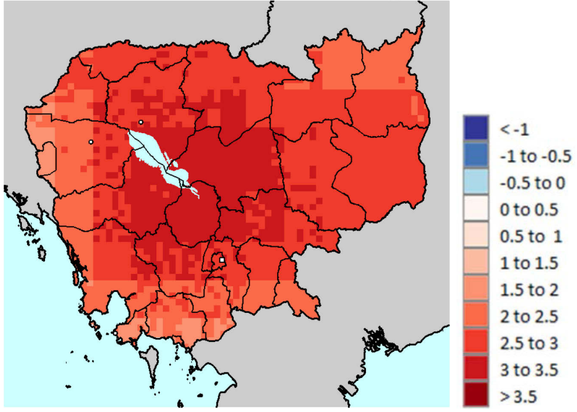
a. Changes in annual rainfall, millimeters



b. Changes in rainfall for the wettest three consecutive months, millimeters



c. Changes in annual high temperatures, degrees Celsius

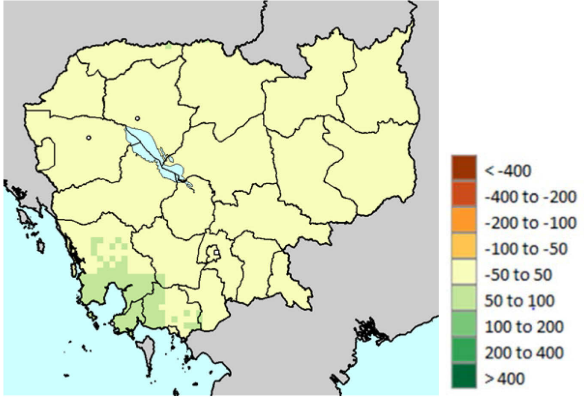


Source: Jones, Thornton, and Heinke (2009).
Note: The change in high temperature is actually the change in the average daily high temperature for the warmest month.

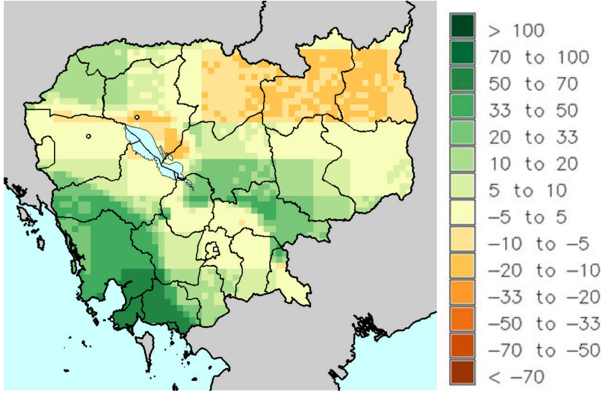
Figure 3.5a shows that CSIRO (the GCM from the Commonwealth Scientific and Industrial Research Organisation in Australia), like CRNM, projects very little change in annual precipitation. Projected changes in rainfall during the rainy season vary depending on the part of the country (Figure 3.5b): the northern two-thirds of the Eastern region is shown becoming much drier in the rainy season, while the coastal area and other parts of the country are projected to become much wetter. CSIRO projects only a moderate increase in temperature for most of the country, of 1 to 1.5 degrees Celsius (Figure 3.5c).

Figure 3.5—Changes in important climate indicators, 2000–2050, for CSIRO-MK3 GCM, A1B scenario

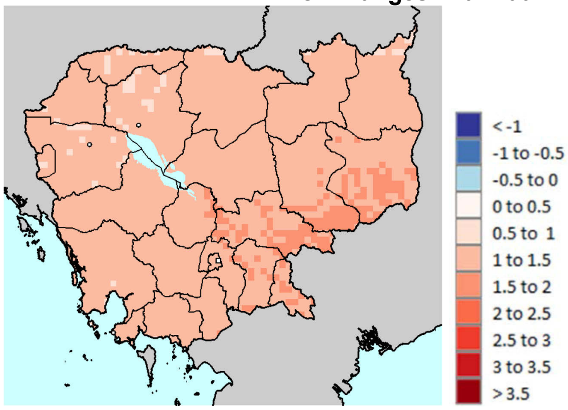
a. Changes in annual rainfall, millimeters



b. Changes in rainfall for the wettest three consecutive months, millimeters



c. Changes in annual high temperatures, degrees Celsius



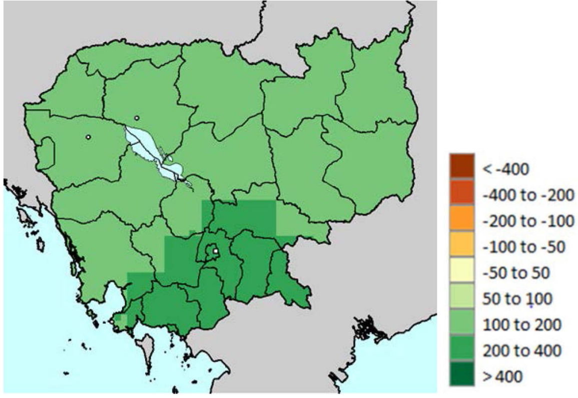
Source: Jones, Thornton, and Heinke (2009).

Note: The change in high temperature is actually the change in the average daily high temperature for the warmest month.

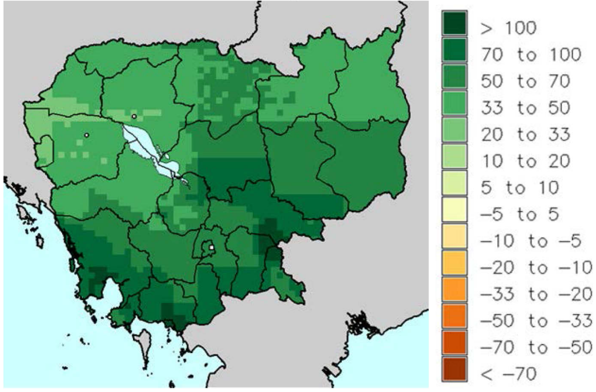
Unlike the preceding two GCMs, ECHAM (developed at the Max Planck Institute for Meteorology in Germany) shows higher annual rainfall and higher rainy season rainfall, particularly in the Central region and the coastal portion of the Western region (Figures 3.6a and 3.6b). Temperatures are projected to increase by more than 2 degrees Celsius for most of the country, except for the coastal region and the northwest, which are expected to see increases of more than 1.5 degrees Celsius (Figure 3.6c).

Figure 3.6—Changes in important climate indicators, 2000–2050, for ECHAM5 GCM, A1B scenario

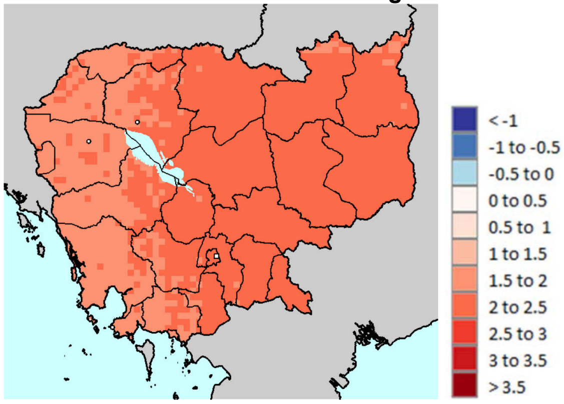
a. Changes in annual rainfall, millimeters



b. Changes in rainfall for the wettest three consecutive months, millimeters



c. Changes in annual high temperatures, degrees Celsius



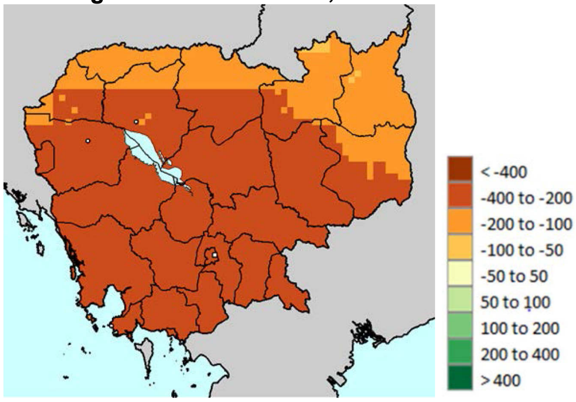
Source: Jones, Thornton, and Heinke (2009).

Note: The change in high temperature is actually the change in the average daily high temperature for the warmest month.

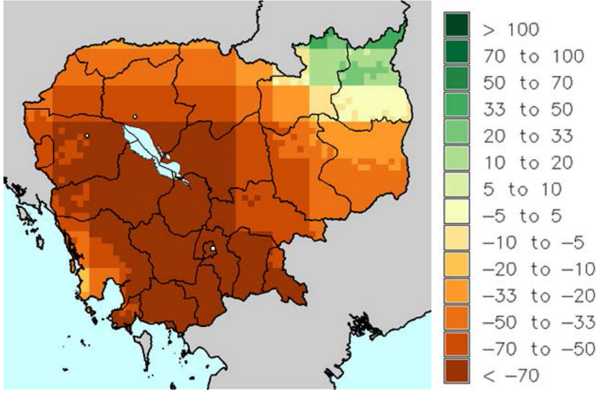
MIROC (the Model for Interdisciplinary Research on Climate, developed at the University of Tokyo) gives the only result showing less annual rainfall throughout the entire country (Figure 3.7a). This GCM projects a wet season that is much drier in almost the entire country except the extreme northeast, which shows some increase in rainfall (Figure 3.7b). MIROC shows little temperature change around Tonle Sap, but relatively high change in the easternmost part of the country, increasing by more than 2 degrees Celsius.

Figure 3.7—Changes in important climate indicators, 2000–2050, for MIROC 3.2 medium-resolution GCM, A1B scenario

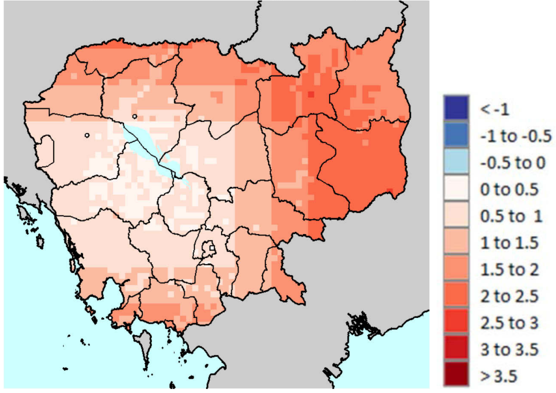
a. Changes in annual rainfall, millimeters



b. Changes in rainfall for the wettest three consecutive months, millimeters



c. Changes in annual high temperatures, degrees Celsius



Source: Jones, Thornton, and Heinke (2009).

Note: The change in high temperature is actually the change in the average daily high temperature for the warmest month.

Tables 3.1 through 3.3 summarize by region the changes mapped in Figures 3.4 through 3.7. These tables give equal weight to each grid cell (pixel) within the region. Table 3.4 summarizes the results from the preceding tables and figures. The table can be referred to in reviewing the crop yield projections discussed in the following section.

Table 3.1—Mean annual precipitation; level for 2000, and changes between 2000 and 2050

Region	Mean annual precipitation, 2000 (mm)	Change in mean annual precipitation, 2000–2050 (mm)			
		CNRM	CSIRO	ECHAM 5	MIROC 3.2
Central	1,557	14	24	203	-252
Eastern	2,064	-22	10	155	-183
Northern	1,439	23	23	137	-189
Western	1,925	27	41	181	-251
All	1,774	10	25	170	-219

Source: Authors' calculations.

Notes: Aggregation was done by giving equal weights to each grid square. The results for each GCM are from the A1B scenario.

Table 3.2—Precipitation in wettest three months; level for 2000, and changes between 2000 and 2050

Region	Precipitation for wettest 3 months, 2000 (mm)	Change in precipitation for wettest 3 months, 2000–2050 (mm)			
		CNRM	CSIRO	ECHAM 5	MIROC 3.2
Central	731	83	12	71	-77
Eastern	1,146	64	-2	55	-20
Northern	764	79	0	44	-53
Western	940	78	24	58	-75
All	*910*	*76*	*9*	*57*	*-56*

Source: Authors' calculations.

Notes: Aggregation was done by giving equal weights to each grid square. The results for each GCM are from the A1B scenario. The wettest three months of the year are computed at each grid square and for each GCM and for the baseline climate data. That means that one cell may have May to July as the wettest months and another may have June to August. For any given grid square, the values for the wettest months could change between 2000 and 2050.

Table 3.3—Normal daily maximum temperature for warmest month; level for 2000, and changes between 2000 and 2050

Region	Normal daily maximum temperature for warmest month, 2000 (degrees C)	Change in daily maximum temperature for warmest month, 2000–2050 (degrees C)			
		CNRM	CSIRO	ECHAM 5	MIROC 3.2
Central	34.3	2.9	1.4	2.2	1.0
Eastern	34.1	2.6	1.2	2.1	1.9
Northern	35.0	2.8	1.1	2.0	1.3
Western	32.7	2.6	1.2	1.9	0.8
All	33.9	2.8	1.2	2.1	1.3

Source: Authors' calculations.

Notes: Aggregation was done by giving equal weights to each grid square. The results for each GCM are from the A1B scenario.

Table 3.4—Summary of climate change impacts between 2000 and 2050, by GCM

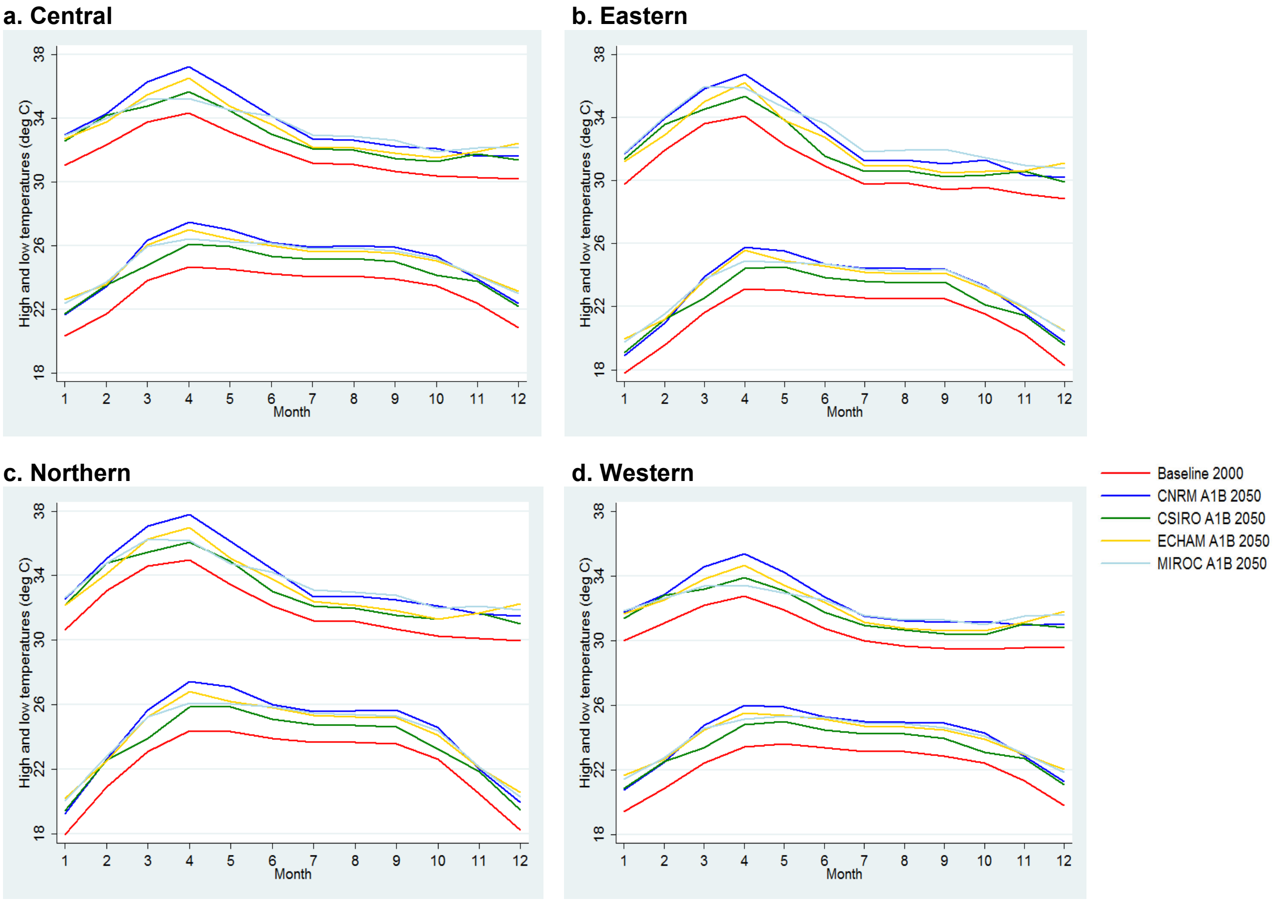
GCM	Temperature	Rainfall
CNRM	Much hotter	No change annually, though the rainy season is much wetter.
CSIRO	Moderate increase	No change annually. The coast is wetter during the wet season, but the northeast is drier during the wet season.
ECHAM	Hotter	Wetter annually, with a larger increase in the southwest and south central parts. The wet season is much wetter, with larger increases in the southwest and south central.
MIROC	Little change in the west, but hotter in the east	Much drier annually, and much drier in the wet season, except in the far northwest, which is slightly wetter.

Source: Authors' calculations from GCM data.

Figures 3.8 through 3.11 show changes in climate by month, throughout the year. These figures indicate that some cropping patterns may shift their timing as a result of climate change. They also give some spatial differentiation, since they are based on regional aggregates.

Figure 3.8 shows the distribution of normal monthly high and low temperatures for each region. The four models generally agree that, both now and in the future and for all four regions, the warmest month for both highs and lows will be April. While the normal daily high temperatures taper gradually from July to January, the normal daily low temperatures drop steeply, from September or October to December and January. Both the lows and highs tend to climb steeply between January and April.

Figure 3.8—Mean daily high and low temperatures by month and district, degrees C (2000–2050, by GCM)


a. Central

b. Eastern

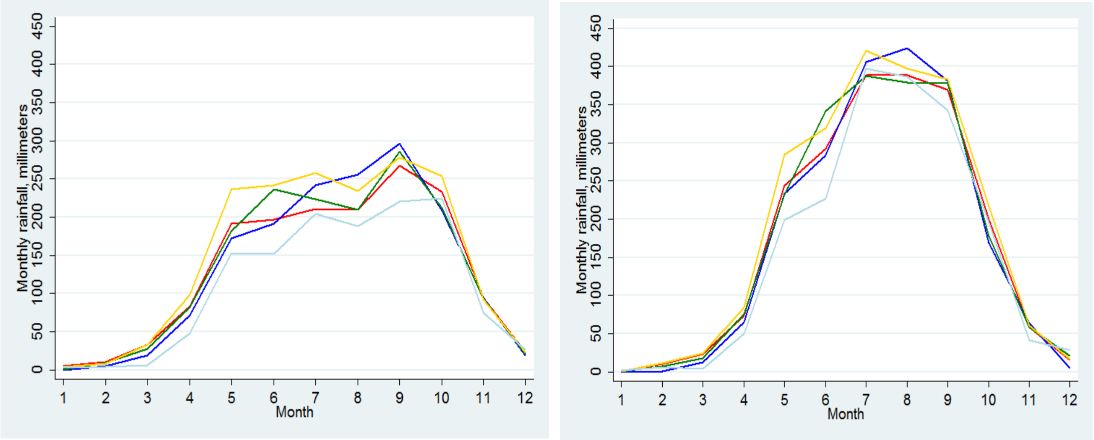
c. Northern

d. Western

Source: Authors' calculations from GCM data.
Note: Data are the average of all grid cells in each division.

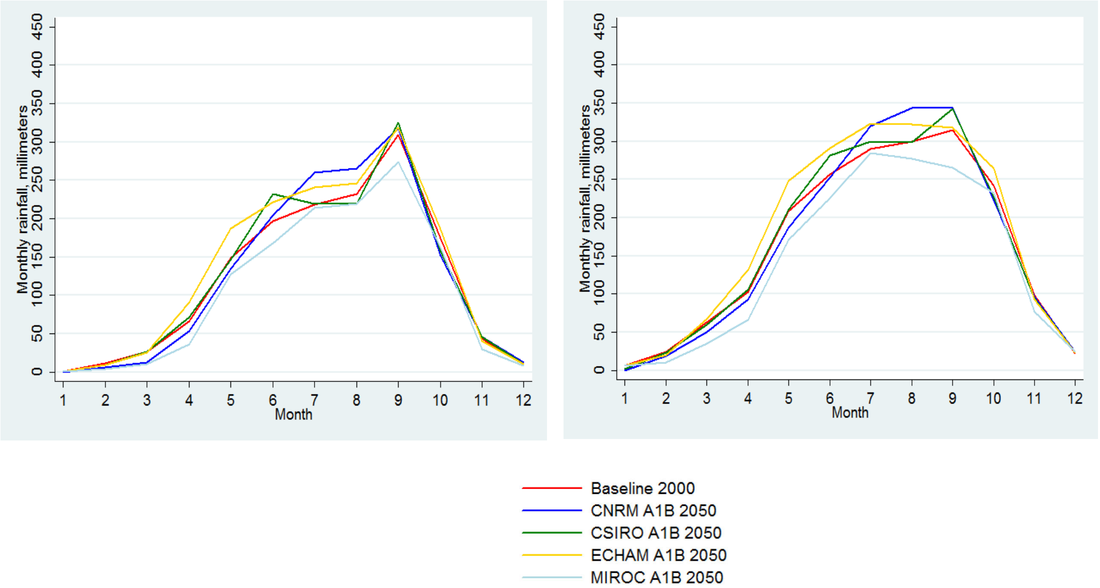
Monthly precipitation (Figure 3.9) appears less smooth, particularly around the wettest month—currently September, or August in the Eastern region. Under climate change, there may be some shifting. For example, ECHAM shows peak rainfall shifting from August to July in the Eastern region and from September to July in the Western region. In the Central region, MIROC shows a shift in peak rainfall from September to October, along with a considerable reduction in rainfall in almost every month.

Figure 3.9—Mean monthly precipitation by district, in millimeters (2000–2050, by GCM)



a. Central

b. Eastern



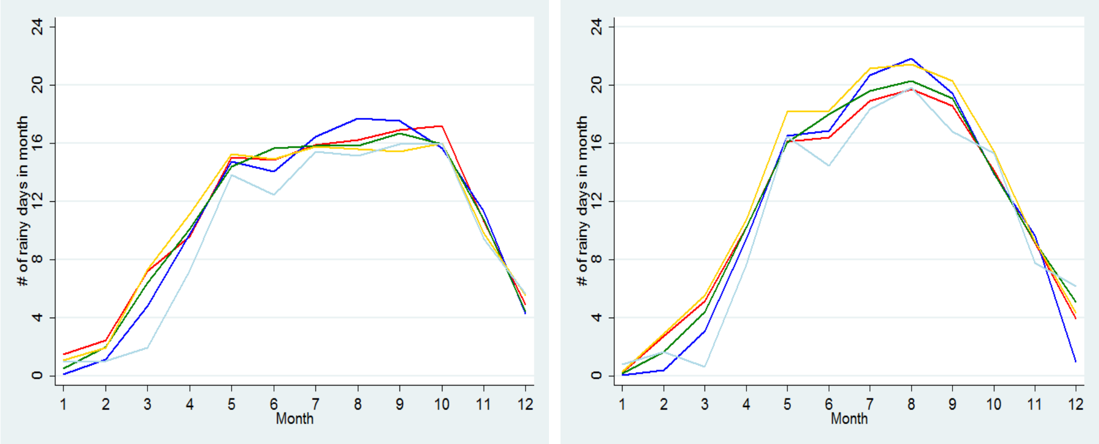
c. Northern

d. Western

Source: Author's calculations from GCM data.
Note: Data are the average of all grid cells in each division.

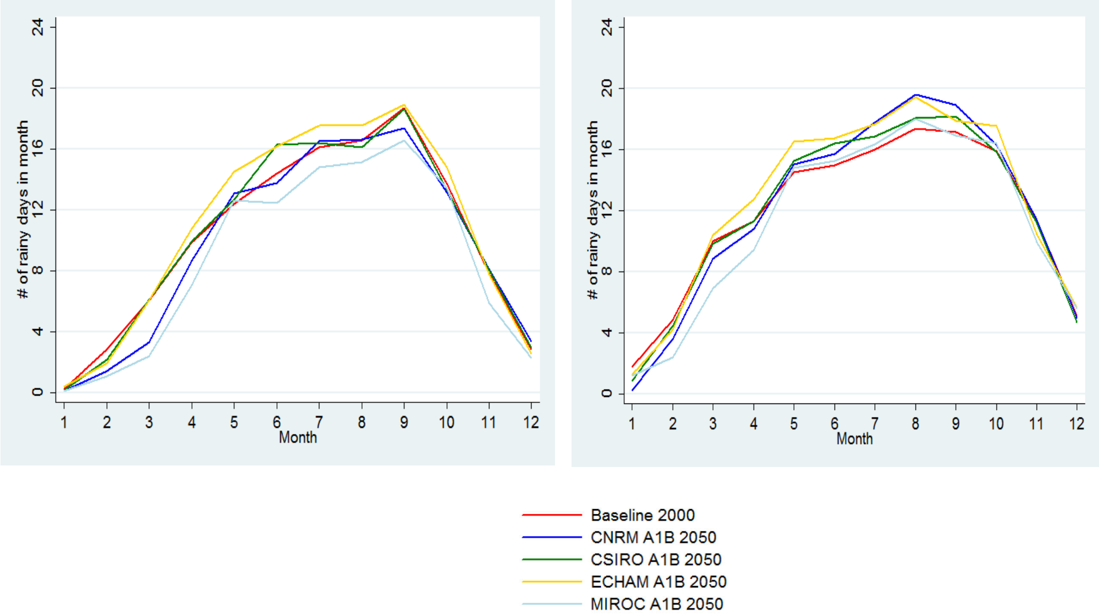
Figure 3.10 shows the number of rainy days. Some researchers define rainfall per day as rainfall intensity: if more rain falls in less time, it must be falling harder. More intense rain can be an indicator of potential damage from flash floods or erosion, as well as potential increases in crop damage from heavy rain (stalks bent or broken). In the Central region, we note in some cases a lower or unchanged number of rainy days together with increased rainfall (shown in Figure 3.9), indicating increased intensity.

Figure 3.10—Mean monthly number of rainy days by district (2000–2050, by GCM)



a. Central

b. Eastern



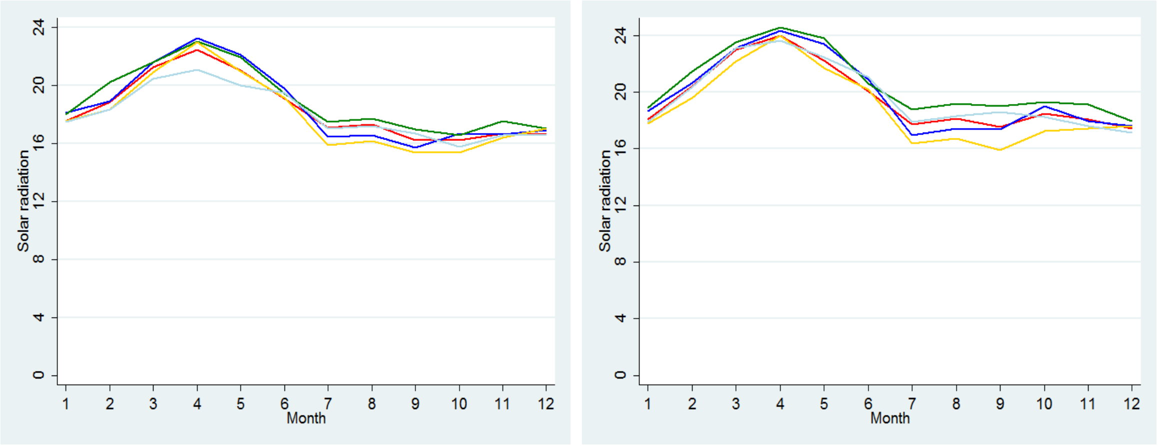
c. Northern

d. Western

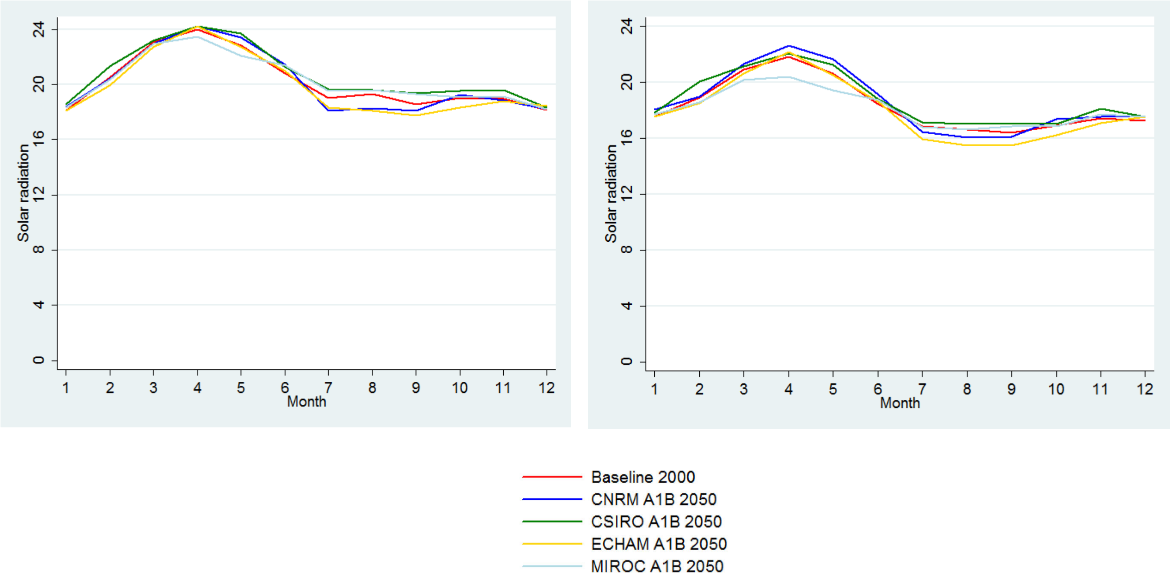
Source: Authors' calculations from GCM data.
Note: Data are the average of all grid cells in each division.

Figure 3.11 shows typical solar radiation under various climates. Generally, highest solar radiation corresponds to what we saw for high temperatures in Figure 3.8. While temperatures that are too high can be bad for crops, generally crops respond favorably to increases in solar radiation. Since climate change appears to generally bring increases in solar radiation—though not in all cases (many of the regions seem to have decreases in the July through September period)—these increases could offset losses due to higher temperatures.

Figure 3.11—Mean daily solar radiation by month and district (2000–2050, by GCM)



a. Central **b. Eastern**



c. Northern **d. Western**

Source: Authors' calculations from GCM data.
Notes: Data are the average of all grid cells in each division. Units are MJ/m^2 d.

Crop Model Results[6]

We used the DSSAT crop modeling software to evaluate crop yields for the climate of the 1950–2000 period and the climates given by the four GCMs for 2050. The DSSAT suite (Jones et al. 2003) models crop growth to predict yields using information on precipitation, temperature, and soils as well as farmers' operations, including planting density and fertilizer use. Weather statistics from climate models are incorporated in order to estimate crop yields under the existing climate and under the various future climate scenarios. DSSAT is a software package that comprises multiple mathematical models equipped for 26 different crops (Jones et al. 2003).[7]

The GCMs provide statistics on weather at a monthly time interval (for example, they provide mean monthly precipitation and mean daily high and low temperatures for each month). DSSAT further refines these weather statistics by stochastically generating daily values for rainfall, temperature, and solar radiation, based on these monthly values.

DSSAT also requires data on soil profiles at each location, and we used data adapted by Dimes and Koo (2009) from the Harmonized World Soil Database (HWSD version 1.1) by Batjes et al. (2009). The climate and soils data enable analysis of impact on yield in every 10-kilometer grid cell.

Our analysis includes 90 different weather simulations, to allow the outcome to be averaged across 90 growing seasons and to obtain a long-term yield perspective that is not unduly influenced by stochastic extremes.

Unlike previous studies, we identified the best planting month and best cultivars by simulating growth and yield scenarios for each crop under consideration. DSSAT, for example, is programmed with 51 rice and 142 maize cultivars.[8] Results are presented as maps of predicted yield changes, as well as in table form.

We solved for the yield at each grid cell based on the optimal cultivar and month to plant and thus were able to produce detailed maps of yield changes; however, in order to analyze data at the subnational level (for a province or district, for example), individual grid cell results need to be averaged appropriately. One way is to compute a simple average of the yield changes in all the grid cells of the province or district in question; however, often, much of the land area is not under crops, so the potential yield in those areas is not being realized. To account for this reality, we took a weighted average based on the proportion of each cell that was under cropland.

We used satellite land-use and land-cover datasets to guide us in determining how much land was cropland. These datasets sometimes misclassify large amounts of land because they misinterpret the image data. Savanna, for example, looks a lot like low-intensity cropland, seasonally flooded areas look like water, and fallowed areas often resemble secondary forest or bush. To avoid misclassification, we use three different satellite datasets: GLC2000 (Bartholome and Belward 2005), MODIS MCD12Q1 Land Cover 2008 L3 Global 500m (NASA 2009), and GlobCover 2009 (ESA 2010). GLC2000—the oldest of the three, but still reliable—has 1-kilometer resolution, while MODIS Land Cover data are at 500-meter resolution (we used the 2008 version for land cover), and GlobCover 2009 is at 300-meter resolution.[9]

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[6] Parts of this section describing the crop model are taken from the description written by one of the authors in a parallel report studying the impact of climate change on agriculture in the Pacific Islands (ADB and IFPRI forthcoming).

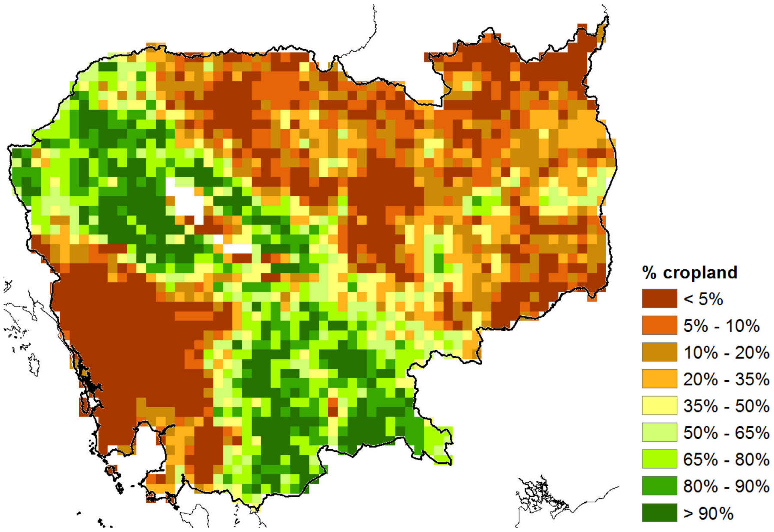
[7] DSSAT's developers regularly add crops; at the time that this study was conducted, 26 crops were available.

[8] The fine spatial resolution and broad range of possibilities covered in the analysis meant the computational requirements of the modeling were significant, resulting in the continuous operation of 20 computers for close to two months.

[9] "Cropland" in the 5 arc-minute composite was taken as the middle value computed from GLC2000, MODIS 2008, and GlobCover 2009. For GLC2000, cropland was computed by counting all the small grid cells in each of the larger 5 arc-minute grid cells classified as cultivated and managed area (Category 16) and adding those to 0.5 times the number of cells classified as mosaics of cropland and vegetation (Categories 17 and 18). Similarly, in MODIS 2008, cropland was computed by counting all the grid cells classified as cropland (Category 12) and adding those to 0.5 times the number of cells classified as mosaics of cropland and vegetation (Category 14). Finally, in GlobCover 2009, cropland was computed by counting all the grid cells classified as irrigated and rainfed crops (Categories 11 and 14) and adding them to 0.6 times the number of cells classified as a mosaic of 50–70 percent cropland and vegetation (Category 20) and 0.35 times the number of cells classified as a mosaic of 20–50 percent cropland and vegetation (Category 30).

Figure 3.12 shows the results of combining these three datasets at 10-kilometer resolution. Most of the cropping is located in areas around the Mekong River (including Tonle Sap).

Figure 3.12—Map of cropland percentage



Source: Authors' calculations using GLC2000 (Bartholome and Belward 2005), MODIS MCD12Q1 Land Cover 2008 L3 Global 500m (NASA 2009), and GlobCover 2009 (ESA 2010).

We evaluated crop yields for eight different crops at 2,162 points in Cambodia, using a grid of 10-kilometer squares,[10] for 2000 and 2050. For each crop, we searched for the best cultivar (variety) in each square, rather than assuming the same cultivar to be used in all locations. We also searched for the best planting month in each square and explored potential gains in changing fertilizer levels and in using irrigation to compensate for rainfall changes.

Figure 3.13 shows the results of our analysis for rainfed rice in the wet season, assuming a high level of nitrogen fertilizer use (90 kg/ha). We allowed the planting months to range from May to October (Figure 3.9 shows that there is very little rainfall from December to March). Figure 3.13 shows the results for the case of "no adaptation": whatever planting month and crop variety worked best for each grid cell in the climate of 1951–2000 was also used in the climate of 2050.

Of the four GCMs, the CSIRO model projects the best outcome for rice production, and the MIROC model indicates the worst outcome. CSIRO shows some yield increases, but most of these increases appear in areas that have very little cropping at present (see Figure 3.12), while the areas that currently have a lot of cropland show yield losses in the 2 to 10 percent range. In the MIROC model, most areas that currently have a lot of cropland suffer yield reductions in the 10 to 20 percent range, and some show losses in the 20 to 50 percent range.

The losses in the MIROC model appear to be driven almost completely by a reduction in rainfall, since it shows very little temperature change in the region where crops are grown. The small losses in the CSIRO model are most likely due to higher temperatures.

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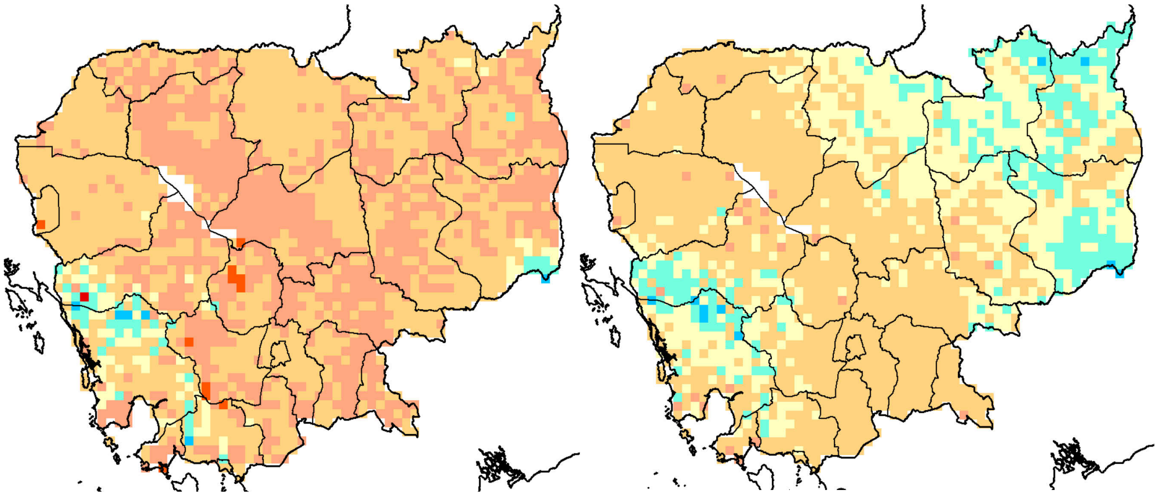
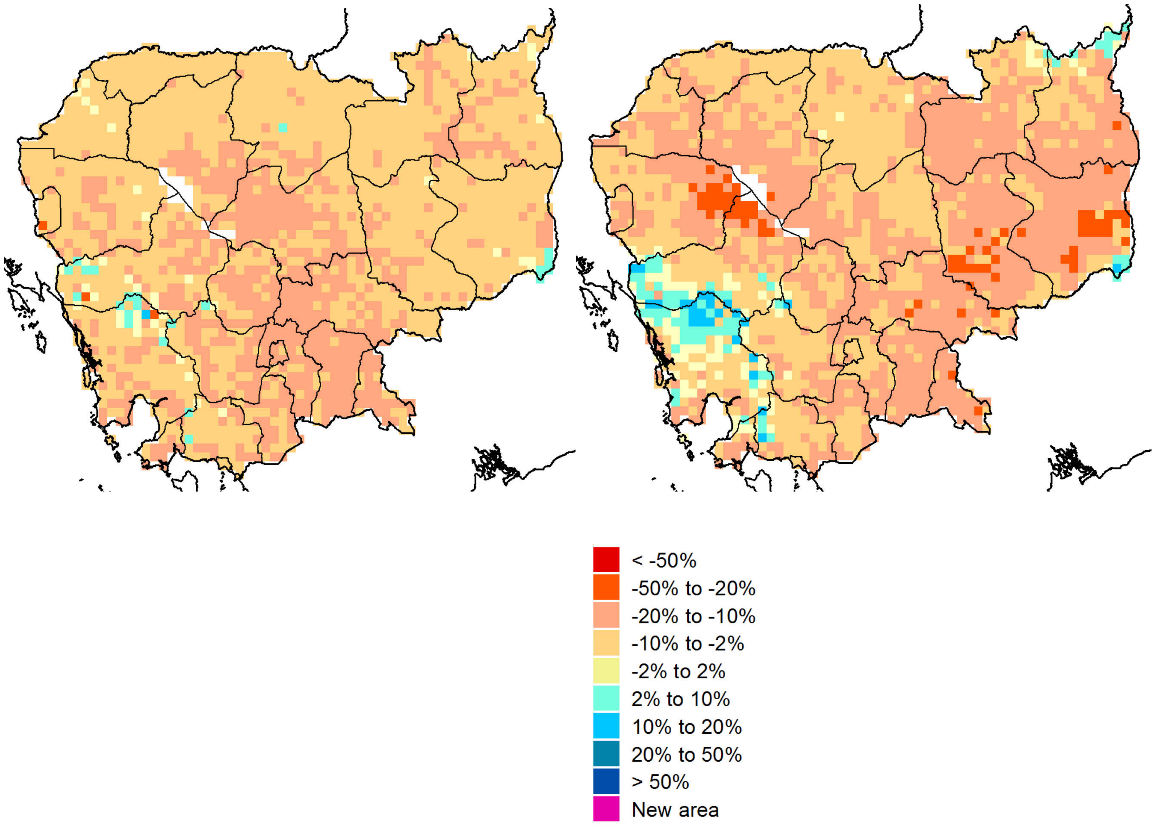
[10] They were actually 5 arc-minute squares, whose sides vary in length depending upon the distance from the equator. We rounded up to 10 kilometers for ease of understanding.

Figure 3.13—Change in yield of rainfed wet-season rice, high fertilizer levels, 2000–2050, with optimal planting date and variety for 2000 and the same used in 2050

a. CNRM **b. CSIRO**



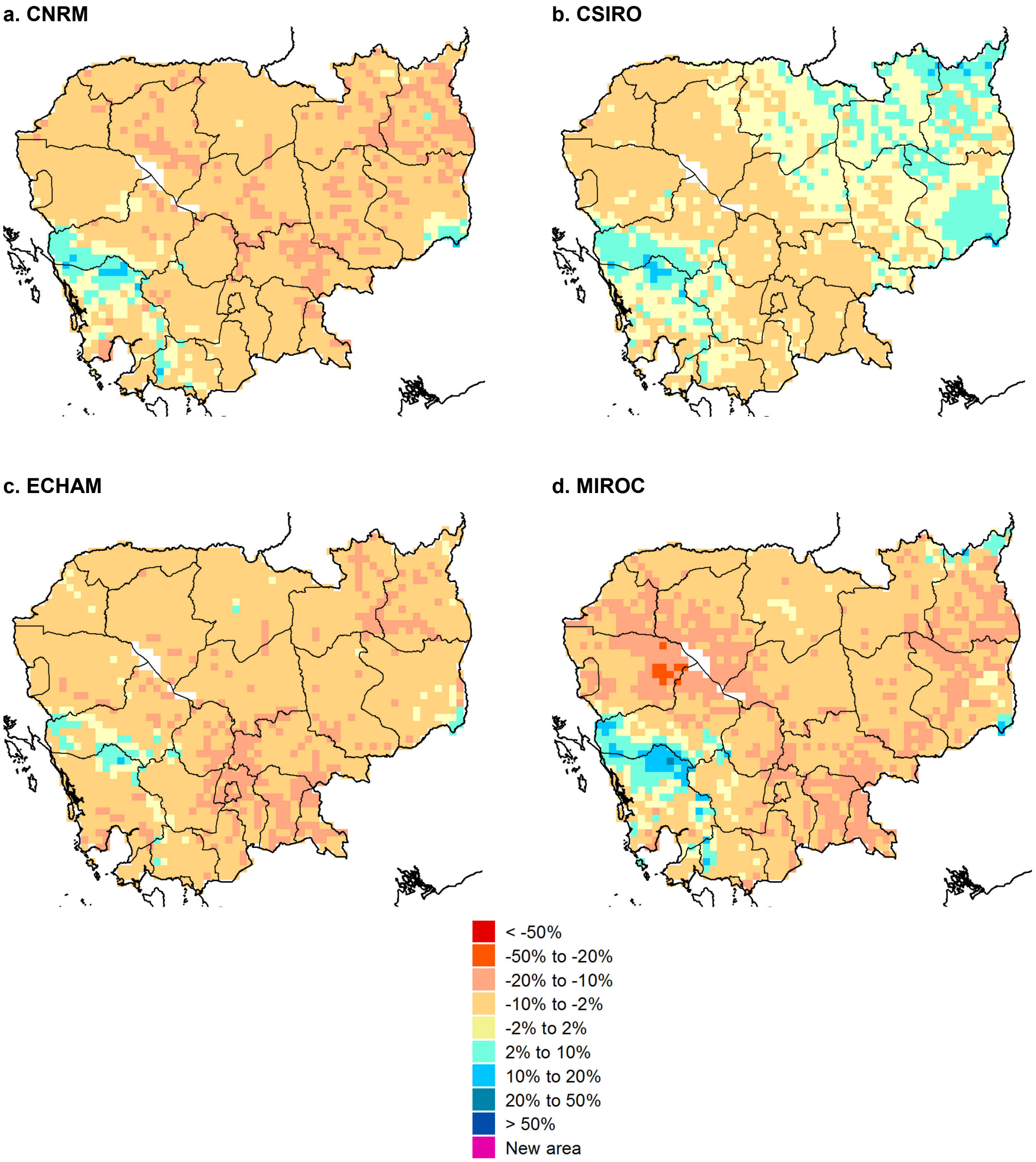
c. ECHAM **d. MIROC**



Source: Authors' calculations.
Note: Scenario A1B.

Figure 3.14 again shows the results of the analysis for rainfed rice in the wet season, while allowing both the planting month and the variety of rice to adapt to the 2050 climate changes—the "adaptation" results. In all the GCMs, we see improvement in comparison to Figure 3.13 (with unchanged planting month and rice variety). As in Figure 3.13, the CSIRO model shows the best results and the MIROC model shows the worst results, yet both are improved over the "no adaptation" results.

Figure 3.14—Change in yield of rainfed wet-season rice, high fertilizer levels, 2000–2050, with optimal planting date and variety for both 2000 and 2050



Source: Authors' calculations.
Note: Scenario A1B.

Table 3.5 summarizes the results of Figures 3.13 and 3.14. It also shows the comparison of low and high use of nitrogen fertilizer (10 versus 90 kg/ha). This was derived by first calculating the weighted average of all grid cells within each region for each GCM, weighted by the percentage (density) of cropland (Figure 3.12); then the median was calculated over the four GCMs. We see less loss and more gain from climate change with low levels of fertilizer. This may indicate that crop varieties that are designed to give high yields (and hence take high inputs) are more easily stressed by high temperatures or low rainfall. This does not mean, however, that higher levels of fertilizer are of no benefit; substantial gains in yield, even under climate change, can be obtained by using fertilizer. Later in this section we will take a closer look at the magnitude of the gains.

Table 3.5—Changes in rainfed wet-season rice yields from 2000 to 2050, median value of the results from the four GCMs

	Low fertilizer		High fertilizer	
Division	Keeping cultivar and planting month the same as in 2000	Optimal cultivar and planting month for 2050	Keeping cultivar and planting month the same as in 2000	Optimal cultivar and planting month for 2050
All Cambodia	-2.3%	2.2%	-9.9%	-7.5%
Coastal	1.8%	5.7%	-8.5%	-4.9%
Plain	-3.7%	2.2%	-11.0%	-8.3%
Plateau/mountainous	-2.0%	3.5%	-9.5%	-7.3%
Tonle Sap	-1.5%	1.2%	-9.3%	-7.2%

Source: Authors.

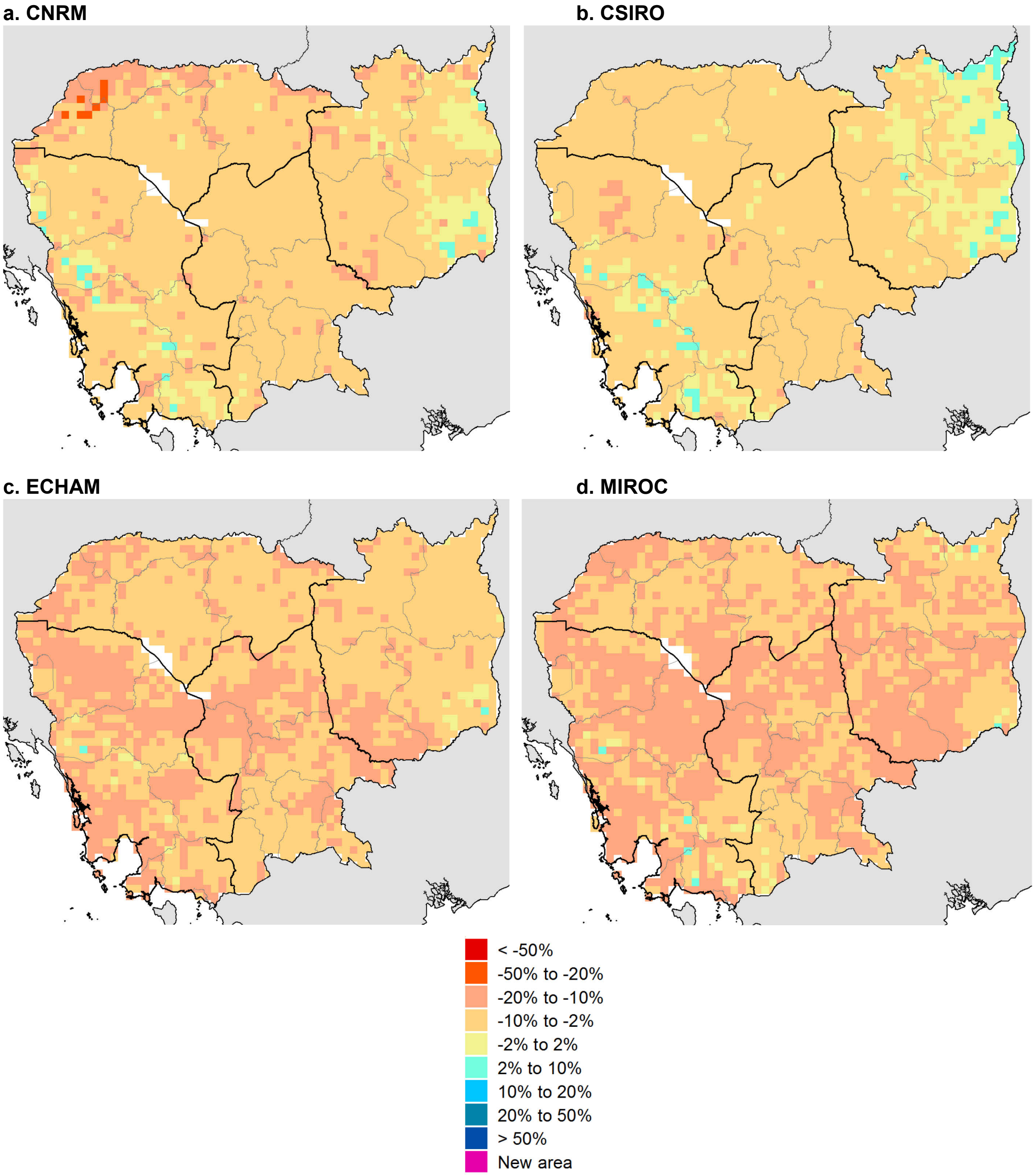
The coastal region seems to lose the least or gain the most under climate change, relative to the other regions: it shows gains under low levels of fertilizer for both the “no adaptation” and the “adaptation” cases and shows the least losses among the regions under high levels of fertilizer in both cases.

For the country as a whole, at low levels of fertilizer use, there is a potential gain of 4.5 percent of total yield if farmers are able to adapt, compared to the “no adaptation” case. Under high fertilizer use, the potential gain from adaptation is only 2.4 percent of total yield. With the help of effective research and extension institutions, farmers can learn to adapt. Indeed, the gain of 2.4 percent in yield due to adaptation may be one way to value investments in research and extension. Moreover, the adaptive gains represented here do not include potential adaptation to future varieties that might give dramatically better yields. As in the case of the Green Revolution, investments in research and extension can have enormous returns.

The results in Table 3.5 suggest that, even with adaptation to the best varieties currently available, climate change could result in a loss of yield of 7.5 percent for rainfed wet-season rice. Since agriculture, and rice agriculture in particular, provides not only sustenance but also income and employment for a large proportion of the population, the potential impact of climate change merits careful attention by policymakers.

Figure 3.15 shows the analysis for irrigated dry-season rice, with no adaptation. We allowed the planting month to range from November to April. In a comparison with rainfed (wet-season) rice (Figure 3.13), projected losses appear to be lower in CNRM and MIROC but not in CSIRO and ECHAM. While CNRM shows very high projected losses in the northwestern-most part of Cambodia for irrigated rice, the largest losses are projected by MIROC; the smallest losses are projected by CSIRO.

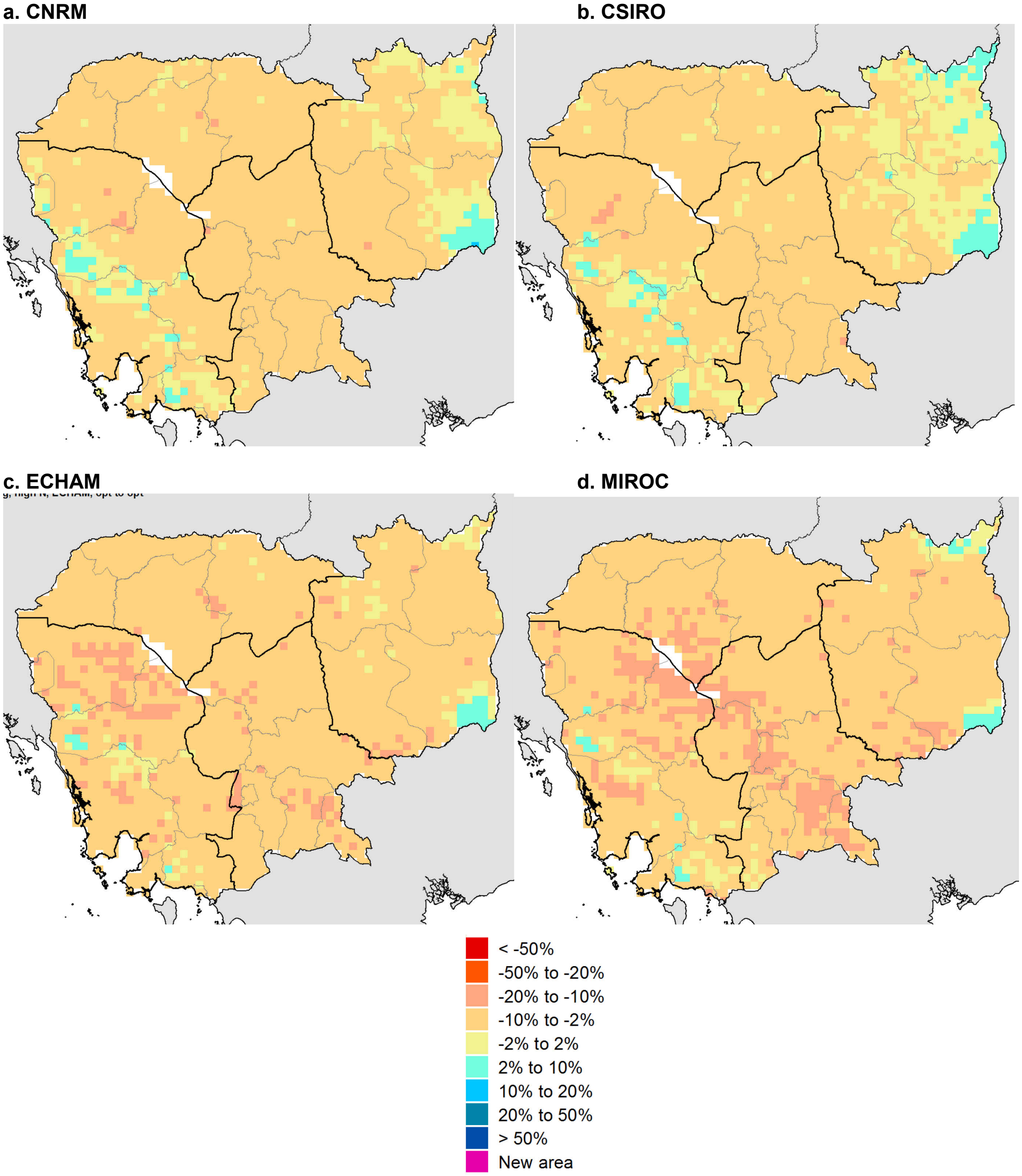
Figure 3.15—Change in yield of irrigated dry-season rice, high fertilizer levels, 2000–2050, with optimal planting date and variety for 2000 and the same used in 2050



Source: Authors' calculations.
Note: Scenario A1B.

Figure 3.16 shows the results for irrigated rice if farmers adapt by selecting planting month and variety. There is very little change under CNRM and CSIRO, and some improvement under ECHAM and MIROC.

Figure 3.16—Change in yield of irrigated boro rice, high fertilizer levels, 2000–2050, with optimal planting date and variety for both 2000 and 2050



Source: Authors' calculations.
Note: Scenario A1B.

Table 3.6 summarizes the results of the four GCMs by region, using the same procedure that was used for Table 3.5. As with wet-season (rainfed) rice, the coastal region shows less adverse impact from climate change than the other regions; also similarly, the percentage yield loss projections are less for low fertilizer use than for high fertilizer use. Adaptation of cultivar and planting month shows potential gains of around 2.3 percent of current yield for low fertilizer levels, and 1.5 percent of current yield for high fertilizer levels. These potential adaptation gains are smaller than in the case of wet-season rice but still important; again, they help in assigning an economic value to returns to agricultural research and extension. Finally, the potential yield loss due to climate change, even allowing for some adaptation, is projected at around 6.2 percent.

Table 3.6—Changes in irrigated dry-season rice yields from 2000 to 2050 (median value of the results from the four GCMs)

	Low fertilizer		High fertilizer	
Division	**Keeping cultivar and planting month the same as in 2000**	**Optimal cultivar and planting month for 2050**	**Keeping cultivar and planting month the same as in 2000**	**Optimal cultivar and planting month for 2050**
All Cambodia	-2.9%	-0.6%	-7.7%	-6.2%
Coastal	-0.9%	1.1%	-6.1%	-3.8%
Plain	-3.0%	-1.4%	-7.5%	-6.7%
Plateau/mountainous	-3.5%	-1.7%	-7.1%	-5.5%
Tonle Sap	-2.8%	0.3%	-8.3%	-6.3%

Source: Authors' calculations.

Table 3.7 summarizes the projected changes in yield for rice and six other crops, at two levels of nitrogen fertilizer use. The low level was set at 10 kg/ha; the higher level varied according to the crop, as what would be a reasonable high for a non-nitrogen-fixing crop such as rice would be too high for a nitrogen-fixing crop such as soybeans. Table 3.8 shows the levels of nitrogen used for the "high fertilizer" experiments for each crop, along with yield response from fertilizer use. Table 3.7 shows that when levels of fertilizer are high, or when levels of fertilizer are low and no adaptation takes place, the impact of climate change on crop yield is expected to be negative. Only one crop scenario shows positive changes from climate change: this is the case of rainfed rice using low fertilizer and allowing adaptation (that is, new varieties and planting month).

We note that higher fertilizer use is increasingly becoming the norm, and that at least some adaptation is likely to take place, considering the farmer's desire to make optimal choices and the current existence of some research and extension support for farmers. We will therefore focus on the final column in the table, showing climate change impacts with higher levels of fertilizer and some adaptation. The projected losses for nonrice crops are similar in magnitude to the losses shown for rice, that is, in the 6 to 8 percent range—with rainfed sugarcane losses predicted to be slightly lower and rainfed sorghum slightly higher, and irrigated taro much higher. These numbers may help policymakers and other stakeholders evaluate the impact of climate change on agriculture and assign an appropriate value to agricultural research directed at finding new varieties that will help farmers to adapt.

Table 3.7—Changes in crop yields from 2000 to 2050 (median value of the results from the four GCMs)

Crop	Low fertilizer		High fertilizer	
	Keeping cultivar and planting month the same as in 2000	Optimal cultivar and planting month for 2050	Keeping cultivar and planting month the same as in 2000	Optimal cultivar and planting month for 2050
Rainfed wet-season rice	-2.3%	2.2%	-9.9%	-7.5%
Irrigated dry-season rice	-4.4%	-0.9%	-7.7%	-6.2%
Rainfed maize	-2.7%	-0.8%	-8.1%	-6.3%
Irrigated maize (any season)	-2.7%	-0.6%	-9.2%	-7.1%
Rainfed soybeans	-7.4%	-6.6%	-8.8%	-7.5%
Rainfed groundnuts	-8.0%	-6.6%	-8.1%	-6.7%
Irrigated groundnuts (any season)	-8.7%	-6.7%	-9.0%	-6.8%
Rainfed sugarcane	-5.2%	-4.8%	-5.2%	-4.8%
Rainfed sorghum	-11.0%	-9.0%	-11.0%	-9.0%
Rainfed taro	-5.7%	-3.1%	-10.3%	-6.2%
Irrigated taro (any season)	-9.5%	-6.6%	-12.4%	-12.0%

Source: Authors' calculations.

Notes: Irrigated sugarcane, soybeans, and sorghum had similar yields to their rainfed counterparts and were omitted from this table. The sugarcane crop model does not include fertilizer response. Aggregation was done by taking a weighted average of cropland in each square.

Table 3.8 supports the conclusion that fertilizer use results in higher yields regardless of the climate scenario. For rainfed wet-season rice, for example, "high fertilizer" for nitrogen is set at 90 kg/ha. Yield changes between low fertilizer levels and high fertilizer levels are in fact more or less linear, based on results obtained for intermediate levels. Increasing nitrogen fertilizer by 10 kg/ha results in an average 7.2 percent increase in yield, for the climate around the year 2000; with the climate of 2050 (averaging over the four GCMs), yield is projected to increase by only 5.5 percent. We conclude that there is value in applying additional fertilizer, as long as the price (marginal cost) of the fertilizer does not exceed the value of the increase in yield (marginal return).

Table 3.8—Yield response for supplementing nitrogen in the soil

Crop	Nitrogen used for high-fertilizer scenarios (kg N / ha)	% change in yield for each additional 10 kg N / ha	
		2000	2050
Rainfed wet-season rice	90	7.2%	5.5%
Irrigated dry-season rice	90	6.7%	5.5%
Rainfed maize	90	4.3%	3.4%
Irrigated maize (any season)	90	4.8%	3.7%
Rainfed groundnuts	30	0.3%	0.2%
Irrigated groundnuts (any season)	30	0.3%	0.2%
Rainfed sorghum	30	0.0%	0.1%
Rainfed taro	90	3.7%	3.1%
Irrigated taro (any season)	90	5.4%	4.5%

Source: Authors' calculations.

Notes: Irrigated sugarcane, soybeans, and sorghum had similar yields to their rainfed counterparts and were omitted from this table. The sugarcane crop model does not include fertilizer response, and the soybean fertilizer response was not measured. Aggregation was done by taking a weighted average of cropland in each square. 4. The value for 2050 shows the median value of the results for the four GCMs using optimal month and cultivar.

Table 3.8 shows that yield losses due to climate change can be reduced, for many crops, by increasing the availability of nitrogen in the soil. Applying nitrogen fertilizer is not the only way to get more nitrogen into the soil for plant use. Another approach is to improve soil fertility management, for example, by using animal manure, cover crops, crop rotation, and crop or agroforestry residue.

Table 3.9 shows the relative importance of crops currently produced. In terms of harvested area, rice is almost 24 times more important than the second most planted crop, maize, and almost 150 times more important than groundnuts, which are ranked tenth in terms of land area. Yu and Diao (2011), using data from various sources, suggest that dry-season (irrigated) rice accounts for only 12.7 percent of total harvested rice area. Thus, losses to wet-season rice due to climate change are more important than losses to dry-season rice, though, as irrigation use increases, the dry-season losses will become more important.

Table 3.9—Harvest area and production of major crops in Cambodia

Crop	Hectares harvested	Production (metric tons)	Yield (metric tons/ ha)
Rice	2,498,972	6,325,775	2.5
Maize	105,926	382,566	3.6
Cassava	78,100	1,644,222	21.1
Other fresh vegetables	77,333	483,083	6.2
Soybeans	85,433	131,461	1.5
Beans	64,951	53,143	0.8
Sesame seed	56,743	37,500	0.7
Bananas	29,993	129,667	4.3
Rubber	20,222	19,880	1.0
Groundnuts	16,781	25,480	1.5

Source: FAO (2011).

Notes: Three-year averages, 2005–2007. Yield was computed by dividing production by area.

In view of the potential gains from optimal farm management, and potential losses from climate change without adaptation, it is clear that adaptive techniques and resources will be critical to maintaining agricultural production. The pace of climate change in the next 40 years is likely to be faster than indigenous methodologies can adapt—faster, that is, than traditional learning and communication can take place between farmers and between generations. Small farmers will suffer the consequences of climate change unless agricultural research and extension can develop successful cultivars and complementary farming practices and pass this essential knowledge to farmers. In order for Cambodia to succeed and thrive, investment must be increased in these institutions, and the institutions must focus on helping the small farmer succeed amid the changes and uncertainty concerning the future environment.

Results from the Global Food and Agricultural Model IMPACT

IMPACT (International Model for Policy Analysis of Agricultural Commodities and Trade) is a partial equilibrium food and agricultural model developed by IFPRI. Covering 32 crop and livestock commodities, it has "115 country (or in a few cases country-aggregate) regions, with specified supply, demand, and prices for agricultural commodities. Large countries are further divided into major river basins" (Nelson, Rosegrant, Palazzo, et al. 2010, 105–106). For technical details about the model, see Rosegrant, Ringler, and Msangi 2008.

In this section, we report the results of Nelson, Rosegrant, Koo, et al. (2010) on the impact of climate change on world commodity prices as well as on agricultural production and food consumption in Cambodia.[11] Unfortunately, the study combines Cambodia and Laos into a single unit of analysis, making

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[11] See Appendix 3 of Nelson, Rosegrant, Palazzo, et al. (2010) for details about how the data were generated.

it impossible to disaggregate some of the model's most interesting results, including projections for 2050 crop area, yield, production, consumption, and trade.

World Commodity Price Projections

IMPACT projects world prices over four decades for important agricultural commodities. Figure 3.17 shows these price projections under the baseline scenario, which assumes moderate population growth and moderate GDP growth for each country in the world. The blue line in each graph represents the IMPACT result without climate change; this result takes into consideration only changes in demand (caused primarily by changes in GDP and population) and changes in supply (caused primarily by increased yields due to technological progress and changes in harvested area, responding to price signals). For rice, we see that between 2010 and 2050, global prices are projected to rise by 34 percent due to these normal growth factors in population, GDP, and technology.

Figure 3.17—Food price projections

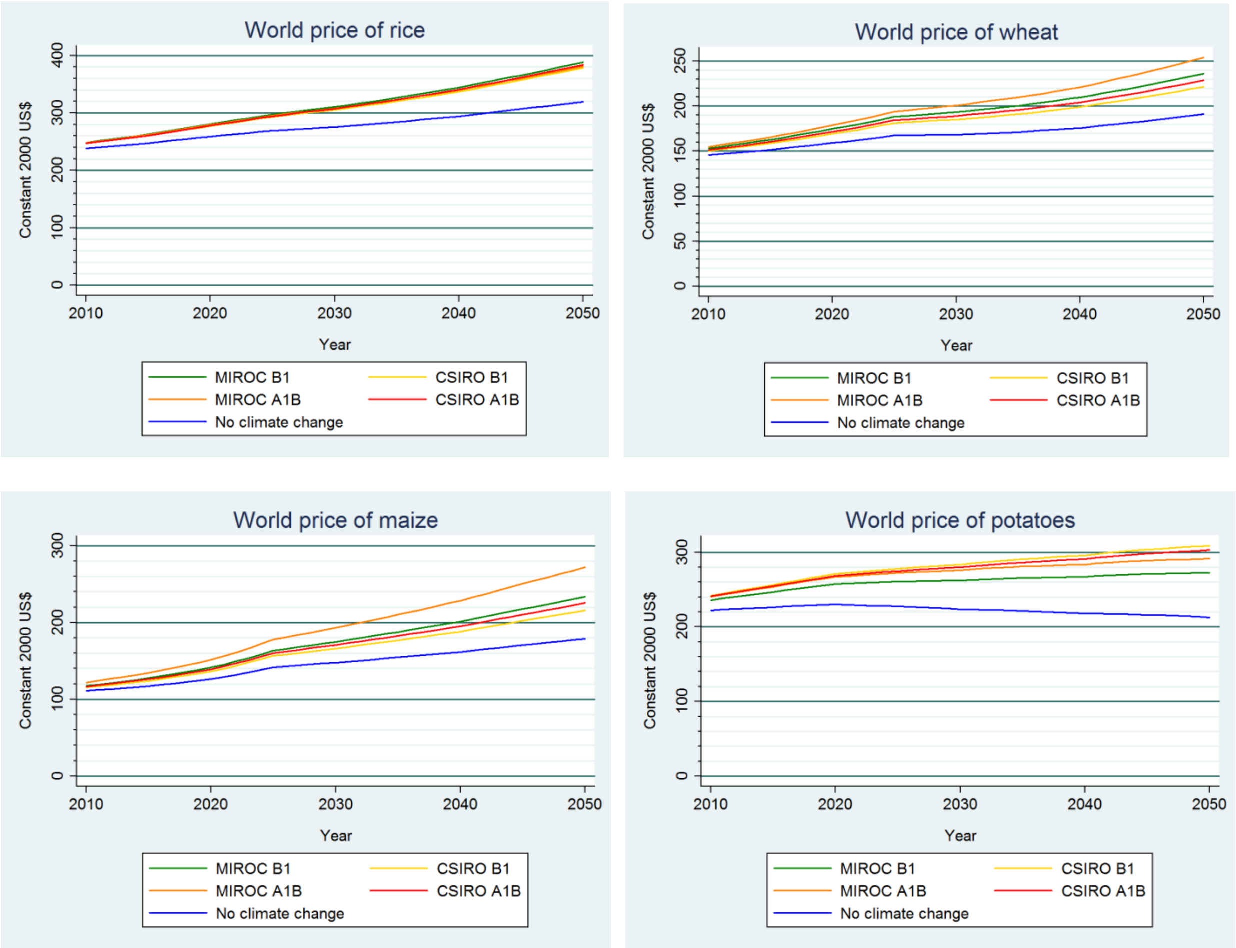


Figure 3.17—Continued

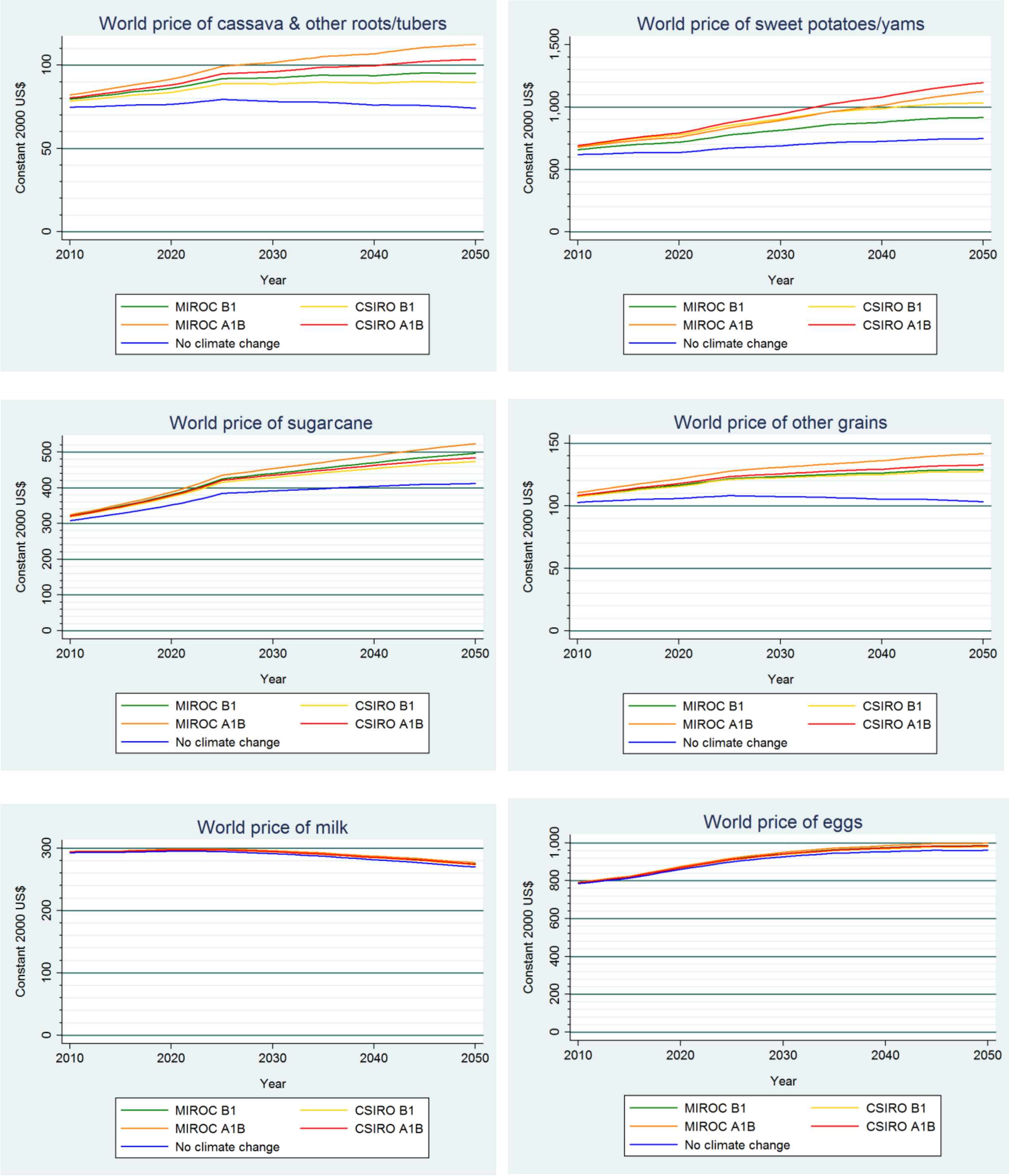
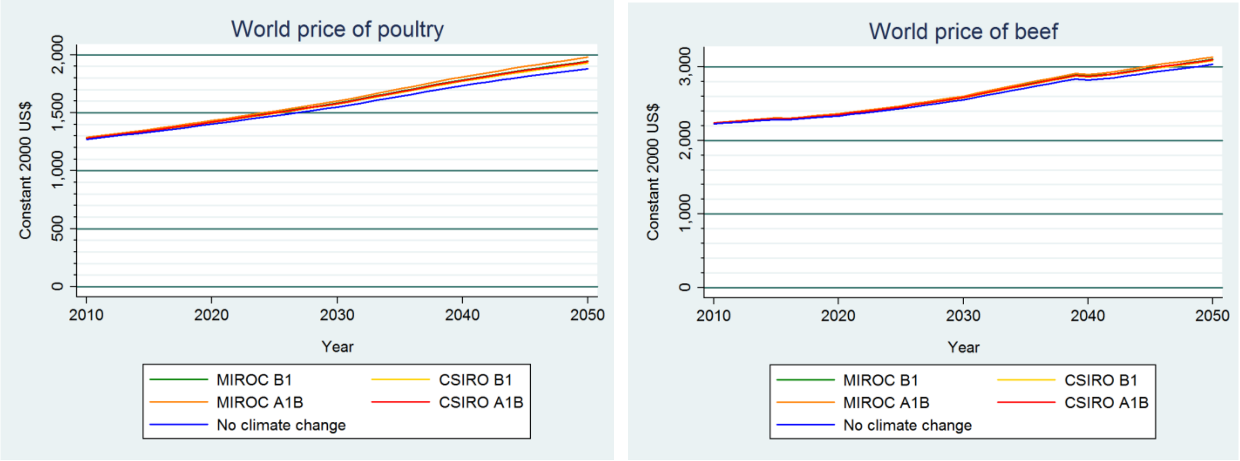


Figure 3.17—Continued



Source: Nelson, Rosegrant, Palazzo, et al. (2010).

The other four colored lines represent changes in price from models that incorporate, along with the nonclimate growth factors, projected yield changes from two climate change scenarios (as well as, to a small extent, projected changes in harvestable land area). Each line represents a different combination of GCM and climate scenarios: MIROC B1, MIROC A1B, CSIRO B1, and CSIRO A1B. The B1 scenario assumes lower greenhouse gas emissions between 2000 and 2050 than in the A1B scenario.

For rice, it is difficult to distinguish these four lines because there is very little difference in the global impact of climate change between these models. For all four models, the total projected price increase for rice between 2010 and 2050 is around 60 percent. If we subtract the 34 percent increase noted for normal growth factors, we conclude that climate change alone would be responsible for rice price increases of 26 percent over 2010 prices, by the year 2050.

For maize, the world price without climate change is projected to rise by 61 percent between 2010 and 2050. Incorporating climate change, the different models show widely different results. The CSIRO B1 model projects a 94 percent increase in the price of maize, as compared to the MIROC A1B projection of a 145 percent increase. The projected price increase due to climate change thus ranges from 33 percent to 84 percent over 2010 prices.

Not all prices are projected to rise in the future, however. Without climate change, the IMPACT model projects a decline in the price of potatoes—a good outcome for net consumers, but generally a bad outcome for net producers (although yield changes might more than compensate producers for any drop in the projected price). However, climate change models show the price of potatoes rising by 2050.

In the case of livestock products, IMPACT shows the greatest change in price from normal growth effects rather than from climate change; the blue line is almost indistinguishable from the other lines in the graph. For the case of milk, even accounting for climate change, IMPACT shows the price of milk declining over time.

The remaining graphs in Figure 3.17 show projected prices for wheat, cassava, sweet potatoes and yams, sugarcane, other grains not already accounted for, eggs, poultry, and beef.

Per Capita GDP Projections for Cambodia

Because IMPACT combines the GDP projections and population projections for Cambodia and Laos, we developed a method to separate them. This allowed us to provide a meaningful income projection against which to compare food price increases to estimate projected impact on food security. Van Vuuren, Lucas, and Hilderink (2006) show in their projections of GDP very similar growth rates for Cambodia and Laos through 2050. Therefore, we used actual values of GDP for the two countries in 2000 to disaggregate the combined (projected) GDP value in IMPACT.

To compute GDP per capita, we downloaded population projections from the United Nations Department of Economic and Social Affairs (United Nations Secretariat 2012) and divided those projections of total population into the GDP measures derived from IMPACT assumptions. The result for Cambodia is shown in Figure 3.18.

Figure 3.18—Projected GDP per capita for Cambodia

Source: Authors, based on World Bank data from IMPACT and United Nations Secretariat (2012).

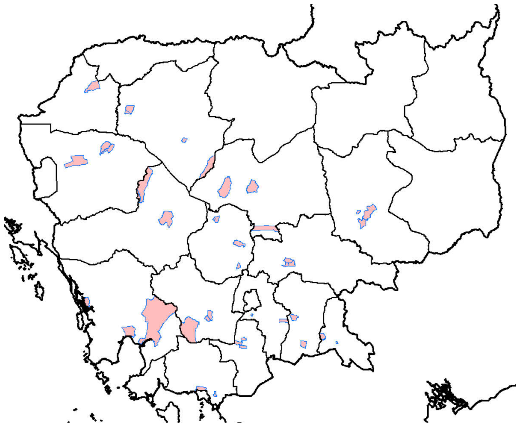
In IMPACT, GDP per capita is projected to rise by 919 percent between 2010 and 2050 (Figure 3.18), based on the baseline scenario of a moderate rise in population and GDP for all countries. This increase is much greater than the projected increase in food prices: the price of rice was shown increasing by around 60 percent. The model indicates, then, that the welfare of most Cambodians will improve greatly between 2010 and 2050. The two numbers are not directly comparable, however, because the typical diet in Cambodia is likely to shift to a more expensive food basket, probably including more meat. Similarly, a typical consumption basket of all goods is likely to shift as well. But because the increase in GDP per capita is so much greater than the percentage increase in rice, the result still projects that overall welfare will be improving by 2050. The model projects more than 5.5 percent annual economic growth (in constant dollar GDP per capita), from now until 2050.

This positive trend in per capita GDP might seem to greatly outweigh the projected overall long-term losses in crop yield of between 7 and 10 percent due to climate change (without adaptation) or 6 to 8 percent (with adaptation). However, agriculture is likely to retain an important place in the overall economy and society, in terms of income, employment, and food security, though it may be less important than in 2010 (at around 30 percent of GDP). Moreover, as in many countries that are slowly transitioning from agriculture to services and industry, many of the poorest people will remain in the agricultural sector. The negative effect of climate change on crop yields is likely to have significant, and unequally distributed, impacts.

4. VILLAGE SURVEY

To provide background information on fertilizer use, soil fertility management, use of seeds and irrigation, method of tillage, weed and pest management, occurrence of natural disasters, and response to extreme climate events in rural communities, a commune survey was conducted for this project in May 2011. Data were collected through focus group discussions (FGDs) with commune officers in 45 communes in Cambodia. The commune officers participating in the FGDs included chief of commune, first chief of commune, second chief of commune, commune council, chief officer of agriculture in the commune, secretary of commune, chief of village, and member of district. The locations of the communes surveyed are shown in Figure 4.1.

Figure 4.1—Map showing the locations of the communes covered in the study

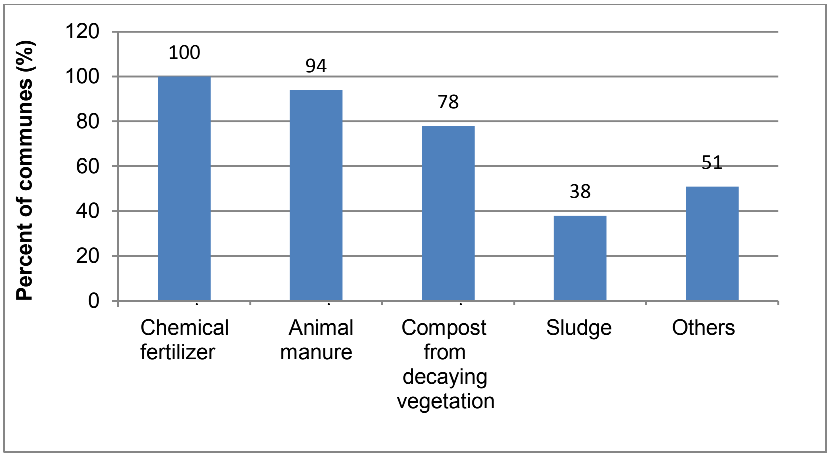


Source:

Fertilizer Information

Commune officers were asked how farmers in their commune fertilized their land. Chemical fertilizer was the most common method reported in all 45 communes covered in the study (Figure 4.2). Animal manure was mentioned in about 93 percent of the communes, and compost from decaying vegetation in 78 percent of the communes. Sludge was mentioned in only 17 communes (38 percent).

Figure 4.2—Use of fertilizer by type (percentage of communes reporting)



Source: Authors.

Commune officers were also asked to estimate the proportion of farmers using each kind of fertilizer. The estimated proportion of farmers using chemical fertilizer ranged from 10 to 100 percent, with a median of 50 percent (Table 4.1). For animal manure, the estimated range was 0 to 72 percent, with a median of 34 percent. For compost use, the estimated range was 0 to 60 percent, with a median of 5 percent; about 25 percent of respondents estimated that no more than 0.5 percent of the farmers were using compost.

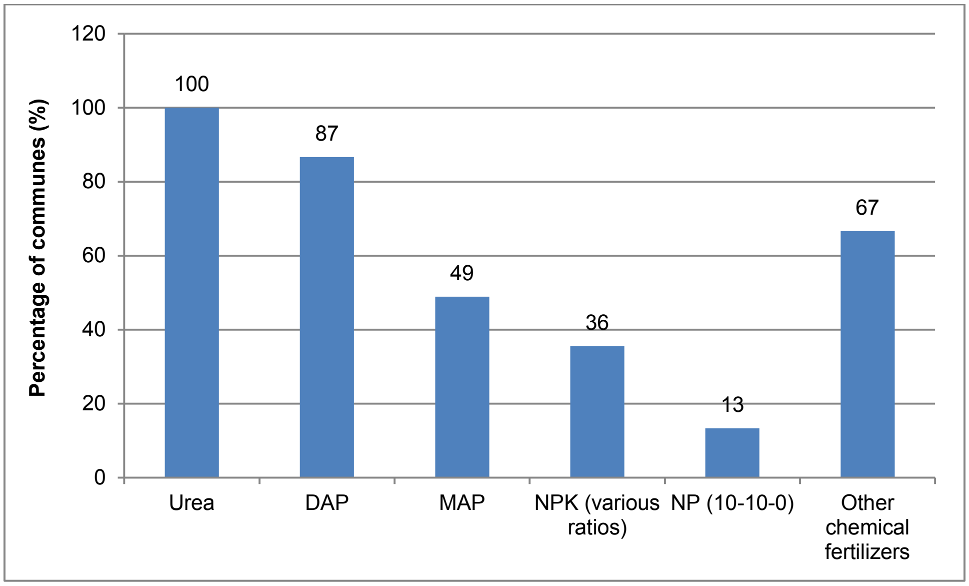
Table 4.1—Percentage of farmers in the commune that use each type of fertilizer, by percentile

Fertilizer	Min.	Max.	10th percentile	25th percentile	50th percentile	75th percentile	90th percentile
Chemical fertilizer	10	100	20	30	50	70	82
Animal manure	0	72	5	15	34	50	65
Compost from decaying vegetation	0	60	0	0.5	5	16	25

Source: Authors.

With regard to type of chemical fertilizer, urea was the most common; its use was reported in all 45 communes (100 percent) (Figure 4.3). The other common chemical fertilizers were diammonium phosphate and monoammonium phosphate, reported for 87 percent and 49 percent of communes, respectively. For urea, the lowest percentage reported was 2 percent, while the highest was 80 percent (median 38 percent). For diammonium phosphate, the reported percentage ranged from 0 to 70 percent of farmers (median 25 percent) (Table 4.2).

Figure 4.3—Percentage of communes that reported use of each type of chemical fertilizer



Source: Authors.
Note: DAP = diammonium phosphate; MAP = monoammonium phosphate; NPK = nitrogen-phosphorus-potassium; NP = nitrogen-phosphorus.

Table 4.2—Percentage of farmers in the commune that use each type of chemical fertilizer, by percentile

Fertilizer	Min.	Max.	10th percentile	25th percentile	50th percentile	75th percentile	90th percentile
Urea	2	80	10	20	38	48	60
DAP	0	70	0	15	25	40	50
MAP	0	60	0	0	0	20	30
NP (10-10-0)	0	50	0	0	0	0	15
NPK (various ratios)	0	40	0	0	0	13	24
Other chemical fertilizers	0	70	0	0	15	25	50

Source: Authors.

Note: DAP = diammonium phosphate; MAP = monoammonium phosphate; NP = nitrogen-phosphorus; NPK = nitrogen-phosphorus-potassium.

Improved Soil Management Practices

The land management practice most commonly reported by communes was crop rotation (reported by 31 of 45 communes, or 69 percent) (Table 4.3). Crop rotation is the practice of growing a series of dissimilar types of crops in the same area in sequential seasons. Fallow—the practice of leaving land unseeded after plowing, in order to allow it to recover its natural fertility—is also practiced in 69 percent of the communes. Intercropping (cultivation of two or more crops simultaneously on the same field) is adopted in 56 percent of the communes. Zero tillage, a method of planting without disturbing the soil through tillage, was reported in only 8 of the 45 communes (18 percent).

Table 4.3—Percentage of communes that practice land management techniques, by type

Land management practice	No.	Percentage
Crop rotation	31	69
Fallow	31	69
Intercropping	25	56
Zero tillage	8	18
Slash and burn	3	7
Terraces/bunds	3	7
Cover cropping	2	4

Source: Authors.

The percentage of farmers in each commune using crop rotation ranged from 0 to 95 percent (Table 4.4). It is notable that, out of the 31 communes where crop rotation is reportedly practiced, about a quarter of communes (75th percentile) had at least 30 percent of farmers adopting the method; 8 of the 31 communes had at least 50 percent adoption. The percentage of farmers using fallow ranged from 0 to 100 percent; the median value (50th percentile) was 40 percent, and about a quarter of the communes had more than 80 percent of farmers practicing it. For intercropping, the percentage ranged from 0 to 100 percent; the median value was only 1 percent, and about a tenth of the communes had at least 60 percent of farmers that intercrop (90th percentile).

Table 4.4—Percentage of farmers in a commune that use various types of land management, by percentile

Land management practice	Min. (%)	Max. (%)	10th percentile (%)	25th percentile (%)	50th percentile (%)	75th percentile (%)	90th percentile (%)
Crop rotation	0	95	0	0	10	30	50
Fallow	0	100	0	0	40	80	90
Intercropping	0	100	0	0	1	10	60
Zero tillage	0	75	0	0	0	0	3
Slash and burn	0	10	0	0	0	0	0
Terraces/bunds	0	6	0	0	0	0	0
Cover cropping	0	5	0	0	0	0	0

Source: Authors.

Seed and Irrigation Information

The commune survey reported on the percentage of farmers in each commune who buy seeds (rice as well as seeds for other crops) and the percentage of farmers that use irrigation (Table 4.5). The percentage of farmers who purchase rice seeds ranged from 0 to 90 percent. For about half of the communes (50th percentile), more than 10 percent of farmers purchase rice seed; for a quarter of the communes, at least 30 percent of farmers purchase rice seed (75th percentile). For other seeds, the range was from 0 to 100 percent of farmers; for 25 percent of the communes, at least 80 percent of farmers purchase other seeds (75th percentile).

Table 4.5—Seed and irrigation information in 45 communes, by percentile

Item	Min.	Max.	10th percentile	25th percentile	50th percentile	75th percentile	90th percentile
Seed information							
Purchase rice seeds	0	90	0	1	10	30	60
Purchase other seeds	0	100	0	5	30	80	96
Irrigation information							
Use irrigation	10	100	20	40	90	100	100
Use manual irrigation	0	100	0	0	5	20	60
Use mechanical irrigation	0	100	10	30	50	94	100

Source: Authors.

For irrigation, the median value (50th percentile) was high, at 90 percent (Table 4.5). Mechanical irrigation was used in more communes than manual irrigation. About 25 percent of the communes had no farmers using manual irrigation (25th percentile), and the median value for manual irrigation was only 5 percent, as compared to 50 percent for mechanical irrigation.

Method of Tillage

Information on method of tillage was obtained through FGDs. The proportion of farmers using animal power for tilling the land ranged from 0 to 99 percent; for about half of the communes (50th percentile), more than 50 percent of farmers were using animal power (Table 4.6). The proportion of farmers using a power tiller ranged from 1 to 98 percent. For half of the communes, at least 40 percent of farmers were using a power tiller. It is notable that in 50 percent of the communes (50th percentile), no farmers were using tractors to till their land.

Table 4.6—Method of tillage in 45 communes, by percentile

Method of tillage	Min.	Max.	10th percentile	25th percentile	50th percentile	75th percentile	90th percentile
Animal	0	99	4	20	50	70	90
Power tiller	1	98	10	20	40	70	85
Tractor	0	60	0	0	0	5	30
Hand tool (human power)	0	10	0	0	0	0	0

Source: Authors.

Information on Weed and Pest Management

Commune officers were asked about the percentage of farmers in their commune using herbicides, insecticides, or integrated pest management (Table 4.7). The percentage using herbicides ranged from 0 to 100 percent. For about half of the communes (50th percentile), up to 20 percent of farmers were using herbicides. For insecticides, similarly, the percentage of farmers ranged from 0 to 100 percent, but a larger percentage of farmers were using them: for about half of the communes (50th percentile), up to 70 percent of farmers used insecticides. It is notable that, for 75 percent of the communes, only 5 percent or less of farmers had adopted integrated pest management.

Table 4.7—Information on weed and pest management in 45 communes, by percentile

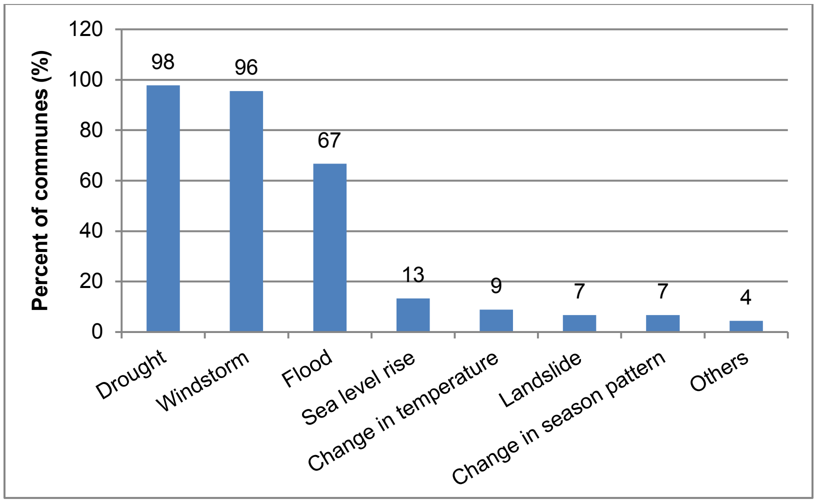
Item	Min.	Max.	10th percentile	25th percentile	50th percentile	75th percentile	90th percentile
Use herbicide	0	100	0	2	20	95	100
Use insecticide	0	100	5	10	70	95	100
Practice integrated pest management	0	85	0	0	0	5	20

Source: Authors.

Top Natural Disasters

In the commune survey, the key informants were asked to identify the top three natural disasters farmers were concerned about in their commune. Drought was the most cited, reported in 44 of the 45 communes (98 percent) (Figure 4.4). In about 96 percent of the communes, windstorm was mentioned; flood was cited in 67 percent of the communes.

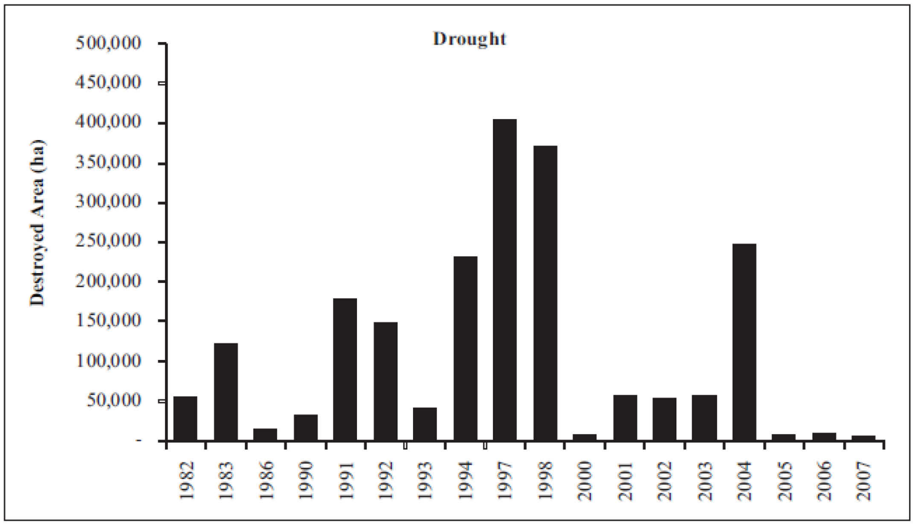
Figure 4.4—Top natural disasters of concern to farmers



Source: Authors.

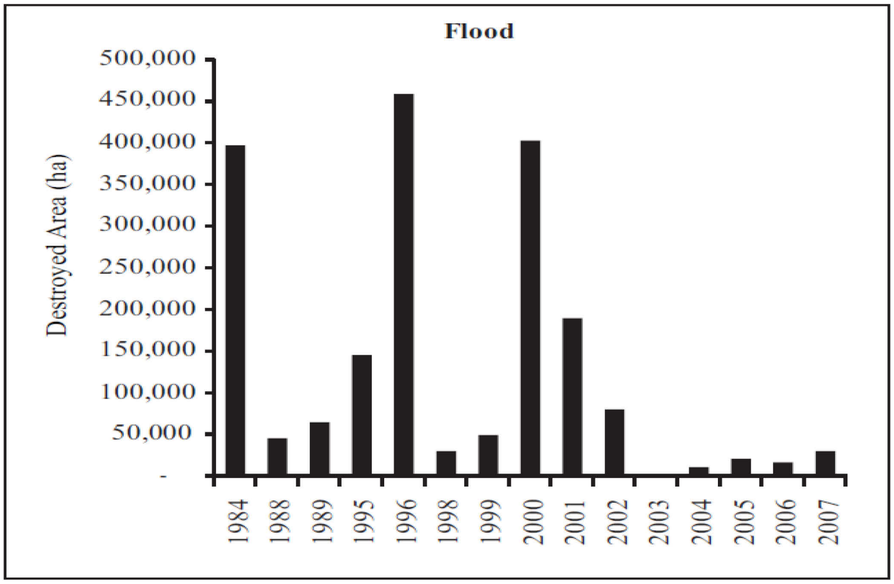
Recurring drought and floods cause significant damage to crops. Figure 4.5 shows damage from drought; the most extensive damage—about 440,000 ha, in 1997—amounted to around 20 percent of the total rainfed rice area, around 2.2 million ha. Similarly for floods (Figure 4.6), the most extensive damage (in 1996) represented about 20 percent of rainfed rice area. The NAPA field survey report (RGC, MoE 2006) investigated rural Cambodian households' vulnerability and adaptation to climate hazards and climate change. All 17 provinces covered in the field survey suffered from at least two floods a year, while seven provinces experienced at least four floods a year; flooding lasted from two days to around six months. The highest flood level in agricultural fields was recorded at 5.1 meters, and 11 of the 17 survey sites recorded flood levels reaching at least 2 meters.

Figure 4.5—Total crop area damaged by drought, 1982–2007



Source: RGC, MAFF (2010).

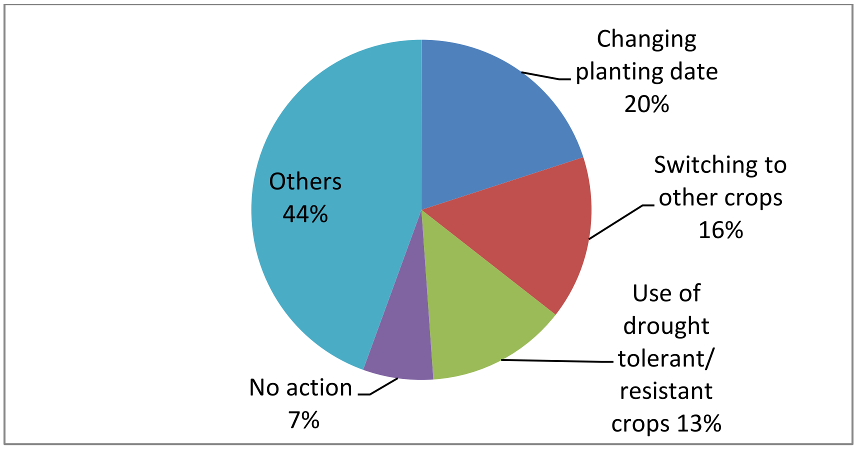
Figure 4.6—Area of paddy damaged by flood, 1984–2007



Source: RGC, MAFF (2010).

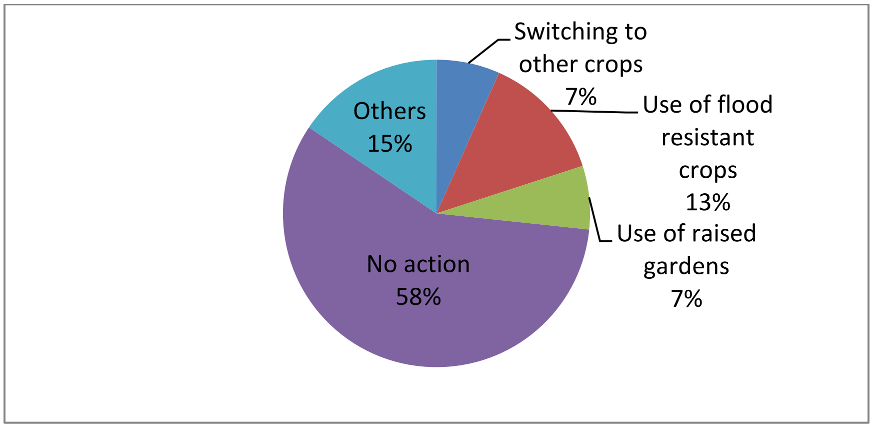
The commune survey gathered information on how farmers adjust their farming practices to respond to extreme climate events. In response to drought, the survey found that farmers switched to other crops in 16 percent of the communes and changed planting dates in 19 percent (Figure 4.7). Only 7 percent of the communes reported no adaptation in farming practices. In response to flooding, farmers used flood-resistant crops in 13 percent of the communes and raised gardens in about 7 percent (Figure 4.8). In fully 58 percent of the communes, farmers were reported to take no action in response to floods. This finding indicates the need for intervention at a higher level than the farm, to help farmers deal with floods.

Figure 4.7—Farmer response to drought



Source: Authors.

Figure 4.8—Farmer response to floods



Source: Authors.

5. CONCLUSIONS

What should policymakers do now to make a difference in the future? And how will these policy measures affect current economic development? Actually, the policies designed to help farmers of the future are also beneficial to farmers of today. The same interventions that could increase current yield and improve farming efficiency would also help farmers prepare for the potential impact of climate change on agriculture. A good example would be improving irrigation capacity, to help both now and in the future.

Strategic Guidelines

ADB and IFPRI (2009), referring to the prioritization criteria of Hallegatte (2009), suggest the following five broad strategic approaches (slightly adapted here).

1. **Implement no-regret strategies,** that is, strategies that will yield benefits even in the absence of climate change.
2. **Implement reversible and flexible strategies,** for example, strategies that require little capital investment and lend themselves to annual or periodic review, such as insurance programs, early warning systems, and changing planting dates or varieties.
3. **Implement strategies to reduce vulnerability at low cost,** such as raising existing dikes to cope with future rising sea levels as well as today's extreme flood events.
4. **Reduce decisionmaking time horizons,** for example, by phasing in shorter-term investments such as small-scale irrigation systems that use groundwater or rainwater (as opposed to building irrigation dams). By scaling down the size of the project, it becomes more flexible (adaptable or reversible).
5. **Enhance synergies among strategies,** for example, to promote mitigation or reduce poverty while adapting to climate change.

Policy Recommendations

The following policy recommendations take into consideration the strategic guidelines as well as the implications of our analysis of climate change impacts.

Develop and promote improved cultivars better suited to future climates through continued agricultural research, development, and extension.

This analysis indicates that climate change will have significant adverse impacts on crop yields. The assessment also finds that when practiced together, using improved cultivars better suited to a changing climate and adjusting planting dates can lessen the adverse impacts of climate change on yields, including yields of both wet- and dry-season rice. However, yield impacts remain negative across all crops, with the exception of low-input rainfed rice. According to the commune survey results, just 7–16 percent of farmers report changing crop variety as a result of extreme weather, depending on the region. Improving farmers' ability to access optimally adapted cultivars will be critical in order to avoid yield losses as the climate changes over the next 40 years. Future research is expected to produce cultivars that will give even higher yields in future climates, pointing to the importance of continued research.

Agricultural research, development and extension can only grow if government investment in the agricultural sector is increased and agricultural research and extension institutions are strengthened.

Increase government investment in the agricultural sector.

Data presented in Theng and Koy (2011) indicate that the proportion of government expenditure devoted to agriculture has been declining over the last decade, from 2.3 percent of the budget in 2003 to around 1.8 percent currently—a drop of more than 20 percent. Especially as climate change adaptation will require a greater focus on agriculture, it will be important to reverse this trend and increase the share of agriculture well above its 2000 level. As a U.S. Department of Agriculture report concludes:

> Both CARDI [Cambodian Agricultural Research and Development Institute] and the MAFF need substantial increases in government funding, as well as effective management oversight, if they are to expand and enhance crop and farming systems research, farm-level agricultural extension (technology transfer), and improved certified seed (IR [imidazolinone-resistant]) production and distribution—possibly subsidizing IR seed costs to farmers.[12] (USDA-FAS 2010)

Strengthen agricultural research and extension institutions.

For farmers to adapt to climate change, the institutions dealing with research and extension need to be strengthened. This will require increasing funding, linking to international research institutes and other national research institutes in Southeast Asia, and focusing the institutions' missions. These institutions can help in a number of ways:

- Developing and disseminating new cultivars that are heat tolerant and drought tolerant
- Helping farmers use optimal levels of fertilizer
- Testing, training, and encouraging farmers to use other soil fertility–enhancing techniques
- Testing and teaching about alternative crops that can give better nutritional or monetary returns per hectare

The following suggestions were offered by experts participating in a June 2011 workshop in Dhaka:

- Personnel: Remedy the shortage of researchers and the current high turnover rate; provide opportunities for ongoing learning and exchange with international colleagues.
- Facilities: Upgrade facilities that are old and underfunded, or lacking in modern equipment.
- Agricultural extension agents: Recruit and train more agents at the village level.
- Private sector: Improve market incentives and remove constraints on involvement in research and extension, especially in seeds, marketing, and machinery.
- Coordination: Improve the exchange of information between various institutions.
- Data: Improve data collection, including carrying out a first-ever agricultural census, or at least a nationally representative agricultural survey.
- Media: Mobilize channels for informing farmers.
- Extension messages: Along with training farmers in adapting to climate change, extension agents will need to help farmers better understand climate change—both its causes and the types of impact they might expect to see, such as higher temperatures or more severe and more frequent weather shocks.

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[12] Imidazolinone is a common herbicide, and IR seeds produce crops that can tolerate the use of herbicides to kill weeds (Tan et al. 2005).

Future increases in production will likely come from farmers using improved seeds with higher yields and faster maturity (allowing two and even three rice harvests annually). In addition, researchers will be working to develop rice varieties that are more suitable to the warmer climate of the future. Availability of the new seeds will be critical.

In addressing this need, two preliminary questions should be considered:

- Are there government price restrictions or other regulatory limitations that keep prices and distribution low?
- Can improved seeds be imported from other major rice producers, such as Thailand or Vietnam?

Box 5.1—Seed production and distribution

USDA-FAS (2010) identifies "extremely low production and availability of improved rice seed" as a serious current constraint. It identifies the following specific issues:

- Only 2,000 tons of certified seed are produced annually, sufficient for only 1.2 percent of national rice area.
- The private company producing seed may be financially challenged.
- Rural distribution is inadequate.

Source: USDA-FAS 2010.

Adjust planting dates to changing climatic realities.

The analysis indicates that when practiced together, using improved cultivars better suited for climate change and adjusting planting dates can lessen the impacts of climate change on yields, including both wet- and dry-season rice. According to the commune survey results, only 20 percent of farmers report changing planting dates as an adaptation strategy to extreme weather. Exploring the feasibility of adjusting planting dates and expanding farmers' ability to do so is an important step in minimizing yield losses due to climate change.

Increase fertilizer use and efficiency.

The analysis shows that losses in yield due to climate change can be compensated for, for many crops, by increasing the availability of nitrogen in the soil. In the survey of communes, every commune reported using some type of chemical fertilizer; however, in a typical commune, only 50 percent of the farmers were using any chemical fertilizer. This indicates that there is room to increase the use of chemical fertilizers. It should be noted, however, that while these fertilizers are often cheap and efficient, during conventional broadcast scattering many of the nutrients are lost either to the atmosphere or below the root zone, where the crops cannot take advantage of them. Excess nitrogen in the soil can go into the atmosphere, further contributing to the accumulation of greenhouse gas, and some chemicals that travel below the root zone contribute to contaminated drinking water and/or the eutrophication of water bodies. For this reason, nonchemical fertilizer use can also be increased. According to the survey, nonchemical fertilizer use, while lower, was reported in 94 percent of communes. The most commonly used nonchemical fertilizer was animal manure, with 34 percent of farmers in the average commune using this method. The next most common nonchemical fertilizer in use was compost from decaying vegetation; however, only about 5 percent of farmers in a typical commune used this method. These results indicate that there is room to increase the use of nonchemical fertilizers as a way to improve soil fertility while minimizing environmental impacts, in addition to expanding the use of chemical fertilizers, as needed.

Mitigate crop loss due to floods.

When respondents were asked to name the top three natural disasters of concern, flooding was cited in 67 percent of the communes surveyed. Despite this, in fully 58 percent of the communes, farmers were reported to take no action in response to floods. This finding indicates the need for intervention at a higher level than the farm, to help farmers deal with floods.

Mitigate crop loss due to drought.

When respondents were asked to name the top three natural disasters of concern, drought was the most cited, reported in 44 of the 45 communes (98 percent). The survey found that in response to drought, farmers switched to other crops in 16 percent of the communes and changed planting dates in 19 percent, while only 7 percent of the communes reported no adaptation in farming practices. Despite the use of farmer adaptation strategies, it is unclear whether these strategies were those best suited to mitigate crop loss. As a result, an evaluation of the current returns of adapting to drought should inform strategies to reduce vulnerability while increasing resilience.

Irrigation has proven to be an important investment positively affecting productivity, reducing drought losses, and also mitigating flood damage through improved water control infrastructure. The increase in rice production in Cambodia in the last decade has been quite spectacular, with production roughly doubling between 2000 and 2010.[13] This decade of growth points to successes of leadership. Cambodia's leaders have made some good decisions on investing in the expansion of agriculture: expansion of harvested area (increasing cropping intensity as well as expanding physical area), adding or repairing irrigation infrastructure, increasing the use of fertilizer, and using improved seeds. The rapid increase in production might be ending, however, because of lower marginal gains to additional investment, and because the areas that can be expanded to double cropping are becoming limited (USDA-FAS 2010). Increasing the irrigation area and promoting shorter-duration rice varieties have made it possible for farmers to grow at least two crops per year.[14]

Yu and Diao (2011), using data from various sources, analyze the growth in rice production. From 1994 to 2004, much of the growth reflected expansion of dry-season rice, through expansion of irrigated areas. From 2004 to 2008, much of the growth came through increases in both wet-season area and wet-season yield, with improved varieties and supplemental irrigation. Theng and Koy report that "expansion of rice cultivation area was largely achieved by clearing forest (slash and burn farming in upland areas), and returning de-mined and idle land to productive use" (2011, 8–9).

Box 5.2—Irrigation planning and issues

MOWRAM has reported "plans and finance sufficient to irrigate an additional 800,000 ha over the next decade." However, there remain serious issues with current irrigation infrastructure:

- Poor engineering of many existing systems
- Almost total lack of system maintenance, owing to expensive and unpopular farm-level user fees
- Systems developed in regions with unsuitable soils or other physical problems
- Unsustainability of many systems over a 10- to 20-year time frame
- Lack of farm credit, which inhibits affordability of on-farm irrigation equipment (pumps, fuel) and tertiary access (feeder canal construction)

Source: USDA-FAS 2010.

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[13] Using three-year averages to smooth out year-to-year variation, rice production doubled between 1999 and 2009, according to FAOSTAT (FAO 2011).

[14] Theng and Koy write that "MOWRAM reported that the national irrigated area was 827,373 ha by the end of 2008, a substantial increase from 407,000 ha in 1998" (2011, 9).

We can expect that weather variability will increase, along with the frequency and severity of drought, floods, and windstorms. Having a broader and more targeted social protection program will be important, especially to include disaster relief. The Ministry of Environment (MoE 2005) reported on a large household survey conducted in 2004:

> A large proportion of villagers (45 percent) interviewed have not benefited from any assistance after climatic hazards have occurred. About 30 percent of villagers benefited from assistance by the Cambodian Red Cross. This is by far the largest provider of post-disaster assistance in the sample surveyed. In comparison, the National Committee for Disaster Management (NCDM) and district and provincial authorities provided assistance to respectively 6 percent and 7 percent of villagers interviewed. Other sources of assistance are much less significant and include: neighbors and friends, commune councils, pagodas and NGOs.
>
> In terms of assistance provided, 40 percent of households received food and medicine, 17 percent received a shelter, 16 percent seeds, 11 percent cash, 9 percent various utensils. Some 3 percent of people were assisted in their evacuation to safer grounds. (RGC, MoE 2005, 15)

In years ahead, a systematic effort to help more farmers recover will be essential, both in alleviating immediate poverty and in ensuring farmers' ability to produce in the next growing season.

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