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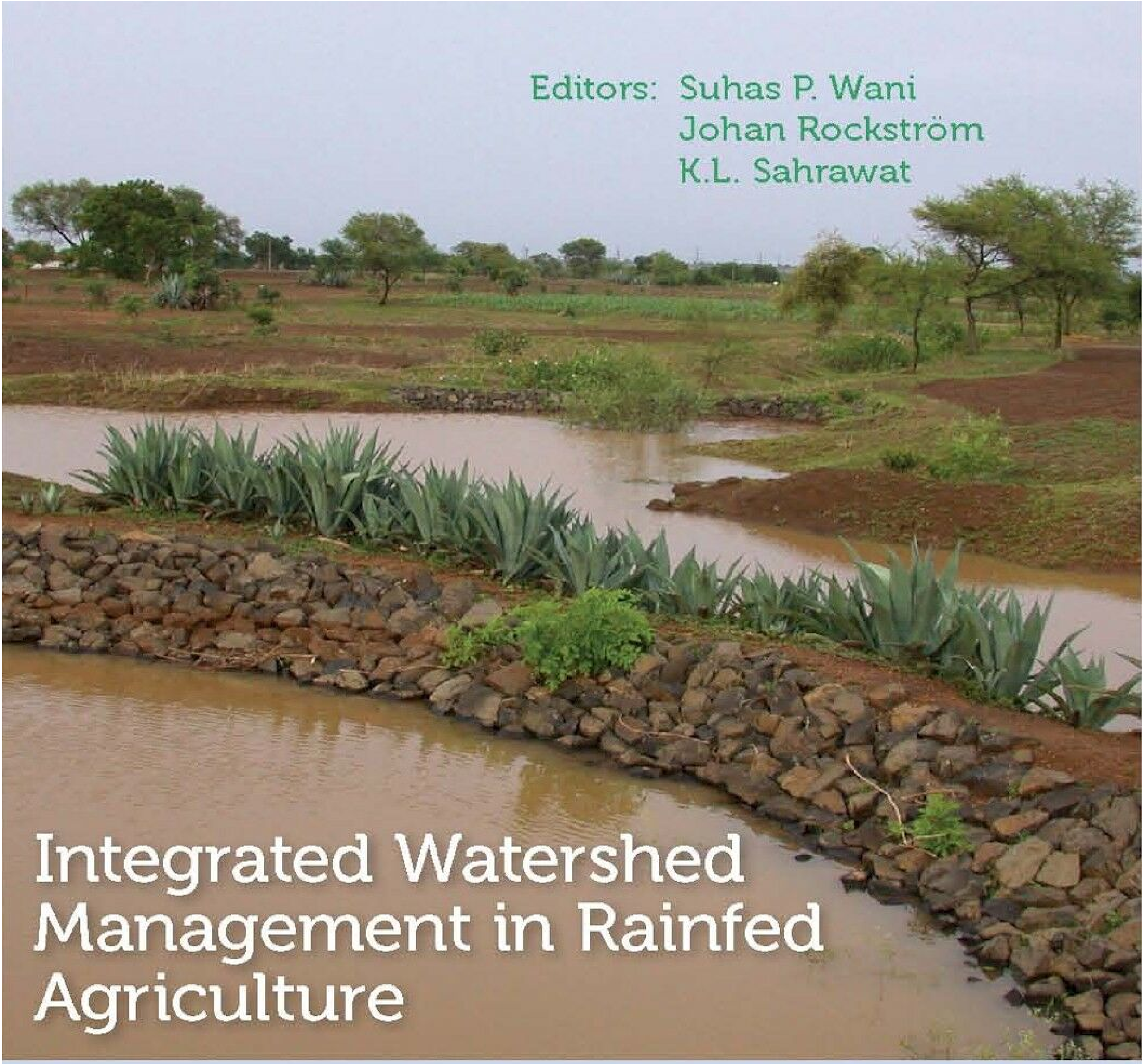

Integrated Watershed Management in Rainfed Agriculture

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Chapter 13

Impacts of climate change on rainfed agriculture and adaptation strategies to improve livelihoods

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13.1 INTRODUCTION

Farmers living and working in the semi-arid tropics (SAT) of Africa and Asia are acutely vulnerable to climate variability and change due to their limited natural and financial resources coupled with poor infrastructure, institutional support, and governance (World Bank 2008). Coping with variability is nonetheless a way of life for many of these farmers, and farmers in many different regions of the world have adopted or adapted strategies to manage variability. In this chapter we first describe the impacts of climate change on crop and livestock production, water resources, and prices, poverty, and malnutrition in South Asia and sub-Saharan Africa (SSA). Secondly, we examine adaptation strategies, focusing on the social/institutional aspects needed to support farmers' adaptation strategies as well as describing briefly strategies used by farmers.

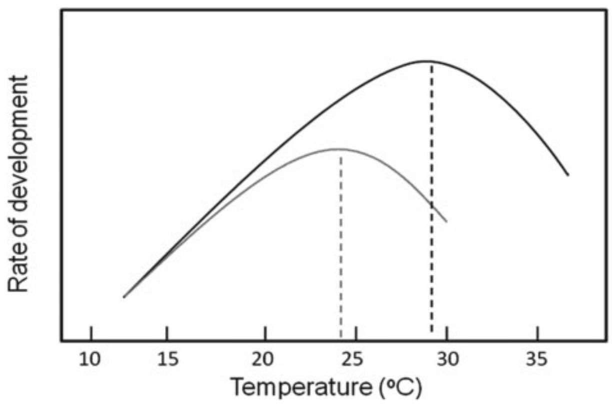
13.2 CLIMATE CHANGE IMPACTS

Climate change impacts on agriculture in the near to medium term (next one or two decades) are more likely to arise from increased climate variability, and increased frequency and intensity of extreme events, rather than from changes in mean or average climatic conditions. Rising temperatures and changes in rainfall patterns, including increased seasonal and inter-annual rainfall variability, can directly reduce crop yields, and indirectly affect irrigation water availability and increase the water requirement of the crops (Nelson *et al.*, 2009). In addition, there are a number of secondary effects of climate change, such as increased pest and disease pressure (Anderson *et al.*, 2004) and heightened risk of soil erosion and other land degradation processes (Boardman 2006) that can negatively impact food production. These factors are usually not accounted for in crop loss models but their effects could be quite significant. The most vulnerable agricultural systems occur in arid, semi-arid, and dry subhumid regions in the developing world, where extreme rainfall variability results in recurrent droughts and floods regularly disrupting food production leading to pervasive poverty (Hyman *et al.*, 2008).

The long-term impacts of climate change on agricultural productivity are not expected to be geographically uniform. Small increases in yield and production could occur in certain high latitude locations, e.g., parts of Europe, northern China, and northern North America, while yields and production in much of Africa, South and Central Asia, the Mediterranean Basin, the Andes, and parts of Central America are likely to be greatly reduced (Baettig *et al.*, 2007; Easterling and Aggarwal 2007), with the maximum impact predicted to be in SSA and South Asia (Nelson *et al.*, 2009) (Figure 13.1). These discrepancies arise in part because at higher latitudes future warming, up to about 2°C, will be favorable for crop development and growth in these cold limited zones (see Box 1). In contrast, at lower latitudes temperatures are already close to the optimum for crop production and dryland conditions are widespread, so any further increase in temperatures and adverse changes in rainfall patterns are damaging. However, more favorable temperatures at high latitude zones would not automatically sustain production at existing levels as crops, cropping systems, and appropriate management practices will still need to be modified and adapted to future conditions, which could include more extreme events as exemplified by record-setting high temperatures and drought in Russia and elsewhere in northern Europe in the summer of 2010.

Box 1. Response to Temperature

The figure below shows a typical rate response to temperature – in this case rate of development – but also applicable to other processes such as dry matter production. As temperature increases, the rate of development increases till an optimum value – approximately 20 to 25°C in temperate species (gray line) and 27 to 32°C in tropical species (black line). Above the optimum, rate decreases and flowering is delayed or dry matter production is reduced. Impacts of climate change, both positive and negative, are strongly linked to how close current ambient temperatures are to the optimum temperature of different crop species. It should also be noted that extreme hot and cold temperatures at certain stages of crop development, notably flowering, cause sterility and hence very poor yields (Matsui *et al.*, 1997; Wheeler *et al.*, 2000; Gunawardena *et al.*, 2003; Prasad *et al.*, 2006; Jagadish *et al.*, 2007).



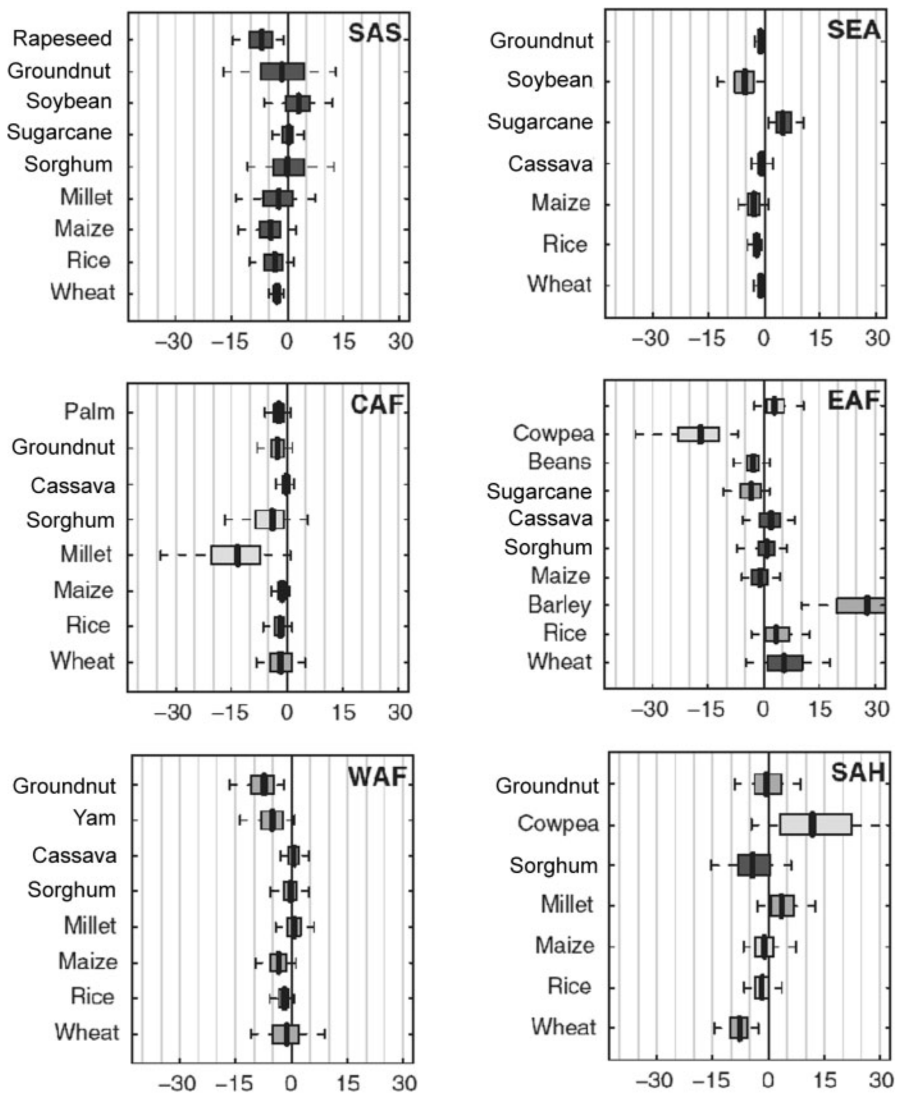


Figure 13.1 Projected impacts of climate change by 2030 for major crops in South and Southeast Asia and most of Africa.

[Note: Probabilistic projections of production impacts in 2030 from climate change (expressed as a percentage of 1998 to 2002 average yields). Broken lines extend from 5th to 95th percentile of projections, boxes extend from 25th to 75th percentile, and the middle vertical line within each box indicates the median projection. Region codes SAS, SEA, CAF, EAF, WAF, and SAH are for South Asia, Southeast Asia, Central Africa, Eastern Africa, West Africa, and Sahel, respectively. Modified and adapted from Lobell *et al.* (2008a, 2008b).]

13.2.1 Crop and livestock production

A recent global modeling study using the outputs from two global climate change models [NCAR (wetter) and CSIRO (drier)], suggests that production of major crops growing in the developing countries will predominantly decline while those in developed countries will be less affected (Nelson *et al.*, 2009). For example, 14% decline is predicted in rice production relative to the no climate change scenario, 44 to 49% decline in wheat production, and 9 to 19% fall in maize production (Table 13.1). Even with CO_2 fertilization effect (on C3 species only; see Long *et al.*, 2006, 2007 for a fuller discussion), yield will still be substantially reduced (Nelson *et al.*, 2009). Apart from SSA and South Asia, other regions predicted to suffer major yield losses are semi-arid northeastern Brazil and areas in Central America (Magrin *et al.*, 2007; Lobell *et al.*, 2008a). A separate study of percent yield change among major crops across most of Africa and South and Southeast Asia compared with the baseline (1980–2000) and projections for 2020–40, assuming an approximate 1°C increase in temperature between 1980 and 2000 (Lobell *et al.*, 2008b), is presented in Figure 13.1. This study also predicts significant negative impacts of climate change on food security that could occur as early as 2030 for several crops in these regions.

More than 600 million people depend on livestock for their livelihoods (Thornton *et al.*, 2009) and hence impacts on this sector are also important though frequently overlooked and not well researched. Livestock will be impacted by climate change directly (heat, diseases) and indirectly (feed quality and quantity, water resources). The Intergovernmental Panel on Climate Change (IPCC) predicts negative impacts of climate change on livestock in arid and semi-arid regions, but positive effects in humid temperature regions, in line with the principles governing crop species adaptation (Christensen *et al.*, 2007; IPCC 2007). Animals, like plants, also grow (and produce milk) best at certain temperatures and are negatively impacted by high temperatures. The ideal range of ambient environmental temperatures for animals is termed as the 'thermoneutral zone'. High temperature stress is defined as a point at which the animal cannot dissipate an adequate quantity of heat to maintain body temperature balance, which is normally calculated as temperature humidity index (THI) based on ambient temperature and relative humidity. Heat stress begins to occur in dairy cattle, beef cattle, swine, and poultry when the THI is above 72, resulting in reduced intake and milk yield, and higher milk temperature in dairy cows (West *et al.*, 2003). In Georgia, for example, cool periods with temperatures of 18 (minimum) and 30°C (maximum) have THI of

Table 13.1 Recent extreme climate events and their impacts on agriculture in sub-Saharan Africa[a]

Country/Region	*Period*	*Climatic event*	*Impact*
Kenya	1997–2000	Severe flooding followed by drought	10% loss of national GDP
Malawi	1991–92	Drought	60% maize yield loss
	2000–01	Floods	30% maize yield loss
Zimbabwe and Zambia	1992	Drought	8–9% loss of GDP from agriculture
Mozambique	2000	Floods	2 million people affected
	2002–06	Drought	800,000 people affected

[a] Source: Padgham (2009).

about 70 compared with a THI of 78 during hot periods with temperatures of 23 (minimum) and 34°C (maximum) (West *et al.*, 2003). St-Pierre *et al.* (2003) have estimated the yearly loss from heat stress without abatement to be US$2.4 billion in the US alone which could be reduced to US$1.7 billion if heat stress abatement practices (e.g., shading) are implemented. The largest proportion of losses was reported for dairy cattle (52%) compared to losses of 21% for beef cattle, 17% for swine, and 10% for poultry.

Water availability, both for direct consumption and for fodder/forage, is also likely to be impacted by climate change. While there are uncertainties in the predictions of water availability for pasture and fodder, the effect of temperature on demand for water is well known (Thornton *et al.*, 2009). For *Bos indica*, water demand increases from about 3 kg dry matter intake at 10°C to 5 kg at 30°C and 10 kg at 35°C. *Bos taurus* requires 3, 8, and 14 kg at the same temperatures. In Australia, water demand for beef cattle is predicted to be 13% higher under predicted climate change. During the severe El Niño year of 1980 countries as widespread as Botswana, Niger, and Ethiopia suffered 20 to 62% cattle deaths.

13.2.2 Water resources

Droughts or floods that last a few months can be highly destructive but when they last for decades the effects can be devastating or even irreversible (Conway 2008). Although significant disagreement among climate models still exists regarding long-term precipitation changes, warmer air holds more moisture; thus rainfall is likely to become increasingly aggregated, with a shift towards fewer but more intense storms and longer periods between rainfall events, as has already been observed across several land areas (Trenberth *et al.*, 2007). Although the total percentage global land area affected by drought has been quite stable from 1950 to 1980s, there has been a significant increase in the area subjected to water deficit stress from 1990 to 2000 (Figure 13.2) and some key cropping systems for food security are highly vulnerable (Hyman *et al.*, 2008).

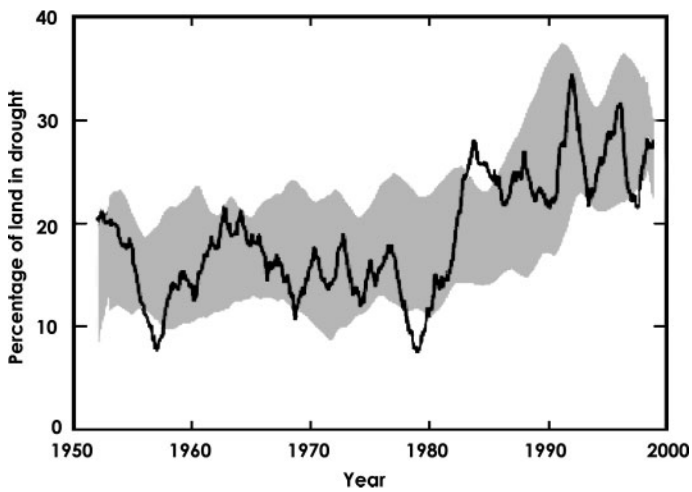


Figure 13.2 Global land area under drought between 1950 and 2000. (http://www.metoffice.gov.uk/research/hadleycentre/pubs/brochures/COP12.pdf)

13.3 REGIONAL IMPACTS

In the following section we examine impacts of climate change on crop production, food prices, poverty, and malnutrition in the highly vulnerable regions of SSA and South Asia.

13.3.1 Sub-Saharan Africa

Northern and Southern Africa are projected to have hotter and drier conditions by the end of this century, potentially resulting in a much greater risk of drought in what are already highly drought-prone sub-regions. The direction of mean annual precipitation change in West Africa is uncertain while East Africa could experience increased precipitation (Christensen *et al.*, 2007), though other analyses (e.g., Funk *et al.*, 2008) indicate a potential drying trend in that sub-region. Median annual temperature changes across Africa by the end of the century are projected to exceed 3°C, assuming a mid-range scenario of greenhouse gas (GHG) emissions (Christensen *et al.*, 2007).

The majority of African countries are highly dependent on natural resources and their agricultural sector for food, employment, income, tax revenue, and exports. Changes in the weather conditions which can damage the agricultural sector will have a major impact on people's incomes and livelihoods. Moreover with weak Government and institutions which are poorly resourced, people are mostly left to cope on their own. For example, in Northeastern Ethiopia, between 1998 and 2000 drought-induced crop and livestock losses were estimated at US$266 per household, which is significantly greater than the annual average cash income for more than 75% of rural households (Carter *et al.*, 2004).

Rainfed agriculture currently constitutes about 90% of Africa's staple food production, making it highly vulnerable to reduced quantity, distribution, and timing of rainfall; in addition growing season length will likely decrease due to higher temperatures (Conway 2008). It is estimated that large areas of the semi-arid and dry subhumid regions could lose 5 to 20% of their growing season length, with the Sahel potentially experiencing >20% loss by 2050 (Thornton *et al.*, 2006; Cooper *et al.*, 2008). There will also be an increased percentage of failed seasons throughout the continent. Moreover, increased climate variability within climate change poses a significant risk to food production in Africa in the near- to medium-term. Africa currently experiences a variety of weather-related disasters on a regular basis (Cornford 2003) that combined with widespread poverty, land degradation, and poor governance reduce its capacity to effectively cope with current climate risks and adapt to future climate change.

An account of the recent extreme water-related disasters dominated either by excess or shortage of water and their impact on agriculture and people in SSA is presented in Table 13.1. Further, the IPCC has estimated that 75 to 250 million more people in Africa will face increased water shortage by 2020, and a 10% drop in precipitation in semi-arid areas of SSA could decrease surface drainage volumes by 50%, according to de Wit and Stankiewicz (2006). Moreover large increases (5 to 8%) in the proportion of arid and semi-arid lands by 2080s, in addition with depleted water resources, will result in more prominent chronic hunger. In some countries the projected yield decline could be as much as 50% by 2020, and crop net revenues could fall by as much as 90% by 2100, with small-scale farmers being the most vulnerable (Carter *et al.*, 2004).

At the ground level, in southern Africa and across western and north-central Africa lower rainfall may also lead to shorter crop growing season, threatening the probability of getting a second crop in some areas and even the viability of a single crop in others (ILRI 2006).

Africa is less likely to be damaged by rising sea levels than Asia. The most extensive inundation is likely to be in the Nile delta. A one-meter rise is predicted to affect nearly 6 million people and inundate lagoons and the low-lying reclaimed lands (http//www.grida.no/climate/vitalafrica/english/16.htm). This in turn would affect one-third of Egypt's fish catches made predominantly in the lagoons and by changing the water quality, the fishing community could be badly affected.

13.3.2 South Asia

Food production in South Asia also faces significant risks from climate change. South Asia's agriculture critically depends on the June-September southwest monsoon, which generates 70% of the subcontinent's total annual precipitation. However, the distribution and timing of monsoon precipitation can be highly variable. For example, under extreme cases, a significant percentage of seasonal rainfall can occur within a period of several days resulting in severe flooding (Mall *et al.*, 2006a). At the other end of the spectrum, failures of the Indian monsoon, which have historically had a strong positive relationship with El Niño events, create widespread drought (Mall *et al.*, 2006b).

The Indian monsoon is expected to intensify with climate change, potentially producing a slight increase in overall precipitation for the subcontinent in the long-term (Christensen *et al.*, 2007). However, greater regional variations in rainfall are possible, with dry regions potentially becoming drier and wet regions wetter, and increase in the number of additional years of record or near-record precipitation (Baettig *et al.*, 2007). These hydrologic changes will occur against a backdrop of rising temperatures, with the region projected to experience an annual median temperature rise of around 3°C by the end of this century, under a mid-range of greenhouse gas emission scenarios (Christensen *et al.*, 2007). Temperature rise will also produce fundamental changes in the dry-season supply of glacial meltwater, an important water source for irrigated agriculture especially in the Indo-Gangetic Plain of South Asia.

Climate change is likely to magnify the adverse effects of existing pressures on agricultural systems in South Asia. For example, more intense rainfall and runoff could reduce groundwater recharge in areas where the unsustainable extraction of groundwater for irrigation has resulted in rapidly declining water tables. The region's two major cereal crops are quite vulnerable to increases in temperature. Wheat is currently near its maximum temperature range, with high temperatures during reproductive growth and grain filling, representing a critical yield-limiting factor for wheat in significant portions of the Indo-Gangetic Plain. Incremental increases in temperature with climate change could thus have a large impact. Ortiz *et al.* (2008) estimate that by 2050 approximately half of the highly productive wheat areas of the Indo-Gangetic Plain could be reclassified as a heat-stressed, short-season production mega-environment. The other major cereal crop in the region, rice, is also quite susceptible to temperature rise, particularly warmer night temperatures, which increase respiration losses (Peng *et al.*, 2004).

Widespread flooding is also expected to increase in Asia. Many small islands and delta regions, for example the Mekong delta, are highly vulnerable to flooding. In

Myanmar, floods caused by the tropical cyclone Nargis (during May 2008) devastated 1.75 million ha of rice land (USDA/FAS 2008) while in Bangladesh, cyclone Sidr caused production losses in the range of 800,000 t of rice during 2007 (IRIN 2008).

13.4 PRICES, POVERTY, AND MALNUTRITION

The direct and indirect effects of climate change on agriculture can be tracked through an economic system wherein climatic change will bring greater volatility to production costs and consumption prices of production and consumption, productivity investments, food demand, and ultimately human well-being (Parry *et al.*, 2009). With no climate change, world prices for rice, wheat, and maize could increase between 2000 and 2050, mainly driven by population and income growth along with a declining productivity. The price of rice could rise by 62% and maize by 63% (Nelson *et al.*, 2009). However, with climate change (note that CO_2 fertilization effects on price are not large) an additional increase in prices by 32 to 37% for rice and 52 to 55% for maize is predicted (Table 13.2). Among livestock products, beef prices are predicted to be 33% higher by 2050 with no climate change and 60% higher with climate change. Similarly prices of all other livestock products including pork, lamb, and poultry were predicted to increase with the same magnitude with both the drier (CSIRO) and the wetter (NCAR) model.

By analyzing the diminishing consumption of cereals, Nelson *et al.* (2009) showed that without climate change caloric availability would increase throughout the world between 2000 and 2050, except for a small decline in Latin America and the Caribbean. The largest increase would be in SSA (12.6%). Even by including climate change in the model, caloric availability not only was lower than the no climate change scenario in 2050 but also declined relative to 2000 levels throughout the world. However, with the beneficial effect of CO_2 fertilization, the decline was predicted to be 3 to 6% less severe though still a considerable decline relative to the no climate change scenario (Table 13.3). In terms of number of malnourished children, only SSA is projected to have an increase in the number of malnourished children between 2000 and 2050 even without climate change, with the other developing countries recording greater reductions in numbers.

Burney *et al.* (2010) provide evidence against the prevailing assumption that higher prices lead to increased poverty in the world given that poor people tend to spend a larger share of their income on food. They indicated that poor people who own their own land could actually benefit from higher crop prices while rural wage laborers and people living in cities will definitely be negatively affected. Hence the study revealed a surprising mix of winners and losers depending on the projected global temperature and the scenario considered. In Thailand, for example, the poverty rate for people in the non-agricultural sector was projected to rise 5%, while the rate for self-employed farmers dropped more than 30%. With the most likely scenario of crop production meeting expectations, a 1°C increase by 2030 in crop yields, food prices, and poverty rates could be relatively small. But under the "low-yield" scenario (crop production towards the low end of expectations), with 1.5°C increase would result in 10 to 20% drop in agricultural productivity and 10 to 60% rise in the price of rice, wheat, and maize, in turn increasing the overall poverty rate by 3% in the 15 countries surveyed.

Table 13.2 Production and price of rice, maize, millet, and sorghum in 2000, 2050 with no climate change (CC), and percent change with CC (range from CSIRO and NCAR models) in 2050 relative to 2050 without CC[a]

	Production (million t^{-1})			
Agriculture product	*South Asia*	*Sub-Saharan Africa*	*World*	*World price (US\$ t^{-1})*
Rice				
2000	119.8	7.4	390.7	190
2050 No CC	168.9	18.3	455.2	307
2050 CC (% change)	−14.3 & −14.5	−14.5 & −15.2	−11.9 & −13.5	32.0 & 36.8 (−15.1 & −17.0)[b]
Maize				
2000	16.2	37.1	619.2	95
2050 No CC	18.7	53.9	1061.3	155
2050 CC (% change)	−18.5 & −8.9	−9.6 & −7.1	0.2 & −0.4	55.1 & 51.9 (−12.6 & −11.2)[b]
Millet				
2000	10.5	13.1	27.8	–
2050 No CC	12.3	48.1	67.0	–
2050 CC (% change)	−19.0 & −9.5	−6.9 & −7.6	−8.4 & −7.0	–
Sorghum				
2000	8.4	19.0	59.9	–
2050 No CC	9.6	60.1	123.5	–
2050 CC (% change)	−19.6 & −12.2	−2.3 & −3.0	−2.6 & −2.5	–

[a]Source: Nelson *et al.* (2009).
[b]Values in parentheses show price changes with CO_2 fertilization (i.e., % change from no CO_2 fertilization).

Table 13.3 Projected number ('000) of malnourished children below the age of 5 in 2000, and in 2050 with no climate change (No CC) and with climate change excluding a CO_2 fertilization effect (+CC) averaged from CSIRO and NCAR predictions[a]

		2050		
Region	*2000*	*No CC*	*+CC*	*CF effect[b] (%)*
South Asia	75621	52374	58168	−3
East Asia and Pacific	23810	12018	16537	−8
Europe and Central Asia	4112	2962	3909	−4
Latin America and Caribbean	7687	5433	6728	−4.5
Middle East and North Africa	3459	1148	2016	−10
Sub-Saharan Africa	32669	38780	48875	−5
All developing countries	147357	112714	136232	−4.5

[a]Source: Nelson *et al.* (2009); adapted and modified from Parry *et al.* (2009).
[b]Percentage difference between the number of malnourished children in 2050 with and without the CO_2 fertilization (CF) effect taking the average of CSIRO and NCAR predictions.

13.5 ADAPTATION

Many of the impacts outlined in the previous section are now regarded as inevitable, given the lag in the climate system that ensures continued warming for several decades even if GHG emissions were to somehow immediately cease, and the fact that efforts to reach a global agreement on limiting GHG emissions has to date failed (Parry *et al.*, 2008). Thus adaptation is now essential rather than optional. The profound changes to the climate system that are projected to occur within this century will have a pronounced effect on crop and livestock production and livelihoods of the poor, resulting in more intense poverty, malnutrition, and conflict. In this section key concepts of coping, adaptation, and resilience are examined, framing a discussion about links between development and adaptation, and the need to enable or 'adapt' to adaptation. Lastly, technological options for adaptation are described briefly, as many of these have been covered elsewhere in this book.

Long-term investments in agriculture not only enhance the capacity of agriculture to better manage risks from climate change but also produce double dividends with respect to slowing the growth of greenhouse gases in the atmosphere. For example, a recent study by Burney *et al.* (2010) demonstrates the beneficial effects of investment in agricultural research: they estimated that from 1961 forward, emissions of three major greenhouse gases (methane, nitrous oxide, and CO_2) were reduced by a quarter ton for every dollar invested in agricultural research. Although, GHG emissions have increased with agricultural intensification, those emissions are far outstripped by the emissions that would have been generated in converting additional forest and grassland to farm land. Considering the total amount of agricultural research funding related to yield improvements since 1961 through 2005, a very nominal price ranging between approximately US$4 and US$7.50 has been invested for each ton of CO_2 that was not emitted. Hence this study clearly demonstrated the huge potential that can be presently achieved, and subsequently reaped by the future generations, by investing in agricultural research, as well as the opportunity costs associated with under-investment in agriculture as has been the case over the past couple of decades.

13.5.1 Coping, adaptation, and resilience

Most poor smallholder farmers are vulnerable to climate variability and change, being highly dependent on agriculture, and especially on natural resources/assets, for their livelihoods (Conway 2008). These natural resources of land, soil, water, and biodiversity are often degraded or overexploited; a situation that is exacerbated by widespread poverty, weak institutions, poor support mechanisms and governance, and lack of infrastructure. Hence smallholder farmers are acutely vulnerable to shocks and stresses, both from climate variability and other factors. Farmers have developed coping strategies over time that allow them to cope with the vagaries of climate and other factors, but these are short-term strategies that respond to expected and observed seasonal variation, and are usually risk averse strategies designed for below-average seasons. While many of these coping strategies can contribute to adaptation, such strategies are essentially internal and are not sufficient for adaptation.

Adaptation is defined as an 'adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities' [Christensen *et al.* (2007); for other definitions of adaptation, see Levina and Tirpak (2006)]. Adaptation thus includes both responses to threats and opportunities, the latter being frequently overlooked. Indeed, in future, making use of opportunities to maximize production and profit could become important as a means of ameliorating the impact of poor years, assuming forecasts of seasonal climate conditions are sufficiently robust, and other production factors adequate, to allow for opportunistic farming. Adaptation includes dimensions of biophysical, social, and economic change and considers coupled human-natural systems and not just biophysical impacts. Adaptation is a key strategy for building resilience, which broadly describes the ability of systems or individuals to cope with sudden (shock) or gradual (stress) changes (Conway 2008).

Adaptation and adaptive capacity need to be understood in the context of sustainable livelihoods and development in general, and not viewed as, or indeed implemented as, a separate package of largely technical fixes (Mortimore 2010). The livelihoods approach has been found to be useful for understanding food insecurity as it emphasizes the importance of looking at an individual's capacity for managing risks as well as external threats to livelihood security such as droughts (Chambers *et al.*, 1989; Scoones 1998). Adaptive capacity at its core comprises the major elements of sustainable livelihoods (Carney 1998); natural or biophysical assets (soil, water, land, biodiversity), human or socioeconomic assets (literacy, gender equality, social networks), and financial and technological assets. However, long-term risks from climate change require that additional measures beyond sustainable livelihoods frameworks be considered. Such measures should foster 'climate aware' development, and may include, inter alia, building capacity for: appropriately interpreting and applying output from regional downscaled climate models; conducting integrated assessments on vulnerability, impacts, and adaptation; and developing climate risk communication strategies and tools appropriate to the needs of vulnerable groups.

Many studies have shown how important sustainable livelihoods factors are in the ability of farmers to effectively manage and cope with risks under current conditions (Chambers *et al.*, 1989; Scoones 1998; Mortimore and Adams 1999). It is essential to understand how any technology that putatively contributes to adaptation will affect such livelihoods-based coping strategies and especially the sustainable use of natural resources. Similarly, in targeting the most vulnerable, who are frequently women, children, and the landless, these factors have to be carefully considered. For example, women are more likely to do natural resource management related livelihood diversification (market gardens, production) while men are more likely to do wage-related diversification as a strategy for coping with risks, both climatic and potentially for adapting to longer term climate change.

It is also important in discussing adaptation technologies, especially in relation to climate change, to recognize that many technologies used by farmers as part of their coping strategies are regarded by them not as means for managing climate risks but for productivity and profitability. This is important to note for at the core of all agricultural development is the need for 'incentive' in order for farmers to adopt technology. Part of this incentive may include technology or technology adoption approaches that have sufficient flexibility so as to allow potential adopters to reconfigure the technology to most effectively meet needs for coping with risk (Nederlof and Dangbégnon 2007). Thus, adaptation strategies need to be devised around understanding constraints and hence entry points linked to incentives or tangible benefits. While stating that coping strategies are short term, we nonetheless fully concur with the sentiments of Cooper *et al.* (2009), who said that first stage in adaptation is to support farmers to cope better with current variability. We add that a parallel tract is needed to identify entry points for developing policies, promoting communication between decision makers at multiple levels and the research community, and building individual and institutional capacity for generating and disseminating new knowledge, which would allow societies to begin to prepare for longer term manifestations of climate change, including that of food production.

It is increasingly recognized that many small farmers have not benefited from technologies available today (Cooper *et al.*, 2009), due to failure either of the technology or more commonly of the delivery mechanism (Renkow and Byerlee 2010). As discussed elsewhere, this is often rooted in either a failure to understand livelihoods and assets or the impact pathway and other actors and organizations needed to deliver technology (Hall *et al.*, 2005). Technology may be 'necessary', but it is rarely if ever 'sufficient' for impact. Collective action, including participatory approaches, that use or build stronger social networks, has been shown to be important in all societies, rich and poor, for technology adoption (Pretty 2008) and for strategies that more broadly reduce impacts from climate change (Adger 2003). Equally important are favorable enabling environments in terms of government and other sectors' support and policies, both national and local (Mortimore 2010). Indeed, for adaptation the role and importance of local organizations and their capacity for supporting adaptation is frequently overlooked, despite the fact that these organizations will be the ones supporting farmers directly. Where farmers perceive weak support for adaptation interventions they are less likely to try what they perceive to be riskier technologies (Pedzisa *et al.*, 2010). As Kandlikar and Risbey (2000) note in a review of adaptation challenges for agriculture, "[F]armers in low income countries face high downside risks from failure of new technologies, especially if information and government support is limited or lacking. In such cases, they are likely to choose options that have been well tested in the past. Studies of [climate change] adaptation need to pay greater attention to these issues to be truly relevant in a global sense."

Another factor frequently overlooked in technology transfer is knowledge transfer, two-way knowledge exchange, and the adaptation or modification of technology to suit local needs and environments. Natural resource technologies are knowledge intensive, especially in comparison with seed-based technology, and not easily adapted without knowledge transfer and exchange and capacity building, as well as technology adaptation in many cases (Pound 2008). As such natural resource based interventions are often local rather than global, including responding to the local policy environment, also limiting their impact (Renkow and Byerlee 2010).

Larger scale natural resource interventions, such as watershed management (Wani *et al.*, 2008), also require community action and may also involve processes around property rights and common property resources (Meinzen-Dick *et al.*, 2004). Again, these interventions require a better understanding of farmer and community livelihood strategies and a 'toolbox' of appropriate skills to facilitate the process. Roncoli *et al.* (2001) also indicate that farmers need more than information to be able to respond optimally to a forecasted climate shock. There is a need for integrating science and development interventions in ways that help improve livelihood options and the productive capacity of farming households, especially those with limited resources. Access to labor saving technologies that accelerate land preparation and planting, and timely availability of locally adapted seed varieties were some of the key elements to more effectively manage risks associated with climate variability, identified by Roncoli *et al.* (2001) in semi-arid Burkina Faso (see Box 2).

Box 2. Case Study – Adaptation in Burkina Faso

The Sahel has long suffered from climate variability and farmers' coping and adaptation strategies to drought have been studied by many (e.g., Mortimore and Adams 1999, Roncoli *et al.*, 2001, Barbier *et al.*, 2009). In a recent study of Tougou in Burkina Faso, adaptation strategies were studied in contrasting seasons in 2004 and 2006. Tougou is an area of high population density (170 km^2 in 1998) and intensive land use and farmers operate in a fairly typical Sahelian context of increasing population, poor policy and enabling environment, declining soil fertility, and poorly functioning markets. The average farm size is 5 ha supporting 12 people and sorghum and millet being the main cereal crops. Farmers' strategies are aimed at increasing yield but reducing variability. Farmers adopted a wide range of low-cost strategies both for crops and animals (see below).

Strategy	*Adoption (%)*	*Strategy*	*Adoption (%)*
Crop management		**Animal management**	
Stone bunds	60	Bull fattening	47
Micro-water harvesting (Zai)	49	Purchased feed	4
Water harvesting (demi-lune)	6	Sorghum stover	54
Soil restoration	49	More animals	13
Row planting	30	Hay	48
Improved seed	49	More milk production	4
Plow	46		
Draft animals	25	**Preferred adaptation**	
Weeder	10	Animal sale	82
Mineral fertilizer	21	Less meals	56
Coralling	42	Diversification, improved seed	32
Manure	41	Change of grazing areas for cattle herds	15
Compost	56	Other activities (gold mining, trade …)	10
Lowland production	51	Less food	70
Vegetable production	61	Waiting for irrigation during the dry season	44
Fertilization of vegetables	59	Migrate to other regions	20
Crop insurance	0	Temporary migration	12
		More fertilization (organic matter, inorganic fertilizers)	6

Many of these strategies contributed to intensification of production, especially crop/livestock systems, as well as reducing variability. Diversification into vegetable production was also important where access to irrigation water was possible. When asked about future strategies in the event of another drought, selling animals would be the most important strategy, followed by eating less meals and consuming less food.

13.5.2 Adaptation strategies

Adaptation strategies often contain both social and technical elements that sometimes act independent of each other and at other times interact. Among social adaptation strategies are maximization of family labor use, including generating remittances from temporary or permanent migration; diversification into non-agricultural enterprises; deployment of social protection schemes and employment schemes; crop and livestock insurance; and realization of collective action and community-based empowerment efforts.

Resilience, in the context of the social elements mentioned above, is strongly associated with diversification of income-generating opportunities that reduce exposure to livelihoods shocks from climatic and non-climatic stressors. Long-term village-level studies in India (Walker and Ryan 1990) have shown that incomes have been diversified over time in response to long-term changes in climate and other changes in agricultural policies and markets, and that agricultural production constitutes a smaller proportion of livelihood than previously (see Box 3). Off-farm and non-farm income sources,

Box 3. Case Study – Adaptation and Coping in India's SAT

ICRISAT initiated a series of long-term village-level studies (VLS) in 1975 in Andhra Pradesh and Maharashtra which provide many insights into coping and adaptation (Walker and Ryan 1990; Bantilan and Anupama 2006). Farmers report that rainfall has become more uneven with more frequent drought years and declining groundwater levels. Mean temperatures have indeed increased slightly (by about 0.7°C) and number of rainy days decreased. The incidence of extreme temperature events has not changed significantly. Over time, there have been adaptations at:

- Farm level: change in cropping patterns, adoption of shorter duration cultivars, diversification away from staple cereals (millet, sorghum) to higher value non-cereal crops
- Institutional level: diversification of agricultural income sources (livestock and dairy, vegetables), more formal credit/lending institutions, rural employment schemes, food security systems
- Technological level: micro-irrigation, rainwater harvesting
- Social level: increase self help groups (SHGs), diversification to non-agricultural sources of income, seasonal and permanent outmigration

Among social wealth classes, adaptation responses also vary:

Household	*Adaptation strategy*
Landless	Seasonal migration, Government employment scheme (in some states)
Marginal	Work as laborer, lending money, some seasonal migration
Medium	Lending money, selling of limited stocks
Large	Using savings, reducing expenses, selling of stock, investing in dairy, irrigation

The most preferred short-term strategies are reducing household expenditure and food intake, selling some assets, and changing planting dates. Selling livestock, changing cropping patterns, or introducing new crops are less preferred.

including migration are now much more important than was previously the case. Likewise village-level studies in SSA have shown that in severe droughts farm families increase the number and type of off-farm income-generating activities (Mortimore and Adams 1989). Rural livelihood programs [e.g., Andhra Pradesh Rural Livelihoods Programme (APRLP), India] also promote non-agricultural livelihoods as a core part of their strategy to cope in drought-prone environments.

Diversification may include greater crop and livestock integration and in many cases intensification or specialization, including dairy production. Small ruminants commonly replace large ruminants. Diversification also takes place into market gardens and vegetable and fruit production, and where livestock are important into fodder production. High-value fruits and vegetable production are associated strongly with market access and demand, and this may be facilitated where small-scale irrigation is required (Wani *et al.*, 2008). Small-scale market gardens are an important entry point for women in particular and this approach has been successfully used in West Africa.

Increasingly important for adaptive capacity will be efforts to bolster support systems provided by government and civil society organizations (CSOs) and to nurture community-based efforts to develop or strengthen local-level support systems. These may include national schemes such as employment guarantee schemes or social protection schemes, or local schemes implemented by CSOs through, for example, drought relief programs. For these schemes to be implemented effectively, and better linked to agriculture, greater capacity building of local organizations is required. Often ‘products’ are delivered to meet targets rather than in the best interests of the target populations. A counterbalance to these top-down schemes are the myriad autonomous forms of support organized at the local level, as described by Agrawal and Perrin (2008).

A major area for investment to help farmers adapt (and cope) with climate variability is seasonal forecasting. The science and delivery of seasonal forecasting is still in its infancy but has considerable potential, especially for taking advantage of better than average years and not just ameliorating poorer than average years (Meza *et al.*, 2008). While considerable uncertainties remain in the forecast itself, more attention is needed on how to deliver these forecasts to farmers and indeed to local government and CSOs that interface with farmers. This is because a forecast, however accurate, is useless without the options being understood and available to farmers, e.g., the availability of seeds of a shorter or longer duration cultivar for a below or above average season, respectively. The primary constraints to realizing the full potential of seasonal climate forecasts include: lack of specificity of the forecasts with respect to end-user needs and inadequate coordination between forecasters and end-users; poor communication and interpretation of forecasts; and inability of farmers to act on forecasts (Vogel and O’Brien 2006; Archer *et al.*, 2007; Patt *et al.*, 2007).

Lastly, all of the above, and many of the technical options in Table 13.4, require much greater investment in capacity building among communities, individuals, and supporting institutions, and a greater orientation of organizations involved in technology delivery towards participatory and collective or community action programs. Participatory extension has begun to take hold over the last several years, and has led to more responsive service delivery by introducing new technologies and the means to empower technology uptake and innovation by farmers (reviewed by Padgham 2009). Supporting expansion of the participatory extension model could aid adaptation efforts by promoting joint learning and the communication and sharing of knowledge among farmers. For example, Thomas *et al.* (2005) found that support for group visits and

Table 13.4 Some examples of technology-based adaptation options

Intervention	*Example*
Change resource allocation between fields	Fallow, abandon outer fields; concentrate effort on inner fields
Rainwater harvesting	Zai pits/planting basins; demi-lunes; bunds (rock, earth), small tanks/pits; small dams
Supplementary irrigation	Drip irrigation
Conservation-effective practices	Minimum tillage; mulching; semi-permanent ground cover
Sowing dates	Earlier, staggered
Crop and livestock species or cultivars	Drought tolerant species and cultivars
Cropping system diversification and agroforestry	Intercropping and within farm diversification; greater use of tree products
Good agricultural practice	Integrated soil fertility management; integrated pest management; weeding strategies; fertilizer strategy
Livestock management	Number; type; grazing and feeding strategies/ feeding (kraaling); crop/livestock integration
Agricultural enterprise diversification	Market gardening; fruit and other trees; dairy; payment for ecosystem services
Seasonal forecasting	Change crop management practices such as cultivar, sowing time, and plant density
Crop insurance	Compensation for drought failure of crops

farmer-to-farmer exchange networks were an effective and low cost means for relaying adaptation-relevant knowledge and information.

There are many technical options that can enhance climate risk management and promote adaptation; some examples are listed in Table 13.4. Cooper *et al.* (2006) suggested that such interventions could be grouped by the timing of the decision, namely, prior to the season (ex-ante), within the season, and after the season (ex-post). Pre-season options may include investing in water conservation technologies (e.g., digging zai pits) or choosing drought tolerant (short season) crop varieties. In-season options (response farming) include adjustments to crop and livestock management in response to weather, and may include abandoning outer fields and concentrating on the home field, or not applying fertilizer to conserve cash or avoid debt, or the converse, applying fertilizer when seasonal forecasts or other decision parameters are favorable. At the end of the season, farmers may make decisions that attempt to either reduce the negative effects of, or in some cases exploit, production outcomes. These post-season actions including such actions as sale of assets and temporary migration for wage labor are often used to protect livelihoods and compensate for insufficient food production. Understanding the complexities of household decision-making at different time periods in agricultural cycles is therefore critical when developing adaptation strategies.

13.6 CONCLUSION

Farmers have evolved many coping and adaptation strategies in the face of climate variability and other factors affecting their livelihoods. Indeed, the role of non-climatic factors such as policy, markets, and other external drivers of change should not be underestimated. Understanding the role of these factors, and promoting good enabling policies and a support for organizations that help farmers to adapt is a key component of any adaptation strategy. At the end of the day, farmers need a range of options and in many cases support to utilize those options in order to adapt.

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