Impacts of climate change on the agricultural and aquatic systems and natural resources within the CGIAR's mandate

Working Paper No. 23

CGIAR Research Program on Climate Change,
Agriculture and Food Security (CCAFS)

Edited by Philip Thornton and Laura Cramer

CLIMATE
CHANGE
AGRICULTURE AND
FOOD SECURITY

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CCAFS Working Paper no. 23

Abstract

The document attempts to distil what is currently known about the likely impacts of climate change on the commodities and natural resources that comprise the mandate of CGIAR and its 15 Centres. It was designed as one background document for a review carried out by the High Level Panel of Experts on Food Security and Nutrition (HLPE) at the behest of the UN Committee on World Food Security (CFS) on what is known about the likely effects of climate change on food security and nutrition, with a focus on the most affected and vulnerable regions and populations. A total of 25 summaries covering 22 agricultural commodities, agroforestry, forests and water resources, present information on the importance of each commodity for food and nutrition security globally, the biological vulnerability of the commodity or natural resource to climate change, and what is known about the likely socio-economic vulnerability of populations dependent partially or wholly on the commodity or natural resource. With a few exceptions, the likely impacts of climate change on key staples and natural resources in developing countries in the coming decades are not understood in any great depth. There are many uncertainties as to how changes in temperature, rainfall and atmospheric carbon dioxide concentrations will interact in relation to agricultural productivity; the resultant changes in the incidence, intensity and spatial distribution of important weeds, pests and diseases are largely unknown; and the impacts of climate change and increases in climate variability on agricultural systems and natural-resource-dependent households, as well as on food security and the future vulnerability of already hungry people in the tropics and subtropics, are still largely a closed book. CGIAR along with many other partners is involved in a considerable amount of research activity to throw light on these issues.

Keywords

Adaptation, Food security, Global tropics, Mitigation, Vulnerability

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Contents

Acronyms

CDM	Clean Development Mechanism
CFS	UN Committee on World Food Security
GHG	Greenhouse Gases
HLPE	High-Level Panel of Experts on Food Security and Nutrition
SA	South Asia
SAT	Semi-arid tropics
SSA	sub-Saharan Africa

1 Introduction

In October 2010 the newly reformed UN Committee on World Food Security (CFS) requested its High-Level Panel of Experts on Food Security and Nutrition (HLPE) to conduct a study on climate change and to "… review existing assessments and initiatives on the effects of climate change on food security and nutrition, with a focus on the most affected and vulnerable regions and populations and the interface between climate change and agricultural productivity, including the challenges and opportunities of adaptation and mitigation policies and actions for food security and nutrition." The HLPE is due to present the final findings at the CFS Plenary session in October 2012.

Climate change is already providing significant challenges to natural systems. Significant changes in physical and biological systems have already occurred on all continents and in most oceans, and most of these changes are in the direction expected with warming temperature [1]. For the future, best estimates of temperature increases are in the range 1.8 to 4°C in 2090–2099 relative to 1980–1999, depending on the scenario of future greenhouse gas emissions that is used to drive the climate models[2]. The combination of generally increasing temperatures and shifting rainfall amounts and patterns will clearly have impacts on agriculture. At mid- to high latitudes, crop productivity may increase slightly for local mean temperature increases of up to 1–3 °C, depending on the crop, while at lower latitudes, crop productivity is projected to decreases for even relatively small local temperature increases (1–2 °C). In the tropics and subtropics in general, crop yields may fall by 10 to 20% to 2050 because of warming and drying, but there are places where yield losses may be much more severe.

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[1] Rosenzweig et al. 2008. Attributing physical and biological impacts to anthropogenic climate change. *Nature* 453 (15 May 2008), doi:10.1038/nature06937

[2] IPCC (Intergovernmental Panel on Climate Change) 2007. Climate Change 2007: *Impacts, Adaptation and Vulnerability: Summary for policy makers.* Online at http://www.ipcc.cg/SPM13apr07.pdf

Climate change will alter the regional distribution of hungry people, with particularly large negative effects in sub-Saharan Africa. Smallholder and subsistence farmers, pastoralists and artisanal fisherfolk will suffer complex, localized impacts of climate change, due both to constrained adaptive capacity in many places and to the additional impacts of other climate-related processes such as snow-pack decrease, particularly in the Indo-Gangetic Plain, and sea level rise. Furthermore, changes in the frequency and severity of extreme climate events will have significant consequences for food production and food security; it is not only projected mean climate change that will have an impact. Increasing frequencies of heat stress, drought and flooding events are estimated to be likely, even though they cannot be modelled in any satisfactory way with current levels of understanding of climate systems, but these will have adverse effects on agricultural and natural systems over and above the impacts due to changes in mean variables alone.

This document is an attempt to distil what is known currently about the likely impacts of climate change on the commodities and natural resources that comprise the mandate of CGIAR and its 15 Centres, and was designed as a background document for the review that the HLPE is undertaking. The climate change Contact Points in each Centre were asked to provide a summary in three parts: the importance of each commodity for food and nutrition security globally; a summary of the biological vulnerability of the commodity or natural resource to climate change; and a summary of what is known about the likely socioeconomic vulnerability of populations dependent partially or wholly on the commodity or natural resource.

These contributions from the Centres have been lightly edited and are assembled here. Section 2 contains summaries for 22 mandate commodities, and section 3 contains summaries on agroforestry, forests, and water. Section 4 contains a brief discussion and conclusions as to the state of knowledge and highlights areas that need further research.

2 Commodities

2.1 Banana

Piet van Asten, International Institute of Tropical Agriculture (IITA); Charles Staver, Bioversity International

The importance of banana (*Musa* sp) for food and nutrition security

Banana is grown in the humid and subhumid tropics, the tropical highlands, and even in the drier subtropics. In terms of production, bananas are the world's fourth most important food crop, mostly grown and consumed in the tropical and subtropical zones. The banana's ability to produce fruits all year round makes it an important food security crop and cash crop in the tropics. The crop is grown in more than 120 countries; around a third each is produced in the African, Asia-Pacific, and Latin American and Caribbean regions. As shown in Table 2.1.1, three categories of bananas are produced. Plantains and cooking bananas are staple foods, while dessert bananas are an important source of calories, minerals (such as potassium) and vitamins consumed as a fruit.

The data in the table do not include production of export bananas. The production figures per capita can therefore be considered the production available for domestic consumption. About 87% of all the bananas grown worldwide are produced by small-scale farmers for local consumption as a food security crop, and for local markets rather than for international trade. They provide a staple food for millions of people, particularly in Africa. The regional figures do not highlight the subregions for which bananas are an important staple. Bananas and plantains supply more than 25% of the carbohydrate requirements for over 70 million people in Africa. These include parts of Uganda, Tanzania, Burundi, Rwanda and Eastern DRC for which East Africa Highland bananas are a staple food consumed in some localities two to three times per day. East Africa is the largest banana-producing and consuming region in Africa with Uganda being the world's second leading producer after India, with a total production of about 10.5 Mt. In some African countries such as Uganda the daily consumption of banana may exceed 1.6 kilogrammes per person, which is the highest in the world.

The plantain zone of Nigeria, Ghana, Côte d'Ivoire and Cameroon figures into the averages for West and Middle Africa. In Asia, the vast majority of cooking bananas is consumed in the Philippines. Papua New Guinea is the major consumer of cooking bananas in Melanesia, while countries such as Colombia and Peru have high per capita consumption of plantains in Latin America.

Table 2.1.1. Banana statistics by region

Region[1]	Average production per year ('000 Mt)[2]				Per capita production (kg)	Average area (1000 ha)	Average yield (t/ha)
	Dessert banana	Plantain	Cooking banana[3]	Total			
Year	2006	2006	2006	2006	2006	2006	2006
Eastern Africa	2538	1275	13371	17184	58.7	3559	4.8
Northern Africa	1650	0	9	1659	8.5	30	56.0
Middle Africa	1334	2577	484	4395	38.5	902	4.9
Southern Africa	343	0	0	343	6.2	7	46.5
Western Africa	1396	6340	657	8393	30.6	1336	6.3
Africa (Total)	7261	10192	14520	31973	34.3	5835	5.5
Central America	2799	958	142	3900	26.5	250	15.6
South America	10006	5330	708	16044	42.7	1590	10.1
Caribbean	1030	934	597	2561	63.2	296	8.6
Americas (total)	13835	7222	1447	22504	39.9	2137	10.5
East Asia	6527	1	460	6988	4.5	296	23.6
South Asia	10341	629	2337	13308	8.3	751	17.7
Southeast Asia	7087	204	7213	14504	25.6	1094	13.3
Melanesia	100	1	514	615	76.8	65	9.4
Micronesia	2	0	5	8	14.5	2	3.1
Oceania	265	0	1	266	10.7	11	23.8
Polynesia	15	0	25	40	67.8	6	6.2
Asia (total)	24337	836	10554	35727	9.5	2226	16.0
Total: 3 continents	45434	18250	26521	90204	17.2	10198	8.8

Source: Lescot (2008) and FAOSTAT

[1] Excludes North America, Central Asia and Europe

[2] Fruitrop Market News for 2007 (passionfruit.cirad.fr/index.php/recherche/(produit)/1): Musa (bananas and plantains) domestic production (with exports deducted) - so production available for domestic consumption

[3] Highland bananas + ABB cooking bananas + others

Approximately 13% of worldwide banana production is destined for the export market. The banana fruit is extremely important as an export commodity especially in Latin America and Caribbean, which contribute over 83% of the total banana in the international market. The banana export industry is also the backbone of the economies of many Caribbean countries, and the crop plays a vital role in the social and political fabrics of the islands. In Africa, only five countries, namely Côte d'Ivoire, Cameroon, Somalia, Ghana, and Cape Verde, export approximately 427,000 t of banana and plantain. There are more than 500 banana varieties in the world, but the Cavendish is the most exported banana cultivar.

Nutritionally, fresh bananas contain 35% carbohydrates, 6–7% fibre, 1–2% protein and fat, and major elements such as potassium, magnesium, phosphorus, calcium, iron, and vitamins A, B6 and C. Bananas are also used to manufacture beer, wine and other products and form an important part of the cultural life of many people.

Biological vulnerability to climate change

Bananas, plantains and cooking bananas are an herbaceous semi-perennial vegetatively propagated crop. The production cycle for a single bunch varies from 10 to 20 months, depending on temperature and water availability. Farmers have developed diverse production systems in different environments to overcome climatic constraints on banana productivity, including irrigation; protective covers, planting density and sucker management and season of planting and production. Smallholders depending on rainfall will be the most affected by changing climate, primarily due to their lack of resources to adapt production practices and due to changes in pest and disease occurrence.

The following parameters define banana and plantain growth. Cultivar groups are known to have somewhat different responses to climatic factors.

- The optimum temperature range is 20–30˚C. Extended periods outside this range reduce production per ha. In the 20–25˚C range, larger bunches and longer vegetative period are achieved; in the 25–30˚C range, smaller bunches with a shorter cycle occur. Total yield per ha through time is generally stable from 20–30˚C.
- Temperatures above 35˚C and below 10–15˚C cause damage to plant tissue and distort flowering emergence and bunch filling. If extreme temperatures do not persist beyond 2–4 days, plants recover, although bunches emerging during the period of stress may not fill

properly. Temperatures below 2–3˚C for several days are lethal to the plant, which does not recover. Cultivar differences have been observed for temperature response. This cultivar difference can be seen in the highland tropics. Certain cultivars are found primarily at low elevations, while other cultivars continue to be grown even above 2000 meters above sea level. The East African Highland bananas have been selected by farmers for their performance in tropical highlands, although climate change may be detrimental by increasing the temperature above their optimal range.

- For temperatures that are outside of the optimum range but not extreme, total production declines due to increased crop cycle length, either due to lower rate of degree, day accumulation or increased respiration.
- Banana is highly sensitive to available soil water. The roots sense slight water deficits, which cause the leaf stomates to close to reduce water loss. This occurs at higher soil water levels for banana and plantain than for many other crops. Banana is therefore a low user of water below optimum and can survive for long periods of drought, only resuming vegetative growth quickly when soil moisture reaches an optimum.
- Optimum rainfall for banana growth is 1300–2600 mm per year distributed equally at 100–200 mm per month, although actual water use is a function of potential evapotranspiration.
- Periods of sub-optimum soil moisture slow the rate of leaf emergence. Bunch size can be affected by lack of moisture, if this occurs during or after flowering, but yield also declines due to the increasing length of the vegetative period under below optimum moisture.

Based on this summary of banana response to climatic parameters, the impact of climate change on banana production can be hypothesized. The effects were projected by Ramirez et al. (2011), although the limitations of the ECOCROP model for semi-perennial crops were described in greater length by Ramirez et al. (2012).

Suitability for banana increases in the sub-tropics due to increases in winter temperatures and a decline in the frequency of frosts and cold snaps. The upper altitudinal limit for banana cultivation in highland tropics will increase due to increasing temperatures. The time from planting to harvest at intermediate altitudes in the tropics will decrease, although bunch size may also decrease. Higher temperatures will also increase the water demand for highland bananas. Productivity of bananas in lowland tropics may decline in those areas with extended periods of temperatures above 30˚C.

The effects of changes in precipitation are harder to project. Greater irregularity of rainfall and declining rainfall will increase the length of the crop cycle and the seasonality of bunch production. Figure 2.1.1 shows that some areas are predicted to have an increase in rainfall, while others are predicted to receive less rainfall. Certain areas of the Caribbean and Central America may experience reductions in rainfall of 150–200 mm per year by 2020.

Figure 2.1.1. Expected changes in precipitation and temperatures in banana-growing areas of the world by the 2020s for the SRES-A2 emission scenario: average of four GCM patterns.

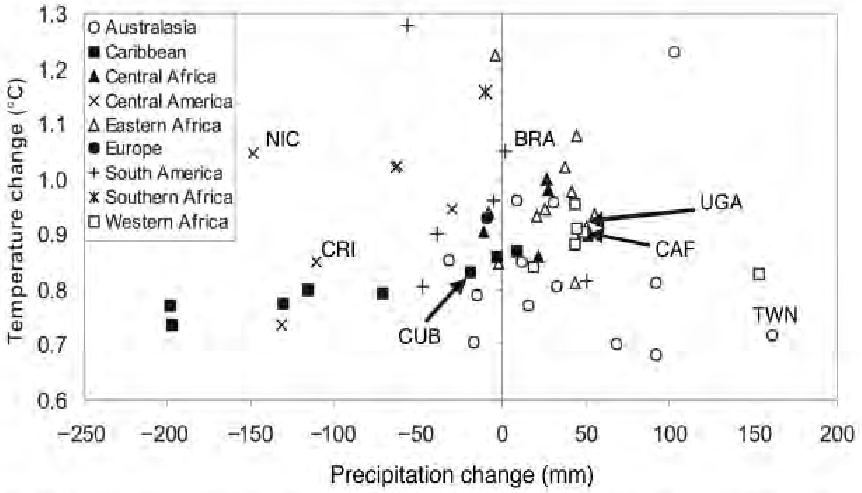


Fig. 20.2. Expected changes in precipitation and temperatures in banana-growing areas of the world by 2020s for the SRES-A2 emission scenario as average of four GCM patterns.

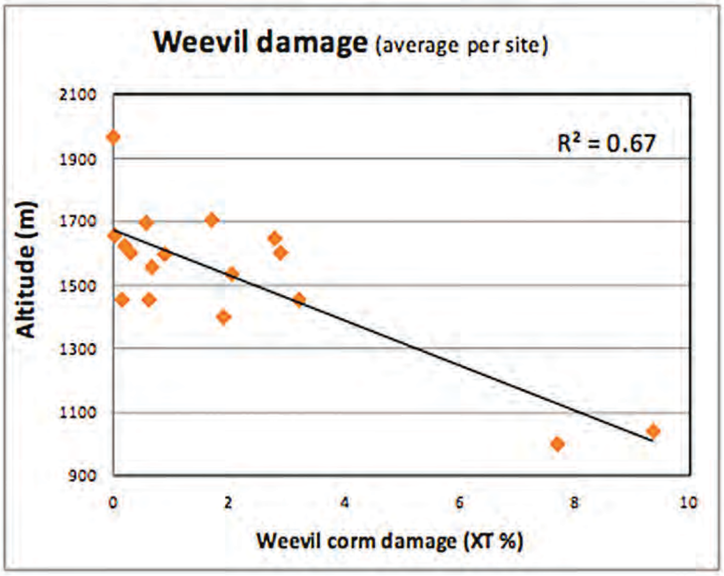
Source: Ramirez et al. (2011).

Recent studies on bananas in East African highland bananas suggest that banana yields might continue to increase with increasing rainfall, at least until 1500 mm per year. For the East African highland bananas, yield losses of 9% were observed per 100mm annual rainfall decrease (Van Asten et al. 2011).

Banana pests and diseases such as black leaf streak and banana bunchy top virus vectored by the banana aphid can be expected to expand into higher altitudes and into the subtropics with increases in average annual temperatures. In lowland areas, more complex interactions with rainfall and relative humidity make predictions of the impact of climate change on the severity of black leaf streak more difficult. Other pests which have temperature-dependent life cycles may also become more severe as temperatures increase in mid- and high-altitude and subtropical production areas.

Highland banana areas that are currently little exposed to nematode, weevil, and sigatoka problems will significantly see yield losses increase (Figure 2.1.2). The major highland banana production areas are currently located over 1300 m above sea level. Weevil damage is still very low or absent at these altitudes. In lower areas, maximum yield is limited by weevils, with approximately 4% banana bunch weight loss per percentage point of weevil corm damage (XT). If temperature increases by 2°C, then the major production areas will be infected and yield losses due to weevils are estimated to increase to 30% or more. Similarly, Radophilis similis nematodes are currently limited to elevations below 1300 m and can cause up to 50% yield loss. Yield response curves are not yet established, but it is estimated that nematodes can contribute to yield losses in the same order of magnitude as weevils. Black sigatoka is currently the biggest plant health constraint in the major lowland production areas and this fungal foliar disease will also become more important in the highland areas. However, little is known about the effects of temperature on interaction with biocontrol agents.

Figure 2.1.2. Corm damage caused by the banana weevil (Cosmpolites sordidus [Germar]) is low at altitudes >1400 m, but average corm damage can reach close to 10% around 1000 m altitude, translating to yield losses of up to 30%.



Source: Based on CIALCA-I technical report (2006-2008) at http://www.cialca.org/ files/files/CIALCA-I_final_technical_report.pdf

Besides increased problems with drought, pests and diseases, bananas are sensitive to extreme weather events such as hailstorms, droughts, floods, and strong winds. These are likely to increase in the future. No information is available on the effect of CO_2 concentration changes on banana productivity.

Socioeconomic vulnerability to climate change

In terms of vulnerability, bananas provide a buffer function in the farming systems. Short drought events at critical periods of annual crops may severely affect their yields, whereas bananas remain much more stable, albeit with yield losses as well. The biggest threat of climate change is an increase of pest and disease outbreaks, particularly in highland areas where farmers currently have bananas as their primary staple. For example, the genetic base of East African highland bananas is very narrow, and new pest and disease dynamics, triggered and/or enhanced by climate change will severely threaten the sustainability of these important buffers in smallholder farming systems.

The highlands of Uganda, Tanzania, Burundi, Rwanda and Eastern Congo stand out for their dependence on bananas for food security. Over 30 million people in poor households consume bananas as frequently as twice a day. This area is highly vulnerable in terms of percentage of poor households with limited resources and the challenges faced by national governments. The area is composed of many microclimates depending on proximity to the lakes, geological origin of soils, and altitudes that vary from 1000–2000 m above sea level, which makes climate change projections somewhat general. Temperatures are projected to increase, which will upset a delicate balance between bananas, annual rainfall (which is near the lower limit for banana production) and evapotranspiration. The increased temperatures may increase the pressure from black leaf streak disease and accelerate the reproduction rate of banana weevils and nematodes, three problems which are kept somewhat in check currently in production areas above 1400 m elevation. The projected increase in rainfall may be positive in offsetting the increased evapotranspiration from higher temperatures, but higher humidity may make conditions more favorable for black leaf streak. In summary, the highland banana areas of Uganda and Great Lakes Central Africa are potentially highly vulnerable, but climate change modelling needs to continue at a finer scale with greater attention to the interaction with pests and diseases and crop productivity.

A second area stands out globally for the importance of bananas in household nutrition. Over 12 million people in poor households of West and Central Africa consume plantains as an important component of their diet. While these households have a more varied diet than the banana-dependent households of East and Central Great Lakes Africa, plantains are a major component of the diet. Up to 100 kg per year of plantain are consumed per person in plantain-growing regions of Guinea-Conakry, Côte d'Ivoire, Ghana, Nigeria and Cameroon. The West Africa forest belt where plantain production is located will experience increasing temperatures, which characterize climate change globally. In these lowland areas temperatures are project to exceed 30°C more frequently, with detrimental effects on total productivity. Increasing temperatures with similar, but possibly more erratic, rainfall will subject plantain gardens to greater water stress with a decline in productivity. This situation may reduce the pressure from black leaf streak with an unclear balance for overall production and household food security, which depends on plantain.

Few areas of Asia and Latin America have such high levels of dependence on bananas and plantains as found in these two zones. In Asia, the Philippines, where bluggoe-type cooking bananas are an important food item, stands out in vulnerability to climate change, including cyclones, floods and droughts.

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2.2 Barley

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The importance of barley for food and nutrition security

Barley is a traditional food commodity in various parts of the world, namely North Africa and countries of the highlands such as Ethiopia, Bolivia, regions of the Himalayas and to a lesser extent countries of the Caucasus (Table 2.2.1). Various uses of barley as food in different countries are summarized in a special ICARDA book edited by Grando and Gomez MacPherson (2005) and a historical review of barley as a food commodity has been summarized by Newman and Newman (2006). Many others parts of the world use it as a beverage (alcoholic or not and local or conventional beer) more integrated in the cultural habit as a nutritional drink.

Barley is becoming an important healthy food (for diabetics) and a functional food product to a large portion of people in the developing and developed world because of the recognized benefit in terms of higher beta-glucans, zinc and iron contents (Finocchiaro et al. 2005; El Haramein and Grando 2010). Improving the added value to local products along the value chain is of interest to ICARDA. Aspects such as improvement of the quality of barley products, their standardization, certification and wider access to local and international markets are crucial to improving the livelihoods of farmers and subsequent investments for the adoption and promotion of technologies and closer interaction with research and extension and markets.

Indirectly, barley is a strategic food and nutrition security commodity because of the importance it plays in feeding calendars for livestock in the production of meat and milk and derived products. This is in fact the most important contribution of barley to food and nutrition security. Barley can contribute to livestock feed through grazing, green forage in mixture with legumes, straw and grain.

Another aspect that cannot be ignored is the considerable importance of barley for alcoholic drinks such as beer and whisky, predominantly in the developed world.

Biological vulnerability to climate change

Specific investigations on the potential effects of climate change on barley are yet to come because barley is still considered as the most flexible crop in drought prone areas. It is evident that climate change will affect barley and plans to assess this effect are being taken into consideration in the research agenda of CGIAR. More biological vulnerability of barley is expected in the dry areas where it is used more as a feed crop, specifically in areas with high pressure from livestock, semi-arid and arid lands closer to the rangelands ecosystems.

Table 2.2.1. Barley statistics by region

Region	Average production per year ('000 Mt)[1]	Per capita production (kg)	Average area (1000 ha)	Average yield (kg/ha)	Quantity (kg/ person/ year)	Calories (kcal/ person/ day)	Protein (g/person /day)
Year	2001/10	2001/10	2001/10	2001/10	2007	2007	2007
Eastern Africa	1472	4.9	1119	1327	3.8	31.3	0.86
Middle Africa	1	<0.1	1	651	0.2	1.5	0.05
Northern Africa	3735	18.4	3526	1035	9.8	70.3	1.97
Southern Africa	203	3.6	80	2525	<0.1	0.4	0.01
Western Africa	1	<0.1	0.5	2133	<0.1	0.2	0.01
Northern America	15388	44.9	5005	3101	0.5	4.6	0.14
Central America	778	5.2	302	2555	0.1	0.9	0.03
Caribbean	NR	NR	NR	NR	NR	NR	NR
South America	2218	5.8	927	2350	0.5	3.8	0.12
Central Asia	2453	41.2	1989	1231	3.7	23.7	0.67
Eastern Asia	3430	2.2	932	3675	0.5	1.9	0.06
Southern Asia	4681	2.9	2600	1792	0.7	3.2	0.09
South-Eastern Asia	19	<0.1	10	1869	0.1	0.5	0.02
Western Asia	10526	56.5	6180	1702	0.3	1.3	0.04
Eastern Europe	38310	129.7	16726	2287	2.3	13.4	0.37
Northern Europe	16002	163.9	3537	4526	2.1	12.0	0.33
Southern Europe	10778	71.0	3849	2792	0.5	2.9	0.08
Western Europe	24168	128.6	4004	6038	0.7	2.6	0.07
Australia and NZ	7794	310.2	4434	1758	<0/1	0.2	0.01
Melanesia	NR	NR	NR	NR	NR	NR	NR
Micronesia	NR	NR	NR	NR	NR	NR	NR
Polynesia	NR	NR	NR	NR			

FAO Statistics Division at http://faostat.fao.or/site/567/default.apx#ancor

Barley is also known for its tolerance to salinity and low input environments and is considered by most farmers as a low-risk crop. Its use predominantly as feed in the dry areas supports the livestock, which can play a key role in mitigating the effects of climate change by sustaining the livelihoods of poor local communities living under harsh conditions.

Issues related to pest and diseases: Climate change and variability affect insect pests, diseases, legume-Rhizobium symbiosis and weeds of cool-season cereals such as barley. Research results on the impacts of elevated CO_2 and temperature extremes on host-pest interactions and management practices are emerging from different parts of the world. Barley diseases and new integrated control measures have been reviewed by Walters et al. (2012). News tools are being developed to integrate several methods via an assessment of the risk of economic injury occurring from disease to guide decisions on the requirement for fungicide treatments. However, barriers do exist to the adoption of integrated management approaches from growers and end-users further down the supply chain and policy incentives from government may be required for these approaches to be taken up in practice.

Issues related to higher temperature: From published results and field observations, temperature and moisture are playing a critical role in affecting pest dynamics over time and space. The incidence of barley stem gal midge (*Syringoparis temperatella*), previously classified as a minor pest, is becoming important in some parts of Syria due to mild winters that increased the pest generations during the season. Some key insect pests of cereals like Hessian fly showed range expansion due to increases in temperature. More research is needed to assess and monitor the changes in pest-pathogen dynamics and distribution and on the virulence of pests, pathogens and the effectiveness of resistance genes under projected changes in climate and climate variability.

Socioeconomic vulnerability to climate change

First we should clearly state that the effects of climate change in different dryland faming systems have not been fully studied and there is much that we do not know concerning how these communities might be affected. That is why we believe research should be a high priority so that we can get a better idea. However, there are clear indicators that obviously raise vulnerability to a very high level in most dryland systems. These include the following:

- There are high chances that higher temperatures will affect crops and livestock, with negative yield impacts, and which could also increase insect pest incidences.
- The increasing water scarcity will be exacerbated by droughts, and irrigated agriculture can become more vulnerable.
- The weak institutions, inefficient input markets and incomplete financial markets which already exist will further increase the vulnerability; we already know that farmers mostly rely on informal financial markets with a high interest rate, and as their productivity becomes more risky due to climate change we expect that interest rates may go up. Formal financial systems are needed to develop and adopt major innovations to provide financial services to small-scale farmers in dry areas; one such innovation could be proper linkages with micro-finance and insurance schemes.
- There are already estimates of 30–60% farm income losses in some farming systems (Molden 2007).

Potential effects of climate change on dryland agro-biodiversity

Beside the anthropogenic effects caused by over-exploitation, destruction of natural habitats and traditional farming systems and land reclamation, the remaining biodiversity hot spots are threatened with the adverse effects of climate change. The agrobiodiversity of the drylands, mainly of Central, West Asia and North Africa (CWANA) and East Africa which encompass the four major Vavilovian centers of diversity, has a global importance to future agricultural development and food security and in sustaining the livelihoods of poor communities living under harsh environments. CWANA contains the centers of diversity for wheat, barley, lentil, chickpea, several genera of forage legumes and dryland fruit trees, and of small ruminants. ICARDA has undertaken an eco-geographic survey during the period of 1999–2010 to assess and monitor the species richness and populations densities along with various factors of degradation. The results indicated that the remaining agrobiodiversity is under severe threats and the remaining traditional farming systems and biodiversity rich natural habitats are not given adequate management to overcome the combined effects of over-utilization and recurrent droughts observed in recent decades (Amri et al. 2005). More efforts are needed to collect samples of the remaining populations through collecting missions targeting valuable traits such as drought, heat and salinity tolerance. Along with ex situ conservation efforts, in situ approaches are promoted to ensure dynamic conservation of species richness and larger within species diversity through diversification of sustainable intensification of production systems, integrated management of natural resources and management of biodiversity rich areas. In the case of barley, ICARDA holds 26,900 accessions in its genebank most of which are landraces collected from the CWANA region. The progenitor of barley, *Hordeum spontaneum*, is found in dry areas and has been used in crosses to transfer drought tolerance to cultivated barley.

Impacts of population growth, economic development, and technical change on global food production and consumption have been investigated by Schneider et al. (2011) using the Global Biomass Optimization Model (GLOBIOM), a partial equilibrium model of the global agricultural and forest sectors. Four scenarios were run with the model with selected crops (barley included). Results showed that per capita food levels increase in all examined development scenarios with minor impacts on food prices. Global agricultural land increases by up to 14% between 2010 and 2030. Deforestation restrictions strongly affect the price of land and water resources but have few consequences for the global level of food production and food prices. While projected income changes have the highest partial impact on per capita food consumption levels, population growth leads to the highest increase in total food production. The impact of technical change is amplified or mitigated by adaptations of land management intensities.

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2.3 Bean

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The importance of common bean for food and nutrition security

Common bean (*Phaseolus vulgaris* L.) is the most important food grain legume in Latin America, the Caribbean and in Eastern Africa, and in localized areas of West Africa and mid-altitude Asia (Table 2.3.1). Akibode and Maredia (2011) have done a thorough review of the role of several grain legumes, studying their current importance and past and future trends. These authors indicate that many of the poorest countries in the world derive the highest proportion of their total dietary protein from grain legumes (10–20% or more). Countries where common bean is the major legume in the diet (together with an indication of the percentage of protein contributed) include: Burundi (55%), Rwanda (38%), Uganda and Kenya (20%), Haiti (18%), Nicaragua and Cuba (16%), Tanzania (14%), Brazil, Cameroon (12–13%), Guatemala, and Mexico (10–11%). Protein malnutrition continues to be a public health concern, especially in populations subject to high levels of infection (Ghosh et al. 2012). Low lysine content relative to human amino acid balance is the limiting constraint in cereal-dominated diets. Legumes are superior sources of lysine, thus increasing the biological value of the combined protein. The current WHO-endorsed index for protein quality is the protein digestibility-corrected amino acid score (PDCAAS). Experts recommend that foodstuffs of at least 70% PDCAAS score should be consumed (Michaelsen et al. 2009). The PDCAAS values of cereals are around 35%, indicating their low protein quality when consumed in isolation. Grain legume PDCAAS ranges from 45–93% with soybean the highest in quality. By combining cereals with legumes in the proportions of 70:30 by weight, this PDCAAS threshold can usually be reached or exceeded (this will vary across cereal and legume species and depends on the age and health of the consumer) (Ejigui et al. 2007, Michaelsen et al. 2009). These principles would apply in particular to maize-and-bean based diets in Central America and East Africa.

Biological vulnerability to climate change

Bean originated in the temperate mid-altitudes of the American tropics under relatively abundant rainfall, and thus is not inherently well adapted to heat or drought stress. Plant domestication has carried common bean to environments where these stresses are frequent, and thus humankind has driven the crop toward improved adaptation.

Table 2.3.1. Common bean statistics by region

Region	Average production per year ('000 Mt)	Per capita production (kg)	Average area (1000 ha)	Average yield (kg / ha)	Apparent consumption per person (kg)	Quantity (kg / person / year)	Calories (kcal / person / day)	Protein (g / person / day)
Year	2001 /10	2001 /10	2001/ 10	2001/ 10	2001/07	2007	2007	2007
Eastern Africa	2528	9.0	3960	627	8.5	6.7	62.3	4.1
Northern Africa	86	0.0	43	1865	0.8	3.7	34.3	2.3
Middle Africa	552	5.0	964	573	5	0.6	5.4	0.4
Southern Africa	71	1.0	67	1073	2.6	2.3	21.2	1.4
Western Africa	213	1.0	369	576	0.8	0.7	6.5	0.4
Africa (Total)	3453	4	5405	632	3.8	3	27.7	1.8
Caribbean	180	5.1	212	8546	8.8	10.19	94.09	6.03
Central America	1660	11.6	2267	7350	10.9	11.07	105.66	6.05
South America	3833	10.4	4495	8529	9.1	9.18	84.71	5.53
Central Asia	66	1.1	33	19131	0.30	0.14	1.28	0.08
Eastern Asia	2093	1.3	1477	14288	0.56	0.47	4.28	0.27
Southern Asia	3750	2.4	8799	4283	2.27	2.64	24.52	1.55
South-Eastern Asia	3066	5.6	3152	9633	1.52	1.39	12.95	0.83
Western Asia	246	1.4	158	15780	1.47	1.33	12.28	0.76
Eastern Europe	280	1.0	180	15682	0.30	0.33	3.05	0.19
Northern Europe	17	0.1	6	27486	0.32	0.37	3.37	0.21
Southern Europe	153	1.0	93	16389	2.16	2.14	19.76	1.26
Western Europe	12	0	4	28358	0.41	0.39	3.60	0.23
Australia and New Zealand	45	1.8	41	11676	0.79	0.62	5.72	0.37
Melanesia	NA							
Micronesia	NA							
Polynesia	NA							

Source: FAOSTAT

However, the genetic diversity of *P. vulgaris* is not ample with regards to tolerance to extreme climates. In contrast a sister species *P. acutifolius* is well adapted to these stresses and has been crossed with common bean.

In a recent review of the likely effects of climate change on bean production, high temperatures emerged as the most widespread and serious problem, followed by drought (Beebe et al. 2011). Regions where heat tolerance will be necessary include lowland Central America and parts of Central Africa, including southern Democratic Republic of Congo and northern Uganda. Central Brazil, where bean production has extended into the Cerrados, will also suffer significant heat stress. Areas where drought has been endemic will continue to suffer, and some areas will become progressively drier, especially Mexico, Central America and southern Africa. In particular, bean production in the central plateau of Mexico has been marginal for many years, and may become unviable. Regions subject to drier years will likely see more problems of insect pests, such as viral vectors (*Bemisia* white flies) or the bean fly (*Ophiomyia*) in Africa.

Breeding efforts have been quite successful in obtaining tolerance to drought under experimental conditions, with yield advantages over commercial checks of 100% or more (Beebe et al. 2008). However, multiple constraints of drought combined with low soil fertility and possibly heat will likely limit impact on farm. Current efforts are focused on developing cultivars with tolerance to multiple stresses (Beebe et al. 2009; Beebe in press). Experimental data suggests that currently, multiple stress-tolerant breeding lines exists that can produce yields of 1127 kg/ha versus 640 kg/ha with an elite commercial cultivar (Beebe et al. in press). It is the opinion of this author that genetic improvement could increase yields in similar conditions to as much as 1500 kg/ha, while any additional gain would need to come from agronomic management.

Fewer areas will suffer excess rainfall on a regular basis, but beans are quite sensitive to soil pathogens, and some areas where these are already a problem will see more intense disease under even modest increases in rainfall. This is the case in Rwanda and highland Uganda.

While estimates of climate variability are still not reliable, one can foresee that alternating years of heavy rainfall and drought will make a genetic response difficult, if each growing season required a different cultivar. Data on the effects of elevated levels of carbon dioxide are scarce, but some preliminary data suggest that genetic differences exist among bean genotypes for responsiveness to higher CO_2 (Bunce et al. 2008). There are suggestions that this could lead to lower concentration of nutrients in the grain due to dilution of nutrients by starch, but we believe that this effect can be countered by conscious selection on the part of plant breeders.

Socioeconomic vulnerability to climate change

The Generation Challenge Program has developed a database to establish priorities of farming systems based on failed seasons (i.e., drought induced failures), poverty, and child stunting (malnutrition). Fourteen cropping systems emerged as especially vulnerable according to these criteria, within which common bean represents 5% or more of the cropping area in four systems: in Latin America, the maize-bean system; and in Africa, the highland perennial, the root crop and the maize mixed systems (Table 2.3.2).

Apart from drought, heat will affect some of the same regions, as well as the coastal plantation mixed system (with 23% poverty), and the dryland mixed system (34% poverty) that predominates in northeast Brazil, which continues to be a hot spot of poverty and drought where bean is a central component of the cropping system and the diet. As mentioned above, we expect that some areas will suffer from occasional extreme rainfall events and associated bean diseases. The highlands of East Africa, where soil pathogens already take their toll, exhibit extremely high population density with a narrow resource base. These are regions that depend heavily on common beans, and such regions will suffer greatly under climate change if there are no significant interventions.

Table 2.3.2. Farming systems in which common bean represents 5% or more of the cropping area, with respective data on population, poverty and stunting of young children (from gismap.ciat.cgiar.org/egiron/GenerationAtlas/)

FS Code	Farming system	Region	POP-Total	Poor, <$2	% Poor	% Stunt	Total crop ha	Bean ha	% Bean area[1]	Countries
1	Irrigated	LAC	42,879,232	4,883,580	0.11	16.3	4,127,335	435,018	11	Chile, Mexico, Peru, Venezuela
3	Coastal plantation mixed	LAC	122,842,064	28,338,900	0.23	15.4	16,347,448	1,273,425	8	Brazil, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Peru, Puerto Rico, Venezuela
4	Intensive mixed	LAC	78,535,760	12,646,400	0.16	5.4	14,453,159	1,047,364	7	Brazil
6	Maize-beans (Mesoamerica)	LAC	76,105,624	9,277,520	0.12	35.9	8,035,324	970,963	12	Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama
9	High altitude mixed (Central Andes)	LAC	17,154,020	4,121,150	0.24	26.8	1,813,688	162,525	9	Argentina, Bolivia, Chile, Ecuador, Peru
13	Dryland mixed	LAC	25,431,482	8,745,400	0.34	19.3	7,075,572	1,858,458	26	Brazil, Mexico
26	Highland perennial	SSA	43,554,096	36,054,200	0.83	37.4	6,172,495	738,138	12	Burundi, Ethiopia, Kenya, Rwanda, Tanzania, Uganda, D.R. Congo
28	Root crop	SSA	69,509,168	64,518,400	0.93	36.7	10,277,674	481,832	5	Angola, Benin, Burundi, Cameroon, Central African Republic, Ghana, Guinea, Liberia, Mozambique, Nigeria, Sierra Leone, Sudan, Tanzania, D.R. Congo, Zambia
30	Maize mixed	SSA	96,684,288	68,987,696	0.71	41.1	16,430,624	744,630	5	Central African Republic, Ethiopia, Kenya, Malawi, Mozambique, South Africa, Sudan, Swaziland, Tanzania, Uganda, D.R. Congo, Zambia, Zimbabwe
35	Coastal artisanal fishing	SSA	38,571,216	28,982,300	0.75	42.5	2,347,203	129,239	6	Ghana, Liberia, Madagascar, Mozambique, Nigeria, Sierra Leone, Tanzania

[1] Represents area planted to bean as % of total crop area

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2.4 Cassava

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The importance of cassava for food and nutrition security

Cassava (*Manihot esculenta*) is the second most important food crop in the less developed countries and the fourth most important in developing countries, with total production of 218 Mt, of which over half is in Africa and another third in Asia (Table 2.4.1). This perennial species is managed as an annual crop, with a long growing season typically of 8–15 months. It is tolerant to many abiotic and biotic stresses, including low-fertility soils, and can be left unharvested until needed. The short shelf-life requires efficient marketing/fresh consumption or processing.

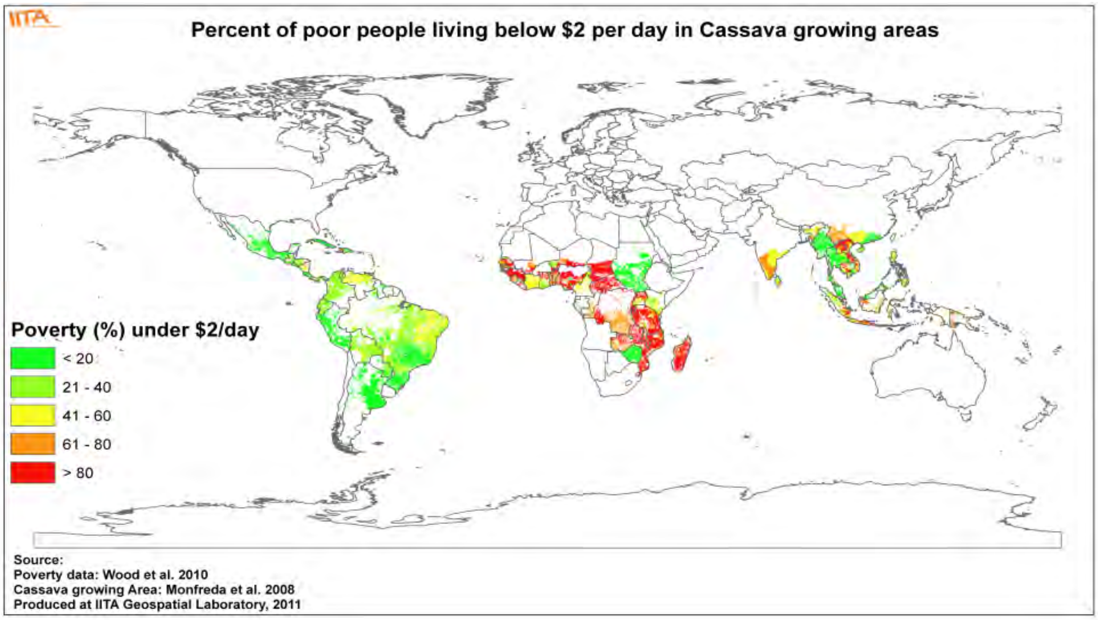
Cassava is mostly grown by smallholders (Figure 2.4.1). Commonly considered to provide only carbohydrates, it also contains significant minerals including micronutrients. High pro-vitamin A cultivars exist and leaves are consumed as a nutritious vegetable in some countries. In Africa most of the crop is destined for human consumption. Cassava in Asia, with the major exceptions of Indonesia and India, is primarily destined for processing for industry, including starch, animal feed and fuel ethanol. As such, it is an important provider of food security through income generation for small landholders. In spite of the high level of centralized processing, most of the cassava farms are a few hectares or less in the region.

Biological vulnerability to climate change

Cassava extends throughout the lowland and mid-altitude tropics, with heaviest concentrations in West Africa, Southeast Asia and Brazil. Across the cassava belt, the general trend will be for hotter and drier, but at the farm level, the main effect that growers will notice is greater frequency of extreme events (wet, dry, hot). For any crop, extreme weather events can be devastating. But cassava has inherent characteristics that buffer against high temperatures and drought.

Once the crop is established, it does not have any particular stage of growth during which it is vulnerable to short hot or dry periods. This contrasts with most cereal or grain legume crops, where flowering is a highly vulnerable stage, and even temporary temperature or water deficit stress can cause severe yield loss or total crop failure. Cassava—the species as a whole—is drought tolerant and adapted to some of the highest temperatures encountered in agricultural areas. These are traits that already exist broadly across the varieties that farmers grow. In addition, drought stress can be further improved through breeding.

Figure 2.4.1. Percentage of people living on less than US$2 per day in cassava-growing areas of the world



Source: Wood et al. 2010 and Monfreda et al. 2008.

On the other hand, cassava is not well-adapted to excess water; it will not tolerate more than several hours of flooding and is highly vulnerable to root rots when exposed to saturated soils for extended periods. The potential to modify this in any significant way is doubtful, though scientists have applied only modest efforts at searching for tolerance to wet soils.

Not only is cassava likely to do comparatively well in its current production areas even as climates change, but it will likely spread into areas where more climate-sensitive crops are pushed out by increasing drought stress and higher temperatures. One such example is in large areas of South Asia. Wheat and rice will see greater difficulty in remaining competitive, and cassava could well move from its current stronghold in southern India, northward into the central region.

Table 2.4.1. Regional distribution of cassava production and consumption

Region	Average production per year ('000 Mt)	Per capita production (kg)	Average area (1000 ha)	Average yield (kg / ha)	Apparent consumption per person (kg)	Quantity (kg / person / year)	Calories (kcal / person / day)	Protein (g / person / day)
Year	2010	2007	2010	2010	2001/07	2007	2007	2007
Eastern Africa	26.2	84.4	3234.7	8094	65.06	63.4	162	1.4
Northern Africa	0.01	0.05	7.8	1730	0.05	0	0	0
Middle Africa	34.3	238.9	3577.3	9597	201.28	201.3	595	3.6
Southern Africa	NA	NA	NA	NA	0.02	0	0	0
Western Africa	60.8	216.8	5050.6	12044	97.64	97.6	245	1.5
Caribbean	1.2	24.05	250.7	4958	18.38	18.4	47	0.2
Central America	0.3	4.1	31.6	10175	1.24	1.2	3	0
South America	31.6	92.9	2396.03	13202	32.32	32.3	80	0.5
Central Asia	NA	NA	NA	NA	NA	NA	NA	NA
Eastern Asia	4.7	2.8	278.5	16821	1.32	1.3	4	0
Southern Asia	8.3	5.2	255.3	32672	4.95	4.9	11	0
South-Eastern Asia	61.6	104.8	3357.7	18391	25.44	25.4	70	0.4
Western Asia	NA	NA	NA	NA	NA	NA	NA	NA
Eastern Europe	NA	NA	NA	NA	NA	NA	NA	NA
Northern Europe	NA	NA	NA	NA	NA	NA	NA	NA
Southern Europe	NA	NA	NA	NA	NA	NA	NA	NA
Western Europe	NA	NA	NA	NA	NA	NA	NA	NA
Australia and New Zealand	NA	0	NA	NA	0.35	0.3	1	0
Melanesia	0.2	8.2	15.6	11361	15.86	15.9	40	0.3
Micronesia	0.01	0	0.8	12625	3.91	3.9	9	NA
Polynesia	0.02	7.6	1.04	15778	7.15	7.2	20	0.1

Source: FAOSTAT

But the fact that cassava is resilient in the face of increasing drought and higher temperatures does not mean that it escapes challenges resulting from climate change. Models show, and experience in the field is beginning to confirm, that the main problems facing cassava as the earth warms up are the changes in the distribution and severity of pests and diseases that will attack the crop. Pests and pathogens may be much more sensitive than the crop itself in response to climate changes. Pests and disease that were once minor problems can turn into major constraints and change their range of distribution with climate change. Recent models illustrated these effects for three major cassava pests: the mealybug, the cassava green mite, and the whitefly (Herrera et al. 2011).

In current production areas, the greater likely challenge of pests and diseases will mean increased focus on integrated management systems, especially host plant resistance and biological control.

Socioeconomic vulnerability to climate change

Farmers know very well how their crops respond to the variations that they confront in their farming systems. They understand the intricacies of selecting crops and management practices that will maximize their chances of success, whether for household food, for animal feeding, for sale in local markets or other. But this traditional knowledge and experience are beginning to prove inadequate as changing climate presents challenges that are different from anything previously confronting agriculture. Farmers will face an ever-increasing set of variables for which they may not have solutions unless the global research and development community accelerates action to provide options and to alleviate the rate of change.

Farmers, and by extension the urban populations that rely so fundamentally on a reliable supply of affordable and nutritious food from farms, will need climate-ready crops and production practices to survive the changes underway. Cassava has some remarkable traits that will allow it to face climate change more successfully than many crops. The principal among these are its high level of tolerance to periodic droughts and its adaptation to high temperatures.

Cassava research will focus on both genetics and management practices to optimize its adaptation to climate change. The focus will be on developing varieties and management systems that (1) allow it to expand into drier areas where other crops are pushed out by lack of drought adaptation; and (2) allow it to thrive in current production areas.

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2.5 Chickpea

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The importance of chickpea for food and nutrition security

Chickpea (*Cicer arietinum* L.), the third most important food legume globally, is vital for the establishment of sustainable and economically viable farming system. Being a crop grown and consumed across five continents in countries such as India, Turkey, Pakistan, Bangladesh, Nepal, Iran, Mexico, Myanmar, Ethiopia, Australia, Spain, Canada, Syria and the USA, chickpea is more important in international markets than other food legumes. According to the Food and Agriculture Organization (FAO, 2010), chickpea is cultivated over an area of 12 Mha with a production of 9.60 Mt and an average productivity of 0.80 t per ha. The major geographical regions of chickpea production are (Table 2.5.1) East Asia (75% of total production) and India (65%). Eight other countries are Pakistan (7.5% of world production), Turkey (7.5%), Iran (3.4%), Mexico (2.8%), Australia (2.4%), Canada (2.0%), Ethiopia (1.8%) and Myanmar (1.7%). Chickpea is a good source of energy, protein, minerals, vitamins, and fibre, and also contains potentially health-beneficial phytochemicals (Wood and Grusak 2007) and high ability to fix atmospheric nitrogen. Chickpea has good nutritional value with few anti-nutritional factors (ANFs) and may play a role in the prevention and treatment of many chronic diseases. There are genetic variations reported for many of the nutrients, however, but little research has been done on the improvement of nutritional aspects of chickpea. There is potential to breed new varieties to enhance and optimize the nutritional value of chickpea through genetic manipulation.

Biological vulnerability to climate change

The cultivation of chickpea on marginal lands with minimum inputs and the adverse effects of diseases, insects and pests, environmental stresses, soil problems, and non-adoption of modern management technologies contribute to low and unstable seed yield. In addition, global warming and change in niches of cultivation may also have implications for the area under cultivation of this crop; for example, greater emphasis on wheat in irrigated areas in northern parts of India has moved chickpea to further marginal lands. There are very limited studies conducted (reviewed by Imtiaz et al. 2011) in chickpea to assess the impact of climate change. It is expected that chickpea will benefit by rises in temperature to a certain extent and the yield is forecasted to be increased by 45–47% under doubled levels of CO_2. However, under temperatures higher than ceiling temperature, future yield loss could be avoided in irrigated conditions through development of heat tolerant chickpea varieties.

Table 2.5.1. Chickpea statistics by region

Region	Average production per year ('000 Mt)	Per capita production (kg)[1]	Area ha	Yield kg/ha	Calories (kcal/ person/ day)[2]	Protein (g/person/ day)[3]
Year	2010	2010	2010	2010	2010	2010
Eastern Africa	303.82	1.004	386290	780	4.509	0.632
Middle Africa						
Northern Africa	95.74	0.473	117922	813	2.125	0.298
Southern Africa	0.00	0.000				
Western Africa	0.17	0.001	345	496	0.003	0.0004
Africa	399.73	0.414	504557	788	1.860	0.261
Northern America	204.23	0.596	162852	1360	2.678	0.376
Central America	168.33	1.135	108936	1538	5.102	0.715
Caribbean	0.00	0.000			0.000	0.000
South America	9.79	0.026	9830	994	0.115	0.016
Americas	382.35	0.421	281618	1406	1.891	0.265
Central Asia	6.89	0.116	8001	999	0.520	0.073
Eastern Asia	8.05	0.005	2340	3459	0.023	0.003
Southern Asia	6576.79	4.056	8565590	763	18.226	2.556
South-Eastern Asia	271.33	0.480	228248	1157	2.155	0.302
Western Asia	728.21	3.911	734614	1015	17.572	2.464
Asia	7591.27	1.909	9538793	792	8.579	1.203
Eastern Europe	25.19	0.085	17278	1460	0.383	0.054
Northern Europe						
Southern Europe	52.55	0.346	64472	870	1.555	0.218
Western Europe	0.00	0.000				
Europe	77.74	0.106	81750	1037	0.477	0.067
Oceania	287.82	11.457	256367	1106	51.476	7.219
World	8738.91	1.322	10663084	816	5.942	0.833

Source: FAOSTAT (FAO, 2010).

[1] Per capita production = Average production per year (kg)/Population (2010).

[2] Calories (kcal/person/day) = 164 Kcal per 100 gr*per capita production (gr)/No. of days per year/100 (per gram).

[3] Protein/g/person/day = 23 gr per 100 gr*per capita production (gr)/No. of days per year/100 (per gram).

Similarly, in the past 10 years survey results in India showed an increased tendency of the minor dry root rot (*Rhizoctonia batatical*) disease becoming an important one on chickpea due to increase in temperature over 35 °C (Pande et al. 2010). The disease is affecting popular Fusarium wilt resistant varieties adopted by farmers. Therefore, there is a need to look for multiple disease resistance to Fusarium wilt and dry root rot to manage the emerging disease problem. The impact of climate change on insect pests of cereal and food legume crops in Central and West Asia and North Africa (CWANA) was revised recently (El-Bouhssini et al. 2011). From published results and field observations, temperature and moisture are playing a critical role in affecting pest dynamics over time and space. Therefore, more research is needed to assess and monitor the changes in pest and pathogen dynamics and distribution and on the virulence of the pests and pathogens and the effectiveness of resistance genes under predicted climate change and variability. Therefore, in the future coordinated efforts are required at the international level to address the production issues, particularly the constraints brought about by abiotic and biotic stresses (drought, heat, cold, salinity, *Ascochyta* blight, *Fusarium* wilt, *Botrytis* grey mold, pod borer) under increasingly variable and changing climates.

Socioeconomic vulnerability to climate change

Due to major emphasis on food security by many national governments, focusing on major cereal and oilseed crops such as wheat, rice and canola, the major challenge for chickpea, as for other legumes, is to increase its competitiveness against these crops. The issues associated with the cultivation of chickpea on marginal lands could be exacerbated by global warming and changes in the climate. This may have implications for smallholder farmers who are the main growers of this crop. Therefore, there is need for a major policy shift at national government level to prioritise legumes for sustainable food and nutritional security purposes and thus increase overall investment in crops such as chickpea to cope with changing climates. This would provide nutritional security to those resource-poor sections of society that rely mainly on such crops for their protein intake. It would also enable researchers to develop climate resilient varieties and production technologies, thereby contributing to the establishment of sustainable production systems in the future.

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2.6 Cowpea

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The importance of cowpea for food and nutrition security

Cowpea (*Vigna unguiculata* [L.] Walp.) is grown mainly for the grains, which are rich in protein. In rural and poor urban communities of sub-Saharan Africa (SSA) cowpea provides protein in peoples' diet, hence it is commonly regarded as a "poor man's meat". In East and southern African countries young fresh cowpea leaves are consumed as vegetables. In addition, the haulm from dry pods, stem and leaves are a good source of feed especially for ruminants such as goats, sheep and cattle. Following an evaluation of several cowpea germplasm lines, Boukar et al. (2011) identified some accessions with up to 32.5% protein, 79.5, 58.0, 1395, 2500, 18450 and 6750 mg per kg of iron, zinc, calcium, magnesium, potassium and phosphorus, respectively. Their study revealed the existence of considerable genetic variability for nutrients content in cowpea grains and so it should be possible to develop, through conventional breeding methods, micronutrient-dense varieties. The production of cowpea is mostly in the dry savannas, where it is grown along with other crops such as millet, sorghum, maize and groundnuts. The dry savanna areas are prone to drought and this could affect the crops adversely even though cowpea is generally more drought tolerant than the other crops. Globally, about 4.5 Mt of grain are produced annually on over 9.5 Mha. Africa produces and consumes about 84% of the world's cowpea crop, and 85% of this is produced by Nigeria, the highest producer and consumer. Cowpea grain yield is lowest in SSA at about 0.4 t per ha although potential yield could be as high as 2.0 t per ha. Since the 1990s, trends in production, yield and land area put to cowpea indicate only marginal increases and a deficit in the amount of available grain by 2020 has been predicted should these trends persist.

Biological vulnerability to climate change

Cowpea is a crop that generally thrives under hot, moist conditions but tolerates drought and low soil fertility, when compared with other crops. Since cowpea utilizes the C_3 photosynthetic pathway, the crop potentially should exhibit increases in photosynthesis with increases in carbon dioxide [CO_2]. According to Hall (2011), the extent to which plants with

C_3 photosynthesize are adapted either to the current CO_2 concentration of about 380 µmol mol^{-1} or to levels of atmospheric CO_2 concentration in the future is not known.

Table 2.6.1. Cowpea statistics by region

Region	Average Area Harvested per year (1000 ha)	Average Production per year (1000 t)	Average Yield per year (kg/ha)	Quantity (kg/ person/ year)	Calories (kcal/ person/ day)	Protein (g/person /day)
Year	2001-2010	2001-2010	2001-2010			
World (Total)	10,154.69	4,665.13	458.77	0.713	7.072	0.430
Africa (Total)	9,923.67	4,407.91	443.45	4.773	47.369	2.877
Eastern Africa	463.13	270.85	584.54	0.934	9.268	0.563
Middle Africa	232.55	164.91	708.23	1.465	14.540	0.883
Northern Africa	86.67	26.56	584.85	0.137	1.359	0.083
Southern Africa	11.00	6.27	570.86	0.114	1.129	0.069
Western Africa	9,130.32	3,939.32	430.99	14.493	143.840	8.736
Americas (Total)	69.16	76.75	1,093.17	0.086	0.855	0.052
Northern America	9.30	23.50	2,031.35	0.071	0.705	0.043
Caribbean	41.88	30.12	719.07	0.748	7.420	0.451
South America	17.98	23.14	1,267.74	0.062	0.615	0.037
Asia (Total)	153.54	154.34	1,002.93	0.039	0.386	0.023
Southern Asia	11.32	11.15	986.27	0.007	0.069	0.004
South-Eastern Asia	141.47	142.52	1,005.01	0.253	2.513	0.153
Western Asia	0.75	0.67	894.37	0.003	0.032	0.002
Europe (Total)	8.32	26.13	3,136.65	0.036	0.354	0.022
Eastern Europe	0.01	0.01	942.68	0.000	0.000	0.000
Southern Europe	8.31	26.12	3,137.89	0.173	1.720	0.104

Source: FAOSTAT, 2012

He also proposed likely detrimental effects of high night temperatures on reproductive development including the interactive effects of photoperiod on the extent of heat stress effects in subtropical compared with tropical zones. Since 1968, droughts have occurred in many years in the drier parts of the semiarid Sahelian zone of Africa. The droughts were so severe that virtually all cowpea landraces that had evolved over hundreds of years in the Sahel could not produce significant quantities of grain in those years. From predictions based on modelling, these parts of the globe are most likely to experience adverse effects of climate change (Hall 2004). Recent droughts in the Sahel have resulted in the growing seasons being considerably shorter than they used to be in the 50 years prior to 1968. Consequently, the first set of cultivars bred had very short cycles from sowing to maturity (Hall 2004). Crops are sown usually at the beginning of the rainy season in early to mid July in the Sahel zone. However, since the 1970s the rainy season has often short with total annual rainfall only able to partially support a crop-growing season of about two months in most years. For example, average annual rainfall at Louga, Senegal from 1970 through 1998 was only 267 mm (Hall et al. 2003). In the Sahelian region, there are long dry seasons of 9 to 10 months with little available moisture in the soil. Evaporative demand is estimated to be 6 mm per day during the cropping season at Louga (Hall et al. 2003). Most of the productive landraces, which mature in more than 100 days, could definitely not receive adequate quantity of water to produce maximum grain yields. Water balance estimates indicate that a cowpea landrace 58-57 that begins flowering at about 45 days from sowing and takes about 80 days from sowing to maturity requires 460 mm of water to achieve maximum grain yields (Hall and Patel 1987). However, Hall et al. (2003) reported that in the 34 years from 1968 to 2001 there were 25 years with less than 344 mm rainfall at Louga. Low rainfall coupled with limited moisture in the soil at the beginning of the season and high evaporative demands have thus resulted in traditional cowpea landraces experiencing extreme droughts in most years from 1968 through 2001. Some landraces may have been lost because they could produce neither flowers nor seeds before the onset of drought.

Craufurd et al. (1996) tested 29 diverse genotypes of cowpea under 30 photothermal environments in Nigeria and Niger with mean temperatures ranging from 19° to 30°C, photoperiods from 10 to 16 h per day, and saturation deficits from 0.5 to 3.1 kPa. They found that 12 of these genotypes were insensitive to photoperiod and their time of flowering showed a similar response to temperature. Time to flowering was also delayed by mean pre-flowering saturation deficits greater than 1.5 kPa. High night-time temperatures during floral development induce male sterility in cowpea. Faisal et al. (1992) found that floral development was normal under a night-time temperature of 20 °C, whereas flowers developed under high night-time temperature of 30 °C set no pods due to low pollen viability and anther indehiscence. Anthers developed under a regime of 33 / 30 °C day-time / night-time temperatures did not exhibit endothecial formation, whereas anthers developed under a regime of 33 / 20 °C day-time / night-time temperatures exhibited normal development of the endothecial layer. In another set of studies conducted with cowpea plants subjected to higher night temperatures during flowering using enclosures in field conditions (Nielsen and Hall 1985a, 1985b), and with almost isogenic pairs of heat-resistant and heat-susceptible lines grown in field environments with contrasting temperatures (Ismail and Hall 1998), increases in night temperature caused 4–14% decreases in both pod set and grain yield for every 1 °C above a threshold of 16 °C (Hall 2004). The main mechanism for these effects on cowpea is that high temperatures occurring in the late night during flowering cause pollen sterility and indehiscence of anthers, resulting in grain yield losses (Hall 2004).

Ntare (1992) has shown that significant differences exist among cowpea cultivars in their ability to flower and set pods under high temperature regimes. The patterns of flowering and pod set showed that flowers formed in the first 10 days after initial flowering resulted in the highest percentage pod set. Potential pod set per plant ranged from 5 to 81%. Ntare (1992) found that there was considerable variation among cultivars in the duration of the reproductive period, crop growth rate and partitioning. Crop growth rate was largely responsible for differences in grain yield among cultivars. Van Duivenboden et al. (2002) reported that groundnut production in Niger dropped from about 312,000 t in the mid-1960s (about 68% exported) to as low as 13,000 t in 1988 and increased again to 110,000 t in 2000, while cowpea showed a different tendency, going from 4,000 t in the mid-1950s to a maximum of 775,000 t in 1997, and its cultivated area is still increasing. In the model used they predicted that in 2025, production of groundnut in Niger is estimated to be between 11 and 25% lower, while cowpea yield will fall 30% at most.

Cowpea wild relatives play an important role as source of genetic diversity for cowpea improvement programs. However, the survival of some of these wild plant species could be threatened because of climate change. Jarvis et al. (2008) used current and projected future climate data for 2055, and a climate envelope species distribution model to predict the impact of climate change on the wild relatives of peanut (*Arachis*), potato (*Solanum*) and cowpea (*Vigna*). They found that climate change strongly affects all taxa, with an estimated 16–22% (depending on migration scenario) of these species predicted to go extinct and most species losing over 50% of their range size. Moreover, for many species, the suitable areas will become highly fragmented. Wild cowpea was the least affected in terms of species extinction. It is projected that *Vigna* would lose between 0 and 2 of the 48 species under unlimited and no migration scenarios respectively. According to these authors, the mean range size was predicted to decrease by 65% (no migration) or increase 8% (unlimited migration), with 8–41 of the 48 *Vigna* species losing more than 50% of their current geographic range. The number of *Vigna* patches would increase by 12–115%, while the size of those patches would shrink by 51–59%. They concluded their paper by pointing out the need to urgently identify and effectively conserve crop wild relatives that are at risk from climate change.

Socioeconomic vulnerability to climate change

With the climatic changes occurring in different regions, farmers are trying to adapt by shifting to alternative cultivars or even crops that are more tolerant of new, harsher environmental conditions. In Niger, van Duivenboden et al. (2002) have reported a decrease in groundnut cultivation from 1960 to 2000 while cowpea cultivation was increasing during the same period of time. A similar situation is being observed in Far North Cameroon where both the length of rainy season period and the quantity of rainfall have been declining in the last 30 years. As a consequence of this situation, farmers particularly in the Sahelian zones are shifting from cotton cultivation to more millet and cowpea cultivation. Cowpea in this region is being considered more and more as a cash crop than a food crop. Alene and Manyong (2006) found that adopters of improved cowpea varieties characterized by early maturity, Striga resistance and drought tolerance, were more food-secure than non-adopters in northern Nigeria in the Sahel and Soudano Savanna agro-ecologies. The impacts of climatic change are more severe on agriculture in these zones. These authors reported that supply of improved seeds and access to markets and extension services are important factors conditioning the rate of adoption. The study revealed the contributions of improved cowpea varieties to food security in northern Nigeria.

Inaizumi et al. (1999) studied the patterns, levels, rate of adoption, and impact of one promising dual-purpose cowpea variety (IT89KD-288) in these same agro-ecologies. Because of the cowpea variety's adaptation to drought prone-area and substantial production of both grain and fodder, the diffusion and uptake of this variety had been very impressive as it reached over 1500 farmers in 1997, only four years after one farmer took away the seed. These authors reported that farmers derived substantial benefits from adopting dry-season dual-purpose cowpea production. These include food security during a critical period of the year, cash income in periods when the prices of cowpea grain peak, crop diversification, fodder, and in-situ grazing after harvesting, and when good quality fodder is scarce. They concluded that growing dual-purpose cowpea in the dry season is thus a profitable venture that farmers will find economically beneficial. In addition, this agro-ecology is a niche for mixed crop-livestock farming systems in the semiarid zones of West and central Africa.

During periods of severe drought in the Sahelian zone of West Africa, it is usually observed that farmers, particularly the young men, leave the villages to move to the big cities or to the wetter parts in the southern regions of West Africa. This movement of young farmers affects labour availability for cowpea production. The main consequence of this reduction in the number of workers in cowpea fields is a reduction in cowpea production, which leads to reduction in both food and income of households.

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2.7 Faba bean

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The importance of faba bean for food and nutrition security

Faba bean is one of the major cool season food legumes. It is distributed worldwide in different ecosystems (Table 2.7.1). In the Central and West Asia and North Africa (CWANA) region, faba bean is cultivated in Mediterranean areas with 300 mm or more of annual rainfall in rotation with wheat. Faba bean is the main source of protein in the daily diet in developing countries where it is grown, particularly Ethiopia, Sudan, Morocco, Egypt, and Syria. In China there are two major production areas, one sown in winter (mainly in the southern province of Yunnan) and the other sown in spring (inner highlands stretching from Mongolia to Tibet). Faba bean is grown in northern India (Bihar, Uttar Pradesh, Madhya Pradesh, Chhattisgarh, Jharkhand, Orissa, West Bengal). In Latin America it is mainly grown in Argentina and Chile. Cultivated faba bean is used as human food in developing countries, and as animal feed (mainly for pigs, horses, poultry and pigeons) in developed countries and in North Africa. In addition to boiled grains, the green seeds and pods are consumed as a dried or canned vegetable. It is a staple breakfast food in the Middle East, Mediterranean region, China and Ethiopia (Bond et al. 1985).

Faba bean has up to 37% protein in dry seeds (Duc et al. 1999). Gains in the production of faba bean will thus affect plant protein produced for consumers. In addition, increasing the seed protein will not affect yield potential in faba bean (Link 2006). Faba bean can thus contribute to reducing malnutrition especially for the more needy consumers in developing countries where the main source of protein in the daily diet comes from such crops, whereas in emerging and more developed countries livestock products are the main source of protein.

Faba bean as a legume is an important crop in cereal rotation as it can fix nitrogen and can break cereal disease cycles. Its ability to fix nitrogen is superior when compared with other legumes and therefore more fertilizer costs can be saved. The faba bean can also be used as a green manure.

Table 2.7.1. Faba bean statistics by region

Region	Average production per year ('000 Mt)	Per capita production (kg)	Area ha	Yield kg/ha	Calories (kcal/person /day)	Protein (g/person /day)
Year	2010	2010	2010	2010	2010	2010
Eastern Africa	550.31	1.818	466732	1179	16.984	1.295
Middle Africa	0.29	0.002	222	1322	0.023	0.002
Northern Africa	646.65	3.195	410898	1575	29.845	2.276
Southern Africa						
Western Africa	1.78	0.006	976	1829	0.058	0.004
Africa	1199.03	1.242	878827	1366	11.601	0.885
Northern America	11.39	0.033	5614	2040	0.310	0.024
Central America	39.12	0.264	41316	950	2.465	0.188
Caribbean	10.34	0.285	7968	1317	2.665	0.203
South America	126.54	0.332	128006	987	3.099	0.236
Americas	183.96	0.202	181220	1014	1.891	0.144
Central Asia	7.36	0.124	3020	2534	1.155	0.088
Eastern Asia	1849.90	1.199	1039998	1796	11.202	0.854
Southern Asia	5.53	0.003	7800	709	0.032	0.002
South-Eastern Asia					0.000	0.000
Western Asia	94.46	0.507	43089	2202	4.740	0.361
Asia	1957.25	0.492	1093907	1806	4.599	0.351
Eastern Europe	38.85	0.131	25642	1502	1.228	0.094
Northern Europe	104.36	1.069	31824	3365	9.983	0.761
Southern Europe	146.19	0.963	111288	1328	8.996	0.686
Western Europe	393.50	2.094	100907	3977	19.564	1.492
Europe	682.89	0.932	269660	2554	8.706	0.664
Australia and New Zealand	212.81	8.471	163191	1321	79.140	6.034
World	4235.94	0.641	2586805	1640	5.989	0.457

Source: FAOSTAT (2010)

Per capita production = Average production per year (kg)/Population (2010).

Calories (kcal/person/day) = 341 Kcal per 100 g*per capita production (g)/No. of days per year/100 (per g).

Protein/g/person/day = 26 g per 100 gr*per capita production (g)/No. of days per year/100 (per g).

Biological vulnerability to climate change

Faba bean is grown in fragile agro-ecosystems in non-tropical dry areas where drought and temperature extremes are common occurrences with varying intensity and frequency. These stresses are predicted to rise further in intensity, frequency and uncertainty under climate change with cascading effects on faba production unless the crop is manipulated genetically to adapt to the production environment and/or the latter is manipulated agronomically to suit the crop requirement. In these regions the crop is indispensable for agricultural production as it plays an important role in system sustainability by fixing atmospheric nitrogen in association with *Rhizobium* bacteria and invigorating other beneficial soil microbial activities. Faba bean is thus an important crop in cereal rotations and in mixed cropping and intercropping systems, as it can fix nitrogen (from 178–251 kg per ha per year) and can break cereal disease and weed cycles.

Faba bean, as for other legumes crops, is severely affected by heat and drought in dry areas. Global climate models predict that climate change will most likely have both positive and negative impacts on these crops. Some of the benefits, such as increased water use efficiency, photosynthesis and yield, and decreased stomatal conductance, have been reported in faba bean. Among the negative effects, there is likelihood of change in the pest spectrum, new pests and races gaining ground in areas where their existence has never before been reported as is the case of *Orobanche* in Ethiopia and *Bruchid* infestation in China.

On the other hand, faba bean is reputed to be sensitive to drought (Amede and Schubert 2003) and grows well in environments with more than 450 mm of rainfall. Drought can cause drastic crop failure, and new germplasm adapted to drought will need to be developed. Heat stress, even for a few days during flowering and pod filling stages, drastically reduces seed yield (Siddique et al. 2002) because of damage to reproductive organs, accelerated rate of plant development and shortened period of growth of reproductive organs.

Socioeconomic vulnerability to climate change

In many developing countries, national governments subsidize crops such as wheat, rice and potato as well as nitrogenous fertilizer, tending to favour monocropping of these crops against faba bean and other legume crop. The major challenge for faba bean is to increase its competitiveness against these crops. The cultivation of faba bean by smallholder farmers without inputs and in view of the adverse effects of diseases, insects and pests, environmental stresses, and soil problems, are all contributing to low and unstable seed yield, which could be further exacerbated by global warming and other climatic changes. This may well have implications for the smallholder farmers who are the main growers of this crop. There is a need for major policy shifts at national government level to prioritise faba bean and other legumes as crops that can contribute substantially to sustainable food and nutritional security, and also to increase the overall investment in faba bean research to cope with changing climates. This would help to provide nutritional security to poorer sections of society relying mainly on such crops for their protein intake. It would also enable researchers to develop climate-resilient varieties, seed maintenance technology and production technologies, all of which could contribute to the establishment of sustainable production systems.

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2.8 Fisheries and Aquaculture

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The importance of fish for food and nutritional security

Fish and other aquatic products provide at least 20% of protein intake for a third of the world's population, and the dependence is highest in developing countries (Béné et al. 2007). Small-scale fisheries are by far the most important for food security. They supply more than half of the protein and minerals for over 400 million people in the poorest countries of Africa and South Asia. Furthermore, fisheries and aquaculture directly employ over 36 million people worldwide, 98% of them in developing countries. They also indirectly support nearly half a billion people as dependents or in ancillary occupations (Richardson et al. 2011).

The data in Table 2.8.1 were obtained from FAOSTAT and also the standalone software FISHSTATJ. For calculating average production per year 2001–2009 the data were separated into fish and shellfish from capture fisheries and aquaculture. In terms of absolute capture production, Eastern Asia (that is, China, Korea and Japan) is the most important region at approximately 19 Mt while the developed countries of Northern Europe (such as Iceland, Norway, UK, Denmark, Ireland, Sweden and Finland), which catch approximately 6 Mt, have by far the highest per capita production at approximately 177 kg per person. When considering fish production by aquaculture, Eastern Asia (that is, China, Korea and Japan) is again the most important region producing around 38 Mt of fish and shellfish at a rate of about 23 kg per capita (see Table 2.8.1).

Standard food supply statistics for both capture and aquaculture fish and shellfish products by region and economic status are also shown in Table 2.8.1. It is clear from these data that, in general, fish comprise a fairly small component of total calories of food needed by people around the globe. If one assumes people need on average between 2500 and 3500 kcal per day, then fish is most important in Micronesia and Polynesia (140 and 97.5 kcal/person/day, respectively).

Despite the relatively small contribution by fish to the calories people need, it is an extremely important source of protein and oils in many (particularly least developed) countries/regions. To illustrate this point, data are also included in Table 2.8.1 to demonstrate the importance of fish for protein supply by region. Fish protein constitutes around 30% of the Micronesian diet and 15% of the Polynesian diet. Obviously these regional averages will tend to 'hide' specific localities within regions (and countries) where fish protein is a far more important constituent (Bell et al. 2009).

We should bear in mind that the data summarized in Table 2.8.1 are crude averages, which are often only partially informative. Mills et al. (2011), for example, concluded that inadequate reporting in official statistics of the small-scale fishing sector in developing countries probably leads to underestimates of global marine catches by about 10% and freshwater catches by about 80%. Mills et al. (2011) further point out that, even with a 10% correction, marine catches might still be underestimated, and for some freshwater fisheries underestimates are much greater than the 80% average value.

The importance, therefore, of sustaining wild capture fisheries to secure ongoing supplies of fish to poor consumers cannot be over emphasized. The fact is that the countries that depend most on fish for food rely primarily on catches from the wild. Although aquaculture continues to grow, there is no immediate prospect that it can replace these supplies. As Garcia and Rosenberg (2010) state: "The potential for sustaining catches, food output and value at or near current levels, and supporting the nutrition and livelihoods of many hundreds of millions of dependent people, will rest critically on managing fisheries more responsibly."

Biological vulnerability to climate change

It is clear that the vulnerability of aquatic food production to climate change is context-specific depending on both the temporal and spatial scales being considered. In some instances climate change will have positive effects on food security, in others negative. Nearly all food production for humans depends ultimately on primary production fuelled by the sun (photosynthesis). On 'first principles' an aquatic scientist might assume that increasing global temperatures will lead to increased vertical stratification and water column stability. Since any water column 'structure' reduces nutrient availability to the euphotic zone, primary (Behrenfeld et al. 2006, Behrenfeld and Falkowski 1997), and subsequently, secondary (Roemmich and McGowan 1995) production will fall. Reductions in global ocean primary production have indeed been noted over recent decades but some models suggest that a small increase can be expected over this century with very large regional differences

(Schmittner 2005). Changes in the dominant phytoplankton groups are certain (Reid et al. 2003, Edwards et al. 2001). Deep tropical lakes, in particular, are likely to see reduced algal abundance and declines in productivity.

In South America climate change will alter the dynamics of coastal upwelling, which sustains huge catches of anchovies, sardines and other varieties of small, pelagic fish. It has been demonstrated that changes induced by the warming effects of El Niño can cause a decline in Peruvian anchovy populations (Keefer et al. 1998).

The literature, however, also has numerous examples of increased productivity due to elevated temperatures. Some high-altitude lakes, for example, have seen increased algal abundance and productivity due to reduced ice cover, warmer water temperatures, and longer growing seasons. Similarly, increasing intensities of monsoon winds caused by higher seawater surface temperatures have led to increased nutrient supplies and upsurges in marine phyto-planktonic biomass in the Arabian Sea (Goes et al. 2005). Factors relating to ice cover can also impact aquatic productivity.

It is certain that the bio-geographic ranges of all aquatic (and terrestrial) species will be strongly impacted by rising global temperatures (Beaugrand et al. 2000, Perry et al. 2005, Beare et al. 2002). Populations at the poleward extent of their ranges will increase in abundance with warmer temperatures (Beare et al. 2002, 2004a, 2004b, 2005; Rijnsdorp et al. 2009), whereas populations in more equatorward parts of their range will decline in abundance as environments warm (Harley et al. 2006). General seasonal life cycle patterns in aquatic biota (for example, spawning, plankton blooms, growing season, and migrations) have been reviewed (Southward et al. 2004) and the changes noted have all been in the direction expected from regional changes in the climate (Edwards and Richardson 2004, Post and Stenseth 1999, Mackas et al. 1998). Differential responses between plankton components (some responding to temperature change and others to light intensity) suggest also that marine and freshwater trophodynamics are being, and can be, altered by ocean warming via simple predator-prey mismatches (Cushing 1990, Gotceitas et al. 1996, Durant et al. 2007, Hipfner 2008).

Table 2.8.1. Fisheries and aquaculture statistics by region

	Global Capture Fisheries		**Global Aquaculture**		**Food supply from fish (both capture and aquaculture)**				**Protein supply from fish (both capture and aquaculture) by region**		
Region	Average production per year ('000t)	Per capita production (kg)	Average production per year ('000t)	Per capita production (kg)	Apparent consumption per person (kg)	Average quantity (kg/person/year)	Calories (kcal/person/day)	Protein (g/person/day)	Fish and shellfish protein (g/person/day)	Other protein (g/person/day)	% fish protein in food supply
Year	2001/2009	2001/2009	2001/2009	2001/2009	2001/2007	2007	2007	2007	2007	2007	2007
Eastern Africa	1040	3.6	52	0.2	3.7	9.4	19.2	2.6	2.6	54.5	4.8
Middle Africa	504	4.5	1	0	9.2	15	27.9	4.1	4.1	53	7.8
Northern Africa	1682	8.9	541	2.8	9.4	8.8	17.4	2	2	86	2.3
Southern Africa	1251	22.9	6	0.1	7.6	6	11.4	1.4	1.4	68	2.1
Western Africa	2053	8.2	78	0.3	12.2	12.2	24.1	3.4	3.4	60.2	5.7
Caribbean	128	3.2	37	0.9	8.9	26.2	48.5	7.2	7.2	75.9	9.5
Central America	1824	12.6	216	1.5	9	7	13.6	1.8	1.8	71	2.5
Northern America	6070	18.1	677	2	23.5	28.3	42.3	6	6	98.7	6.1
South America	14632	39.5	1261	3.4	8.5	11.6	23.2	3	3	71.9	4.2
Central Asia	51	0.9	4	0.1	1.3	1.4	3.6	0	0	80.2	0
Eastern Asia	19279	12.7	38765	25.5	29.2	29.8	61.8	8.6	8.6	79.4	10.8
South-Eastern Asia	15102	27.2	7722	13.8	26.5	26.4	49.1	7.5	7.5	64.5	11.6
Southern Asia	6116	3.8	3947	2.5	5.5	32.1	67.4	9.9	9.9	68.1	14.5
Western Asia	1123	5.3	175	0.8	6	8.6	15.9	2	2	85	2.4
Eastern Europe	3817	12.8	223	0.8	13.7	10.8	24.8	3	3	88.7	3.4
Northern Europe	6369	177.6	825	22.9	30.5	34.1	72	10.1	10.1	107.9	9.4
Southern Europe	1548	10.8	582	4.1	29.5	20.8	39	5.6	5.6	97.2	5.8
Western Europe	1368	7.4	355	1.9	21.9	20.7	44.4	5.3	5.3	104.7	5
Australia and New Zealand	728	29.9	146	5.9	24.2	25	40	6	6	101.5	5.9
Melanesia	399	50.2	2	0.3	7.3	28.8	62	8.2	8.2	69.8	11.8
Micronesia	80	149	4	8.5	12.8	74	140	21	21	73	28.8
Polynesia	39	60.3	2	3.1	32.7	46.5	97.5	13	13	89	14.6

Source: FAOSTAT

Coral reefs are among the world's most biologically diverse ecosystems but are especially vulnerable to three aspects of climate change: (1) ocean-acidification, (2) rising temperatures and (3) rising sea-water levels. From the aspect of food security, coral reefs are extremely important since they support important fisheries close to many human communities particularly dependent on coral reef fish for food (Jones et al. 2004). Increased levels of CO_2 in the atmosphere have already caused large falls in ocean pH (increased acidity) which can affect shell and/or skeleton growth in corals (Hughes et al. 2003) but also many others (Kleypas et al. 1999, Zondervan et al. 2001). The potential ability of fish (and marine biota in general) to adapt to increasing levels of ocean acidity (Le Quesne and Pinnegar 2011) is not known but many cope continually with large, natural (seasonal) fluctuations in pH (Provoost et al. 2010). The fact that coral reefs, however, may be particularly vulnerable to ocean acidity is a serious concern for food security due the relative importance of reef fisheries in the most vulnerable countries. Corals are also susceptible to abrupt increases in water temperatures, which cause their symbiotic algae to leave, resulting in the phenomenon of coral bleaching. When bleached corals do not recover, algae can grow over them transforming the ecosystem. Bleaching usually occurs when temperatures exceed a threshold of about 0.8 to 1 °C above mean summer maximum levels for at least four weeks (Hoegh-Guldberg et al. 2007, Hughes et al. 2003). Many reef-building corals live very close to their upper thermal tolerances and are thus extremely vulnerable to warming (Hughes et al. 2003). Numerous cases of coral bleaching due to recent warming have been reported (Hoegh-Guldberg 1999, Hoegh-Guldberg et al. 2007, Sheppard et al. 2003). As mentioned above for fish, one of the most obvious expected consequences of rising temperatures will be a poleward shift in species distributions. Many corals, however, are not expected to be able to keep pace with predicted rates of sea level rise (Knowlton 2001).

Furthermore aquatic biota may be vulnerable to changes in other aquatic chemical properties including dissolved oxygen and other inorganic nutrients. It is known that the oxygen concentrations in the 'ventilated thermocline' have been decreasing in most ocean basins since 1970 (Emerson et al. 2004) although it is not clear what impact such changes will have on marine productivity and fisheries.

On a global scale, it has also been noted that outbreaks of disease have increased over the last three decades in many marine groups including corals, echinoderms, mammals, molluscs and turtles (Ward and Lafferty 2004). Causes remain uncertain, although temperature is one factor that has been implicated. Previously unseen diseases have also emerged in new areas through shifts in distribution of hosts or pathogens, many of which are in response to climate change (Harvell et al. 1999).

As far as impacts of climate change on aquaculture are concerned the Third Assessment Report of the IPCC (IPCC 2001) identified the following potential negative impacts:

1. Stress due to increased temperature and oxygen demands;
2. Uncertain supplies of freshwater;
3. Extreme weather events;
4. Sea level rise;
5. Increased frequency of diseases and toxic events and;
6. Uncertain supplies of fishmeal from capture fisheries.

There may also be additional problems with non-native species invasions, declining oxygen concentrations, and possibly increased blooms of harmful algae (Parry et al. 2007), although these latter are also strongly influenced by non-climate related factors. Local conditions in rearing areas may become unsuitable for many traditional species, which may then need to be moved poleward (Stenevik and Sundby 2007) or to cooler offshore water, or replaced with other species.

Possible positive impacts of climate change on aquaculture include increased food conversion efficiencies and growth rates in warmer waters, increased length of the growing season, and range expansions poleward due to decreases in ice (Parry et al. 2007). If primary production increased in aquaculture areas, it could provide more food for filter-feeding invertebrates (Parry et al. 2007). De Silva and Soto (2009) provide a review of potential impacts of climate change on aquaculture. They note that 50 to 70% of aquaculture occurs between the Tropics of Cancer and Capricorn, particularly in Asia. The highest production is by finfish in freshwater, while the culture of crustaceans is greatest in brackish waters, while that of molluscs is mainly marine. De Silva and Soto (2009) concluded that the impacts of climate change are context specific and difficult to predict. Salinity changes may be particularly important in brackish waters (mainly crustaceans) due to changes in runoff, marine circulation, etc. In temperate regions increases in harmful parasites and other pathogens might occur (for example, Handisyde et al. 2006).

There is limited observational information on climate change impacts on all aquatic (especially marine) ecosystems, compared to what is available on land. For example, only 0.1% of the time series examined in the IPCC reports were marine (Richardson and Poloczanska 2008). Many uncertainties and research gaps remain, in particular the effects of synergistic and cumulative interactions among stressors (such as rising temperatures, fishing and pollution combined), the occurrences and roles of critical thresholds, and the abilities of marine and aquatic organisms to adapt and evolve to the changes (Berteaux et al. 2004, Skelly and Freidenburg 2012).

Socioeconomic vulnerability to climate change

Human activities are especially vulnerable to the direct threats caused by rises in sea level which may completely wipe out some island communities in the next few decades (Pelling and Uitto 2001, Titus and Richman 2001, Lewis 1990). Global average sea level has been rising at an average rate of 1.8 mm per year since 1961 (Douglas 2001, Miller and Douglas 2004, Church et al. 2004), and the rate has accelerated since 1993 to about 3.1 mm per year due to waning mountain glaciers and snow cover, and losses from the ice sheets of Greenland and Antarctica (Bindoff et al. 2007). Specific socio-economic vulnerabilities to climate change and sea level rise exist where the stresses on natural low-lying coastal systems coincide with low human adaptive capacity and/or high exposure and include: deltas, especially Asian megadeltas (such as the Ganges- Brahmaputra in Bangladesh and West Bengal); low-lying coastal urban areas, especially areas prone to natural or human-induced subsidence and tropical storm landfall (such as New Orleans, Shanghai); small islands, especially low-lying atolls, such as the Maldives (Nicholls and Cazenave 2010, Nicholls et al. 2011). Little attention has been paid to the connections between land use and inland fish capture production, such as dry season trade-offs between rice and inland fish production on the floodplains of Bangladesh.

The world's fisheries provide more than 2.6 billion people with at least 20% of their average annual per capita protein intake, according to the United Nation's Food and Agriculture Organization (FAO). Localized studies on the importance of fish for food security have been published. Bell et al. (2009), for example, highlighted the relatively high importance of fisheries to feeding populations in Pacific Island states, while Allison et al. (2007) focused on sub-Saharan Africa. The only globally comprehensive study examining the vulnerability of fishing communities (Allison et al. 2009) suggests that millions of people will face unprecedented hardship in the future. One hundred and thirty two national economies were examined for vulnerability to climate change using environmental, fisheries, dietary and economic factors. Countries most at risk were not necessarily those that will experience the greatest direct environmental impacts on their fisheries. Instead, they are countries where fish are crucial for diet, income and trade yet there is a lack of capacity to adapt to problems caused by climate change (such as loss of coral reef habitats to the bleaching effects of warmer waters). The fisheries in four countries in Africa (Malawi, Guinea, Senegal and Uganda), four Asian (Bangladesh, Cambodia, Pakistan and Yemen), and two from South America (Peru and Colombia) were identified as the most economically vulnerable. Of the 33 countries that were considered highly vulnerable, 19 had already been classified by the United Nations as 'least developed' due to their particularly poor socioeconomic conditions. It was noted that these 'highly vulnerable' countries also produce 20% of the world's fish exports (by value), and these countries should be prioritized for adaptation efforts that will allow them to endure the effects of climate change and maintain or enhance the contribution that fisheries can make to poverty reduction. It is also worth noting that marine fisheries production by northern countries will see most direct climate change impact, but economically those in the tropics and subtropics will suffer most, because fish are so important in their diets and because they have limited capacity to develop other sources of income and food. Uganda, for example, though landlocked, depends greatly on freshwater fish, making it highly vulnerable to climate change impacts. One of the shortcomings of Allison's study is that data on such variables as the social and economic impacts of fisheries at country levels were often lacking and this was particularly evident for subsistence fishing in the Pacific Ocean.

In conclusion it is difficult to improve on the following summary by Cochrane et al. (2009):

"Although resource-dependent communities have adapted to change throughout history, projected climate change poses multiple additional risks to fishery dependent communities that might limit the effectiveness of past adaptive strategies. The FAO Technical Workshop in Rome (2009) concluded that adaptation strategies will require to be context and location specific and to consider impacts both short-term (e.g. increased frequency of severe events) and long-term (e.g. reduced productivity of aquatic ecosystems). All three levels of adaptation (community, national and regional) will clearly require and benefit from stronger capacity building, through raising awareness on climate change impacts on fisheries and aquaculture, promotion of general education and targeted initiatives in and outside the sector. Options to increase resilience and adaptability through improved fisheries and aquaculture management include the adoption as standard practice of adaptive and precautionary management. The ecosystem approaches to fisheries (EAF) and to aquaculture (EAA) should be adopted to increase the resilience of aquatic resources ecosystems, fisheries and aquaculture production systems, and aquatic resource dependent communities. Aquaculture systems, which are less or non-reliant on fishmeal and fish oil inputs (e.g. bivalves and macroalgae), have better scope for expansion than production systems dependent on capture fisheries commodities. Adaptation options also encompass diversification of livelihoods and promotion of aquaculture crop insurance in the face of potentially reduced or more variable yields. In the face of more frequent severe weather events, strategies for reducing vulnerabilities of fishing and fish farming communities have to address measures including: investment and capacity building on improved forecasting; early warning systems; safer harbours and landings; and safety at sea. More generally, adaptation strategies should promote disaster risk management, including disaster preparedness, and integrated coastal area management. National climate change adaptation and food security policies and programmes would need to fully integrate the fisheries and aquaculture sector (and, if non-existent, should be drafted and enacted immediately). This will help ensure that potential climate change impacts will be integrated into broader national development (including infrastructure) planning. Adaptations by other sectors will have impacts on fisheries, in particular inland fisheries and aquaculture (e.g. irrigation infrastructure, dams, fertilizer use runoff), and will require carefully considered trade-offs or compromises. Interactions between food production systems could compound the effects of climate change on fisheries production systems but also offer opportunities. Aquaculture based livelihoods could for example be promoted in the case of salination of deltaic areas leading to loss of agricultural land."

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2.9 Forages

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The importance of forages for food and nutrition security

Worldwide there are about 3.4 billion ha of grazing lands; in addition, a quarter of the world's crop production area is utilized for livestock feeding. This equals two thirds of total agricultural land area. Sustainable intensification through improved grasses and legumes provides an unprecedented opportunity for many smallholders to improve their livelihoods, in particular in vulnerable areas with low soil fertility. In addition to effects at the household level, forages can play a crucial role in enhancing agricultural systems performance and mitigating greenhouse gas emissions.

For native and sown tropical pastures, the regional distribution is shown in Table 2.9.1. Data on the exact area of planted forages are relatively sparse; in Latin America and the Caribbean (LAC), cattle are raised largely on sown pastures, with an estimated 100 million ha of Brachiaria pastures in Brazil alone; in West Africa, cattle typically graze native pastures; cut-and-carry systems are dominant in tropical Asia; and in Eastern, Central and Southern Africa, both grazing native pastures and cut-and-carry systems are common. Monogastrics are fed with a diverse range of materials, particularly by smallholders, where locally produced feed is important. A large part of grazing lands and planted forages is degraded, globally at least 20% (FAO 2009) and up to 50% in Brazil (Cederberg et al. 2009), 60% in Central America (Szott et al. 2000) and up to 73% in dry areas (UNEP 2004).

Table 2.9.1. Regional distribution of native and sown tropical pastures

Region	Average area (1,000 ha)	Share of total land (%)
Year	2007	2007
Developing Asia	832,800	31.5
Sub-Saharan Africa	833,700	35.3
Latin America and the Caribbean	555,100	27.1
Total Developing countries	2,294,800	29.7

Source: FAO (2009)

In terms of food security and poverty impacts, direct impacts of forages are even more difficult to measure as the product is usually a livestock product or improved crop production through positive effects on soil fertility. Forages themselves rank among the highest value crops in many countries and contribute to sustainability of crop-livestock systems. Animal-source foods occupy four of the world's top five agricultural commodities by value or 40% of the global value of agricultural output. Demand for milk, meat and eggs is increasing rapidly in developing countries, especially in the rapidly growing economies: for example, milk by 1.8% annually and meat by 1.7% annually compared to 0.4% for grains, with this trend projected to continue up to 2050 (Delgado et al. 1999, Herrero et al. 2009).

Livestock products provide an important contribution in the diet in terms of energy and in particular protein, that is, 15% of total food energy and 25% of total dietary protein, and have a particular role in nutrition security not only in view of energy and protein but also in essential micronutrients and essential fatty acids which are difficult to obtain from plant based foods alone; at the same time, these micronutrients are often provided simultaneously in combination and are often more readily bioavailable (Murphy and Allen 2003). This has particular implications for child nutrition.

Close to 1 billon poor people are dependent on livestock and aquaculture for their livelihoods (Staal et al. 2008) and much of the feed is from local resources such as native and planted forages, crop residues and by-products.

Biological vulnerability to climate change

Little is known about the impact of climate change on native and sown forages. In view of the huge diversity and adaptation of forages to more marginal environments (Peters et al. 2001, Rao et al. 2011) it is assumed that forages are likely more resilient to climate variability and change either through inherent plant attributes or via the possibility of substituting one forage option with another. The biggest constraint may be increased climate variability with droughts and excess water occurring over different times during the year. As forage grasses or legumes are mostly perennial species it is essential to have options suitable for both drought and waterlogged conditions for extended periods; for tropical forages this could mean adaptation to 4 to 8 months of terminal or intermittent drought and to short times of continuous waterlogging (1 to 3 weeks). It appears that forage options for excess water are more limited, thus requiring increased attention for research (Rao et al. 2011).

Livestock is considered to be one of the main contributors to greenhouse gas (GHG) emissions. It is estimated that 50% of all agricultural sector GHG emissions are from livestock (Steinfeld et al. 2006, Scherr and Sthapit 2009). Large ruminants emit more GHG per kg of meat than monogastrics. Indirect effects include the association of livestock production with land-use changes, though there is debate on the attribution.

On the other hand, improved management of crops and grassland and restoration of degraded land and organic soils offer the greatest opportunity for mitigation of GHG emissions, providing 75% of global biophysical mitigation potential (Smith et al. 2008). Sown forages, through their effects on livestock systems and cropping systems, can contribute to this potential in all of them. Other benefits from improved forages include opportunities for sustainable intensification to reduce methane emissions per unit of livestock product (Herrero et al. 2009) and reduction of nitrous oxide emissions through forage root characteristics to inhibit nitrification in soil (Subbarao et al. 2012). A comprehensive review on the potential of forages to mitigate climate change can be found in Peters et al. (2012).

Socioeconomic vulnerability to climate change

Specific information on the impacts of climate change on forages is sparse; as noted above, impacts are mostly indirect, through effects either on crop production or on livestock production. Improved climate-resilient forages can be seen as a means to mitigate the effects of climate change on socioeconomic vulnerability as they enhance resilience of crop-livestock systems at the field level or though the global effects on mitigating GHG emissions

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2.10 Groundnut

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The importance of groundnut for food and nutrition security

Groundnut (*Arachis hypogaea*) is known by many local names including peanut, earthnut, monkey nut and poor man's nut. Though groundnut is native to South America, it is successfully grown in other parts of the world and became an important oil seed and food crop. From a nutritional point of view, groundnuts are very important in the lives of poor as they are a very rich source of protein (26%) and monounsaturated fat. In addition to protein, groundnuts are a good source of calcium, phosphorus, iron, zinc and boron. While China and India are the leading producers worldwide, millions of smallholder farmers in sub-Saharan Africa (SSA) grow groundnut as a food and cash crop, which accounts for 9 million ha of cultivated farmland (2007 datum). While this area is 40% of the world total, this percentage represents only 25% of the total production due to low yield (950 kg/ha, versus 1.8 t/ha in Asia) (Table 2.10.1).

The SSA and South Asia (SA) regions are characterized by high levels of undernourishment and poverty. Currently there are more undernourished people in both of the two regions than there were 20 years ago (FAOSTAT 2012). The total number of undernourished people in the two regions accounts for approximately 63% of the world total. Estimates from various sources suggest that more than 18 million rural households (about 86 million people) in SSA and more than 6 million households in SA (about 26 million people) grow groundnuts for their use as sources of improved nutrition, for income generation, and for maintaining soil fertility (Abate et al. 2012).

Biological vulnerability to climate change

The main constraints hampering higher yields and quality are intermittent drought due to erratic rainfall patterns and terminal drought during maturation. Yield losses from drought run to millions of dollars each year (Sharma and Lavanya 2002). A drought-related quality issue is pre-harvest contamination of seeds with aflatoxin, a carcinogenic mycotoxin produced primarily by the fungus *Aspergillus flavus*, which consequently shuts out groundnuts from export markets. In addition, major foliar fungus diseases like early leaf spots (ELS) and late leaf spots (LLS) and rust, and virus diseases like rosette, peanut clump and bud necrosis, cause devastating yield losses (50–60% yield losses by ELS–LLS, Waliyar, 1991; Grichar et al. 1998) and as much as 100% by rosette in epidemic years (Yayock et al. 1976, Olorunju et al. 1992).

Table 2.10.1. Groundnut statistics by region

Region	Average production per year ('000 Mt)	Average area (1000 ha)	Average yield (kg/ha)	Food supply quantity (kg/cap/ yr)	Food supply (kcal/cap/ day)	Protein supply quantity (g/cap/day)	Fat supply quantity (g/cap/day)
Year	2001/10	2001/10	2001/ 10	2007	2007	2007	2007
Africa (Total)	9286.3	9698.6	960.6	2.03	30.58	1.3	2.51
-Eastern Africa	1094.5	1685.2	649.5	1.37	20.18	0.86	1.66
-Middle Africa	1379.8	1621.5	851.3	3.25	48.36	2.04	3.95
-Northern Africa	1059.3	1117.4	975	1.11	17.3	0.74	1.42
-Southern Africa	105.8	74.7	1428.3	0.72	11.03	0.48	0.92
-Western Africa	5647	5199.8	1093.8	3.12	47.18	2.01	3.87
Americas (Total)	2917.9	1056.1	2762.1	1.32	21.23	0.97	1.81
-Northern America	1865.4	537.8	3472	2.51	41.55	1.88	3.6
-Central America	237.6	85.9	2780.7	1.11	16.56	0.78	1.35
-Caribbean	46.6	48.7	954.2	0.79	11.9	0.56	0.98
-South America	768.4	383.8	1987.5	0.38	5.67	0.26	0.46
Asia (Total)	24056.3	12498.2	1927.5	1.23	17.1	0.74	1.42
-Central Asia	12.6	6.5	1957.8	0.04	0.64	0.03	0.06
-Eastern Asia	14266.4	4578.8	3130.9	1.74	24.62	1.06	2.04
-Southern Asia	6774.2	6135.7	1100	0.34	4.75	0.2	0.39
-South-Eastern Asia	2861.4	1735.7	1648.1	2.66	35.15	1.51	2.91
-Western Asia	141.6	41.5	3446.4	0.83	12.69	0.55	1.06
Europe (Total)	8.6	10.6	814.6	0.81	12.69	0.58	1.08
-Eastern Europe	6.9	10.1	689	0.71	10.99	0.5	0.95
-Northern Europe	0	0	0	1.39	21.75	0.99	1.85
-Southern Europe	1.7	0.6	3015.7	0.56	8.68	0.4	0.74
-Western Europe	0	0	0	0.89	13.88	0.63	1.16
Oceania (Total)	32.4	16.9	1920.4	1.65	24.45	1.11	2.1
-Australia and New Zealand	27.6	12.1	2256.7	1.69	25.05	1.14	2.16
-Melanesia	4.1	3.5	1187.7	1.43	21.01	0.91	1.75

Source: FAOSTAT, 2012

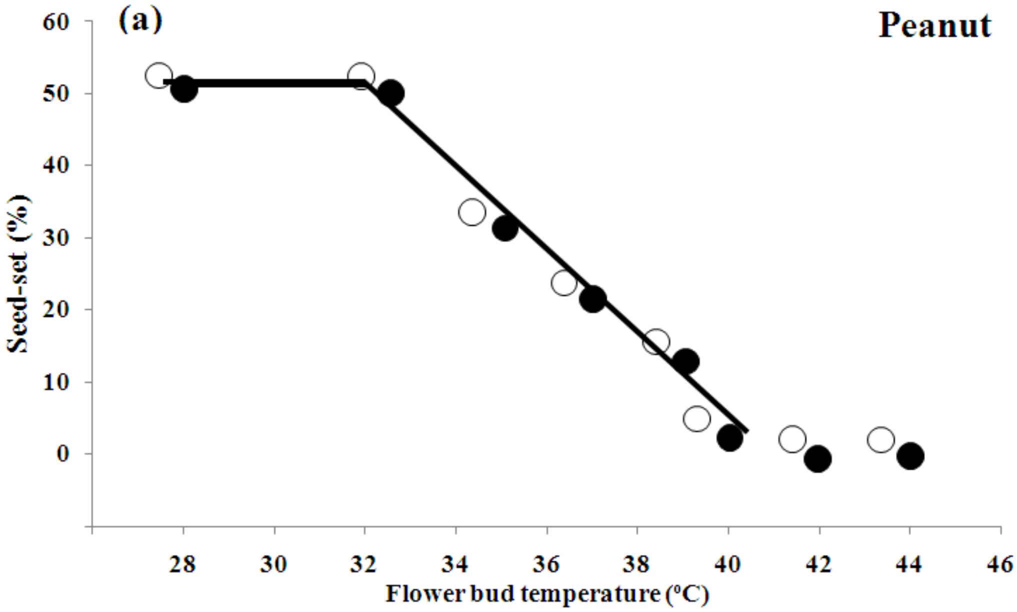
Seed is the costliest input in groundnut cultivation. Low seed multiplication ratio, bulky nature and quick loss of viability are the bottlenecks. It is expected that high temperature and erratic rainfall distribution will still worsen the situation as it poses problems in drying (to desired moisture level) and storage resulting in accelerated loss of viability. Loss of viability of groundnut seed stored at high temperature was reported (Sastry et al. 2007). This can further worsen the variety and seed replacement situation in groundnut, which is already in a dilapidated state in SSA and SA; as a consequence both yields and farmers' income go down.

Many studies have mentioned the impact of different climatic factors stresses at critical stages of groundnut which influences yield. Short-term exposure of high temperature (38/22 °C day/night temperatures) during flowering of groundnut does not affect flower production; however, high temperature reduces the proportion of flowers forming pegs (Prasad et al. 1999a). Lee et al. (1972) indicated that when plants are exposed to high humidity (95% vs. 50%), flower production increases. Increase in temperature from 28 to 48°C reduces pollen production and pollen viability by 3.9% per flower $°C^{-1}$ and 1.9% $°C^{-1}$, respectively (Prasad et al. 1999b). Warmer nights (28 vs. 22°C) reduce mean pollen number from 4389 to 2800 per flower and mean pollen viability from 49 to 40% (Prasad et al. 1999b). It has been reported that the threshold temperature for pollen production and viability is 34°C and a strong negative linear relationship could be observed between both pollen production and viability and accumulated temperature above 34°C (Prasad et al. 1999b). Concentrations of CO_2 or interaction of CO_2 and temperature on the other hand do not show any significant effect on pollen viability (Prasad et al. 2003). Thus, fewer pollen grains and reduced pollen viability due to high temperature stress finally reduce fruit set. High temperature stress during different periods of the day could also affect fruit set. Prasad et al. (2000a) observed that floral bud temperatures above 36°C during the morning and the whole day significantly reduced fruit-set (number of pegs and pods), whereas high afternoon temperature had no effect on fruit set (Figure 2.10.1). Talwar (1997) showed that flower buds of groundnut are sensitive to temperature stress at a stage 3 to 5 days before anthesis, which coincides with microsporogenesis (Xi 1991, Martin et al. 1974).

Cox (1979) reported that temperatures above 26/22°C (24°C mean temperature) reduced the pod weight per plant. Similarly, Ong (1984) observed significant reduction in number of subterranean pegs and pods, seed size and seed yield by 30–50% at temperatures above 25°C.

Pod development takes place inside the soil, hence unfavourable soil temperatures could also affect the development of pods and hence the yield of groundnut. Studies by Dreyer et al. (1981), Ono (1979) and Ono et al. (1974) observed that soil temperature above 33°C reduces mature pods and seed yields.

Figure 2.10.1. Response of seed set to temperature in peanut. Effect of temperature on seed (fruit)-set in peanut



Redrawn from Prasad et al. (2000a)

Groundnut plants produce more dry matter accumulation and higher pod yield in the enriched treatment (1000 µmol mol^{-1} CO_2) as compared to the ambient treatment (340 µmol mol^{-1} CO_2) (Chen and Sung 1990). Prasad et al. (2003) observed that at elevated CO_2 (700 µmol mol^{-1}) increasing temperature from 32/22 to 44/34°C decreases pod yield by 87% and 89% under ambient (350 µmol mol^{-1}). With the same increase in temperature, the seed yield decreases by 88% and 90% at respective concentrations of CO_2. On average, elevated CO_2 (700 µmol mol ^{1}) increases total dry matter yield by 36% and both pod and seed yields by 30% across all the temperature regimes. Elevated CO_2 coupled with well-watered and limited watered conditions also increases pod yields compared to ambient CO_2 with greater benefit in drought conditions. Clifford et al. (1993) observed increase in pod yields by about 25% in well-irrigated plots and 6-fold in drought treatment plots at elevated CO_2 (350 ppm) compared to ambient CO_2 (350 ppm). Total dry matter of four groundnut cultivars (ICGV 86015, 796, ICGV 87282 and 47–

16) was reduced by 20% to 35% at higher temperature (38/22°C) as compared to 28/22°C treatment (Craufurd et al. 2002). Similarly, Prasad et al. (2000b) reported significant reduction of total dry matter production and dry matter partitioning to pods and pod yields at the exposure of groundnut plants to high air (38/22°C) and/or high soil temperature (38/30°C). This reduction of dry matter partitioning to seed at high temperature results in low shelling percentage for groundnut (Craufurd et al. 2002). Studies of Prasad et al. (2003), Ketring (1984) and Talwar et al. (1999) reported similar results. Thus, the results establish significant effect of temperature and CO_2 on dry matter, pod yield and seed yields. The interaction of temperature and CO_2 does not show significant effects in most of the studies.

Socioeconomic vulnerability to climate change

Production of groundnuts, especially in SSA and SA is characterized by poor smallholder farmers depending on crop and livestock production for their livelihoods. Currently, yields of groundnuts are only about 62% (SSA) and 69% (SA) of the world average (FAOSTAT 2010). Since both abiotic and biotic stresses affecting yield are likely to be aggravated by climate change, groundnut farmers in SSA and SA are particularly vulnerable.

Groundnuts, like sorghum, millet and pigeonpea, are typically part of mixed cropping systems in the Semi-Arid Tropics (SAT) and are rarely grown as monocrops over large areas. The exception is perhaps groundnut in southern India, where for example Anantapur District of Andhra Pradesh has more than 900,000 groundnut farmers. Also, data on value by commodity are hard to find in Africa. As such, it is hard to ascribe vulnerability to particular crops.

The SAT contain about 160 million rural poor, of whom 100 million are in India. Poverty is declining in rural India, but not elsewhere. Rural households are predominantly net buyers of food, so any reduction in production and/or increases in price affect them proportionately more, women headed households especially (Walker 2010). In India the sorghum, millet, groundnut and pigeonpea area is now about 30% of the cropped area and accounts for about 20% of the value of production, so the net effects on vulnerability in India as a whole are less than 50 years ago (Walker 2010). However, more than 70% of the value of production of sorghum, groundnut and pigeonpea (2003–04 figures) is in the Indian SAT. In India, agriculture still accounts for about 40% of per capita income in rural areas. In the SAT of West and Central Africa, sorghum, millet and groundnut occupy about 40% of arable land

and in East and Southern Africa between 15 and 20%. Compared to 50 years ago, the reliance on agriculture has declined and non-farm income is far more important, increasing resilience.

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2.11 Lentil

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The importance of lentil for food and nutrition security

Lentil (*Lens culinaris* ssp. *culinaris*) is an integral part of dryland agriculture, mainly because of its ability to thrive comparatively well under water-limiting environments. As a result, the crop, which provides protein-rich food and animal feed, is largely grown under rainfed conditions. Globally, it is cultivated on 3.74 Mha producing 3.40 Mt at an average yield of 915 kg per ha. The major geographical regions of lentil production (see Table 2.11.1) are South Asia and China (44.3%), the Northern Great Plains in North America (41%), West Asia and North Africa (6.7%), sub-Saharan Africa (3.5%) and Australia (2.5%). Lentils play an important role in the food and nutritional security of millions, particularly in Asia. Lentil as an important pulse is part of the staple diet in many developing countries, being variously eaten in different food products and often as a meat substitute, particularly by the poor. Lentil grain is highly digestible and nutritious with high levels of protein, minerals and vitamins. The crop is grown in rotation with cereals in the winter in Mediterranean and sub-tropical regions and as a summer crop in temperate and high elevation areas. Consumption data confirm the importance of lentil in the diet in several developing countries such as Bangladesh, Eritrea, Nepal and Sri Lanka. Lentil grain is a vital source of protein, with a mean of 28.3% ranging from 15.9 to 31.4%, especially for the poor, who cannot afford animal products. Additionally, lentil seed contains high amounts of macro- and micronutrients (Ca, P, K, Fe and Zn), vitamins (Niacin, Vitamin A, Ascorbic Acid and Inositol), fibre and carbohydrates for balanced nutrition. It is also rich in lysine, an essential amino acid, found only at low levels in cereal protein. Cereals and lentil complement each other nutritionally: For instance, cereals are high in sulphur-containing essential amino acids such as methionine, cysteine and tryptophan. Although naturally lentil has most of the nutrients essential for human health and contains good amounts of iron and zinc, recent success of biofortification of lentil varieties with enhanced iron and zinc contents has further added value as a contribution towards alleviating hidden hunger for many people.

Food insecurity currently receives considerable attention, but the lack of nutritional security—access to balanced nourishment—is much less visible and equally devastating to the health and economic development of poor populations. In Nepal where lentil consumption is the predominant pulse and consumption is relatively high, the total protein supply from cereals is 38.1 g per person per day while that from lentil is 3.2 g per person per day (FAOSTAT, 2010), but they are complementary nutritionally. Lentil carbohydrate has a low glycemic index and thus is a good food for diabetics.

Table 2.11.1. Lentil statistics by region

Region	Average production per year ('000 Mt)	Per capita production (kg)	Area ha	Yield kg/ha	Calories (kcal/person/day	Protein (g/person/day
Year	2010	2010	2010	2010	2010	2010
Eastern Africa	77.44	0.256	95171	794	2.474	0.182
Middle Africa	0.00	0.000				
Northern Africa	28.11	0.139	50383	542	1.343	0.099
Southern Africa						
Western Africa						
Africa	105.55	0.109	145554	723	1.057	0.078
Northern America	1125.24	3.283	854316	1263	31.754	2.339
Central America	6.32	0.043	6645	932	0.412	0.030
Caribbean	0.92	0.025	2115	445	0.246	0.018
South America	9.84	0.026	14167	696	0.249	0.018
Americas	1142.32	1.257	877243	1249	12.157	0.895
Central Asia	0.97	0.016	1610	600	0.158	0.012
Eastern Asia	131.60	0.085	78950	1751	0.825	0.061
Southern Asia	1309.45	0.808	1977387	663	7.811	0.575
South-Eastern Asia	1.49	0.003	2584	590	0.026	0.002
Western Asia	624.30	3.353	525174	1179	32.427	2.388
Asia	2067.82	0.520	2585705	799	5.030	0.370
Eastern Europe	10.05	0.034	12042	833	0.329	0.024
Northern Europe	0.00	0.000				
Southern Europe	19.73	0.130	29452	689	1.257	0.093
Western Europe	10.81	0.058	8150	1324	0.557	0.041
Europe	40.60	0.055	49644	827	0.536	0.039
Australia,New Zealand	124.08	4.939	132360	964	47.766	3.518
World	3480.36	0.527	3790506	915	5.094	0.375

Source: FAOSTAT (2010)

Per capita production = Average production per year (kg)/Population (2010).

Calories (kcal/person/day) = 353 Kcal per 100 g*per capita production (g)/No. of days per year/100 (per g).

Protein/g/person/day = 26 g per 100 g*per capita production (g)/No. of days per year/100 (per g)

Biological vulnerability to climate change

Lentil yields are low because of the crop's limited yield potential and vulnerability to an array of stresses that are likely to increase with climate change. Yield limiting factors include lack of seedling vigour, slow leaf area development, low harvest index, lack of lodging resistance, and low or no response to inputs. The major abiotic factors limiting production are low moisture availability and high temperature stress in spring, and, at high elevations, cold temperatures in winter. Mineral imbalances such as boron along with salinity and sodicity problems, though localised, do cause substantial yield loss. Among biotic stresses, rust, vascular wilt and *Ascochyta* blight are the most important fungal diseases. Additional constraints to production include agronomic problems of pod shedding and lodging, and sub-optimal crop management, especially weed control.

Drought and heat stresses are the major yield constraints of lentil in dry areas. These stresses are predicted to rise further in intensity, frequency and uncertainty under climate change with cascading effects on production unless the crop is manipulated genetically to adapt to the production environment and/or the production environment is manipulated agronomically to suit crop requirements. In South Asia the crop is grown exclusively as a post-rainy season crop on residual moisture and so early cessation of rains adversely affects establishment. In spring the crop is faced with a sudden rise in temperature and depleting soil moisture at the grain filling stage, causing forced maturity. In West Asia, spring-planted lentils at higher elevations frequently experience terminal drought and heat stress, whereas the winter-planted crop encounters cold temperatures and frost injuries. Drought often affects the crop concurrently with heat stress with confounding effects on productivity. The individual effects of these two stresses are rather difficult to dissect. Water stress can cause heavy yield losses depending on the crop stage, drought severity, evaporative demand of the atmosphere, and moisture holding capacity of the soil. Heat stress, especially when linked to moisture stress, even for a few days during flowering and pod filling, drastically reduces seed yield in lentil because of damage to reproductive organs, accelerated development and shortened reproductive period. With atmospheric temperatures expected to rise due to climate change, increased incidence of heat stress in lentil may be anticipated. Although no single trait is sufficient to determine yield under water and heat stresses in view of stress heterogeneity and the complexity of yield, several traits have been implicated, among which the outstanding ones are drought escape through early flowering, early growth vigour, and rapid root growth. Several researchers have reported useful genetic variation in response to drought stress under different conditions within the cultivated germplasm. There is clearly scope to select for improved heat and drought stress in lentil.

In relation to elevated carbon dioxide levels, lentil exposed to elevated CO_2 showed an average increase of nodule numbers and improvement in nitrogen and phosphorus uptakes (Nasser et al. 2008).

Global climate change is projected to increase temperature in the upper soil (0–5 cm) by 1.6–3.4 °C by 2100, which is likely to have several effects on soil insects such as *Sitona* spp, root weevils that are important in lentil production in West Asia. Higher temperatures could speed up egg development, resulting in more than one generation per year of the pest (Scott et al. 2010).

From published results and field observations, temperature and moisture are playing a critical role in affecting pest dynamics over time and space. Therefore, more research is needed to assess and monitor the changes in pest and pathogen dynamics and distribution and on the virulence of the pests and pathogens and the effectiveness of resistance genes under projected changes in climate and increases in climate variability.

Socioeconomic vulnerability to climate change

The major challenge is to increase the competitiveness of lentil against more remunerative alternative crops such as cereals and oilseeds such as soybean and canola. Since lentil is mostly grown under rainfed conditions with limited precipitation, lentil farmers are highly vulnerable to climate change. Many governments in the developing world have been rightly concerned to increase cereal production, especially wheat and rice, for food security. As a result, subsidies on water, electricity and fertilizers are geared toward cereals. However this is at the expense of pulse production. Additionally, the structure of production for subsistence among smallholders has resulted in few incentives to increase productivity and invest in the pulse sector. There must be a major policy shift to increase overall investment in the sustainable intensification of production systems that include legumes such as lentils, which have been especially neglected. Looking ahead, escalating costs of producing inorganic nitrogen fertilizer, reductions in the availability of water for agriculture, climate change, food insecurity and an increasingly nutrition-conscious consumer society collectively give a bright future for a highly nutritious food produced by a nitrogen-fixing crop such as lentil adapted to the cereal-based farming systems of marginal lands.

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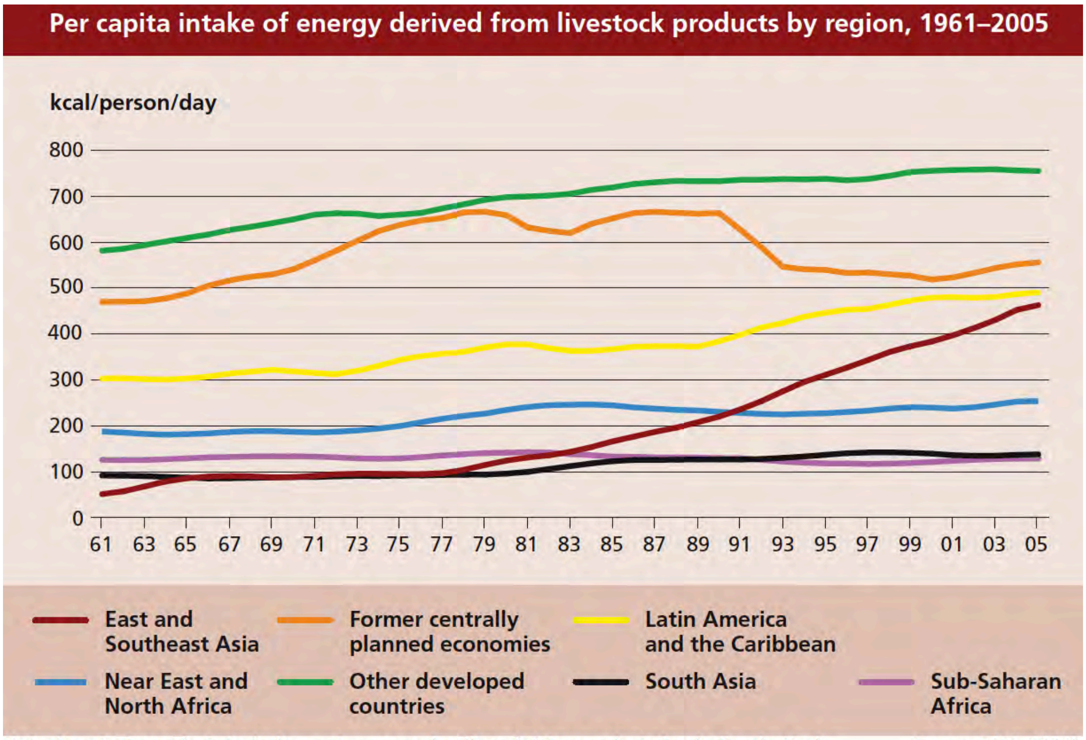
2.12 Livestock

Mario Herrero, International Livestock Research Institute (ILRI)

The importance of livestock for food and nutrition security

Vast differences in the level of consumption of livestock products exist between rich and poor countries (Figure 2.12.1). The level of consumption of milk and meat per capita in the developed world is higher than in the developing world but there is significant heterogeneity between regions. Growth in consumption has increased in most parts where economic development and industrialization have also increased. Stagnating consumption of animal products has occurred in Africa and South Asia.

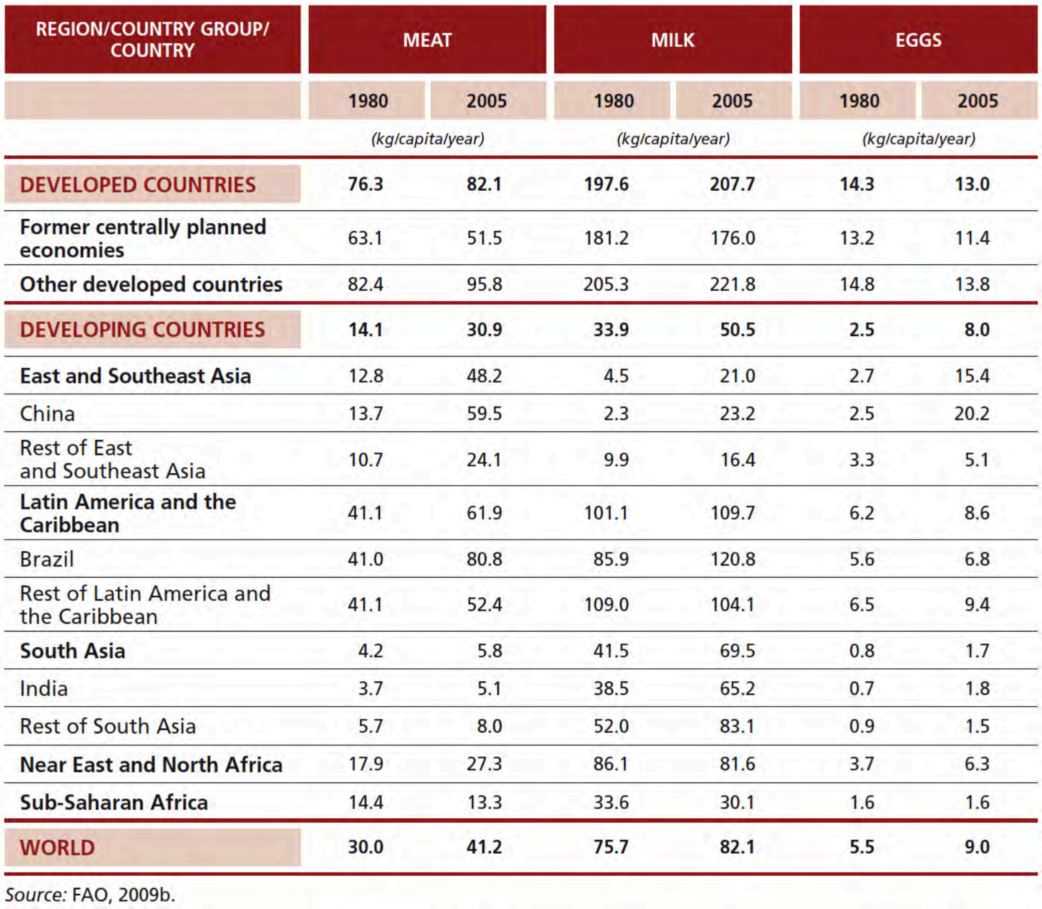
Figure 2.12.1. Per capita kilocalorie consumption of animal products (1961-2005)



Note: Livestock products include meat, eggs and milk and dairy products (excluding butter). *Source:* FAO, 2009b

The demand for livestock products is rising rapidly in developing countries, mainly as a consequence of increased human population, urbanisation and rapidly increasing incomes. Until 2005 the total consumption of animal products in both the developed and the developing world was roughly similar, but per capita consumption, while it doubled, remained less than half of that in the developed world. Considerable growth in per capita consumption occurred in East and South East Asia (notably in China) as a result of increasing incomes and urbanization (Table 2.12.1).

Table 2.12.1. Per capita consumption of livestock products by region, country group and country, 1980 and 2005

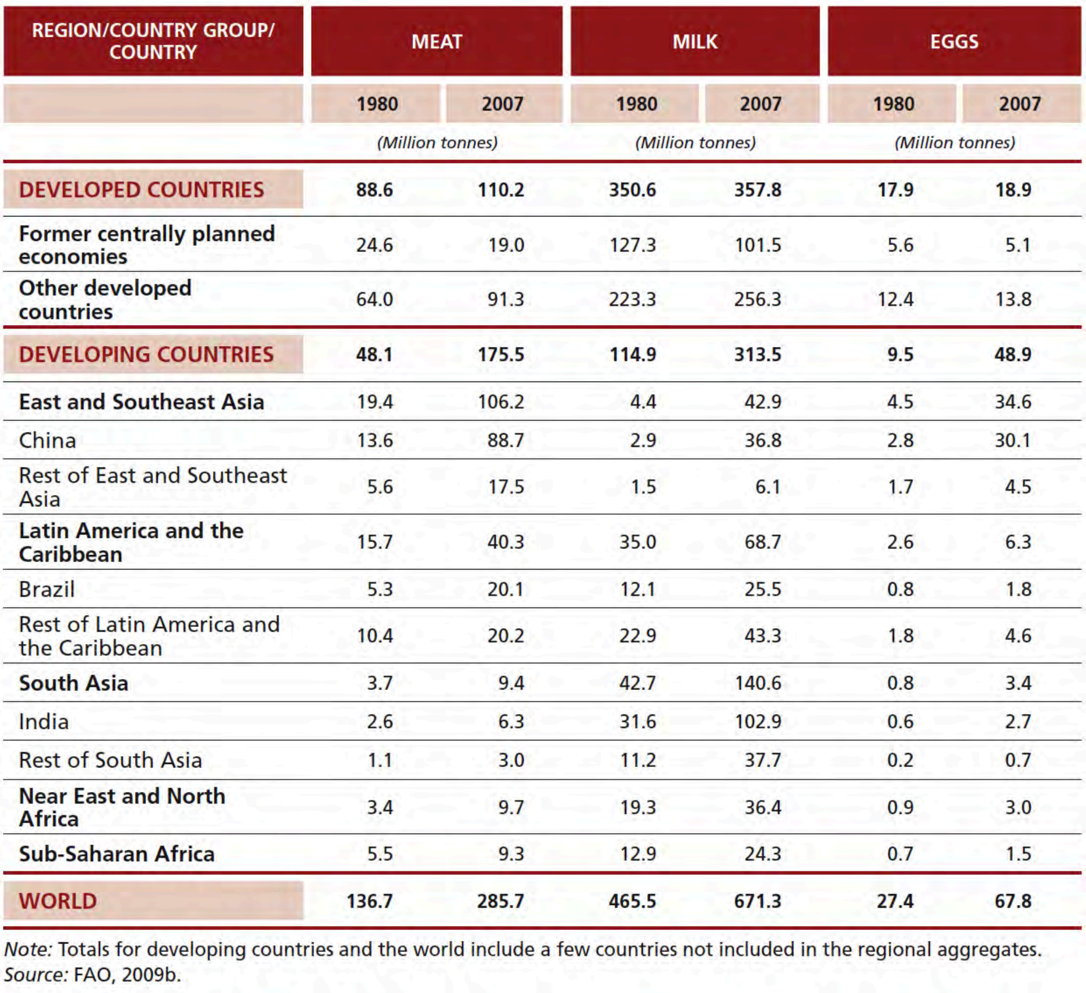


REGION/COUNTRY GROUP/ COUNTRY	MEAT		MILK		EGGS	
	1980	2005	1980	2005	1980	2005
	(kg/capita/year)		(kg/capita/year)		(kg/capita/year)	
DEVELOPED COUNTRIES	**76.3**	**82.1**	**197.6**	**207.7**	**14.3**	**13.0**
Former centrally planned economies	63.1	51.5	181.2	176.0	13.2	11.4
Other developed countries	82.4	95.8	205.3	221.8	14.8	13.8
DEVELOPING COUNTRIES	**14.1**	**30.9**	**33.9**	**50.5**	**2.5**	**8.0**
East and Southeast Asia	12.8	48.2	4.5	21.0	2.7	15.4
China	13.7	59.5	2.3	23.2	2.5	20.2
Rest of East and Southeast Asia	10.7	24.1	9.9	16.4	3.3	5.1
Latin America and the Caribbean	41.1	61.9	101.1	109.7	6.2	8.6
Brazil	41.0	80.8	85.9	120.8	5.6	6.8
Rest of Latin America and the Caribbean	41.1	52.4	109.0	104.1	6.5	9.4
South Asia	4.2	5.8	41.5	69.5	0.8	1.7
India	3.7	5.1	38.5	65.2	0.7	1.8
Rest of South Asia	5.7	8.0	52.0	83.1	0.9	1.5
Near East and North Africa	17.9	27.3	86.1	81.6	3.7	6.3
Sub-Saharan Africa	14.4	13.3	33.6	30.1	1.6	1.6
WORLD	**30.0**	**41.2**	**75.7**	**82.1**	**5.5**	**9.0**

Source: FAO, 2009b.

The developing world produces 50% of the beef, 41% of the milk, 72% of the lamb, 59% of the pork and 53% of the poultry globally (Rosegrant et al. 2009, Steinfeld et al. 2006, Herrero et al. 2009). China produces almost half of the meat in the developing world (mostly pork and poultry), while South Asia accounts for nearly half of the milk production (Table 2.12.2). These shares are likely to increase significantly to 2050 as rates of growth of livestock production in the developing world exceed those in developed countries (>2% per year and <1% per year, respectively). Mixed extensive and intensive crop-livestock systems produce 65%, 75% and 55% of the bovine meat, milk and lamb, respectively, of the developing world share. This type of system is of particular importance from a food security and livelihoods perspective because over two-thirds of the human population lives in these systems and apart from livestock products, they also produce close to 50% of the global cereal share. These are also the systems that are under the highest environmental pressures, particularly in high potential areas of Asia, where water tables and biodiversity are decreasing, and in Africa where soil fertility is rapidly declining.

Table 2.12.2. Production of livestock products by region (1980 and 2007)



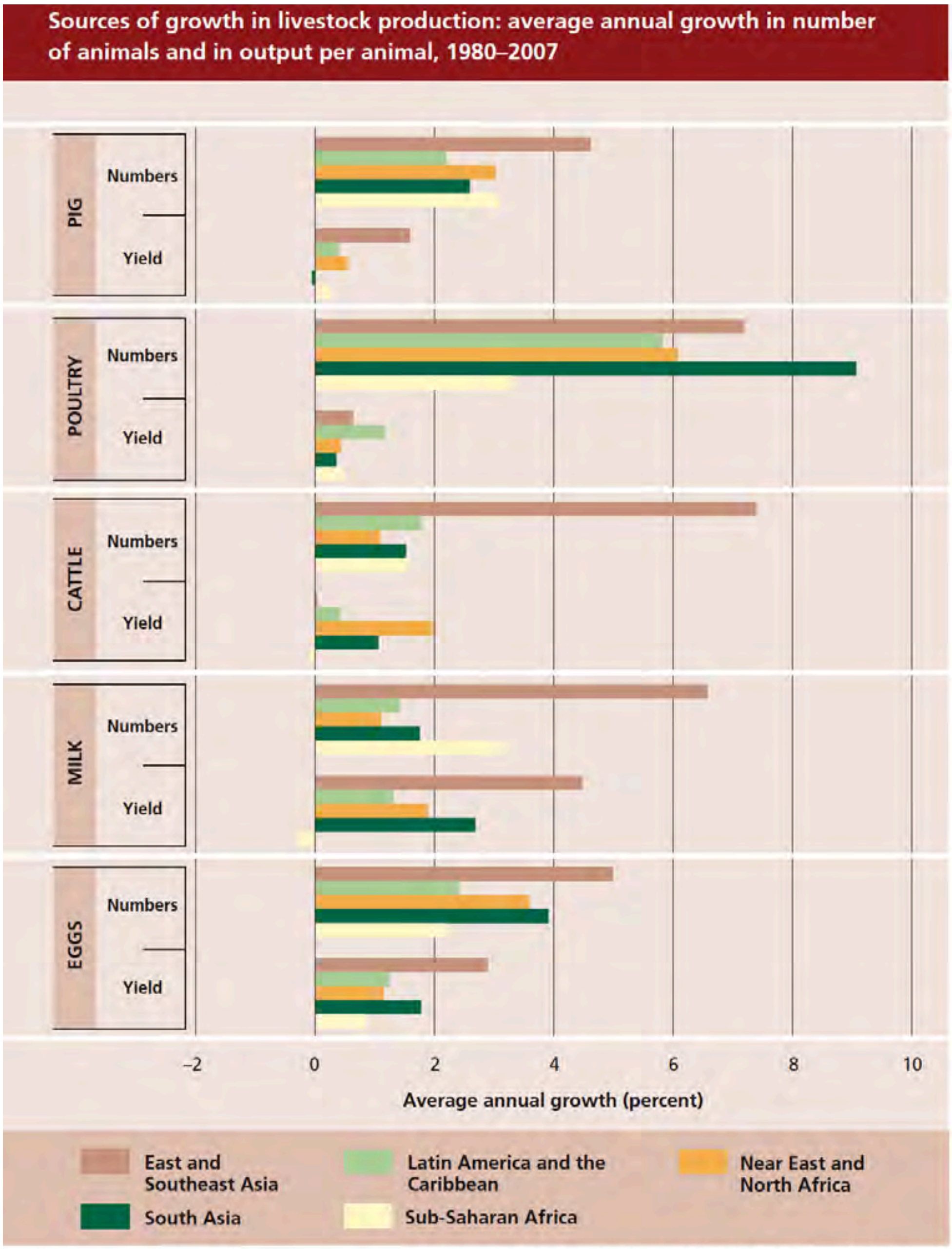
REGION/COUNTRY GROUP/ COUNTRY	MEAT		MILK		EGGS	
	1980	2007	1980	2007	1980	2007
	(Million tonnes)		*(Million tonnes)*		*(Million tonnes)*	
DEVELOPED COUNTRIES	**88.6**	**110.2**	**350.6**	**357.8**	**17.9**	**18.9**
Former centrally planned economies	24.6	19.0	127.3	101.5	5.6	5.1
Other developed countries	64.0	91.3	223.3	256.3	12.4	13.8
DEVELOPING COUNTRIES	**48.1**	**175.5**	**114.9**	**313.5**	**9.5**	**48.9**
East and Southeast Asia	19.4	106.2	4.4	42.9	4.5	34.6
China	13.6	88.7	2.9	36.8	2.8	30.1
Rest of East and Southeast Asia	5.6	17.5	1.5	6.1	1.7	4.5
Latin America and the Caribbean	15.7	40.3	35.0	68.7	2.6	6.3
Brazil	5.3	20.1	12.1	25.5	0.8	1.8
Rest of Latin America and the Caribbean	10.4	20.2	22.9	43.3	1.8	4.6
South Asia	3.7	9.4	42.7	140.6	0.8	3.4
India	2.6	6.3	31.6	102.9	0.6	2.7
Rest of South Asia	1.1	3.0	11.2	37.7	0.2	0.7
Near East and North Africa	3.4	9.7	19.3	36.4	0.9	3.0
Sub-Saharan Africa	5.5	9.3	12.9	24.3	0.7	1.5
WORLD	**136.7**	**285.7**	**465.5**	**671.3**	**27.4**	**67.8**

Note: Totals for developing countries and the world include a few countries not included in the regional aggregates.
Source: FAO, 2009b.

Globally, agro-pastoral and pastoral systems cover 30% of the earth's usable surface and supply 24% of the global meat production. Industrial pork and poultry production account for 55% and 71% of global pork and poultry production, respectively (Steinfeld et al., 2006). These systems account for over 70% of the increases in meat production, especially in Latin America and Asia. However, large concentrations of animals are creating pollution problems and promoting transfers of nutrients and resources from ecologically vulnerable parts of the world. The demand for maize and coarse grains is projected to increase by 553 Mt by 2050 as a result of this monogastric expansion, and will account for nearly half of the grain produced in the period 2000–2050 (Rosegrant et al. 2009).

While yield per animal has increased in recent years, notably for monogastrics, most growth in production has been mediated via increases in animal numbers (Figure 2.12.2), which have also increased resource use pressures. Sustainably intensifying the growth of the sector at lower environmental footprints is the subject of considerable research.

Figure 2.12.2. Sources of growth in livestock production (FAO 2009)



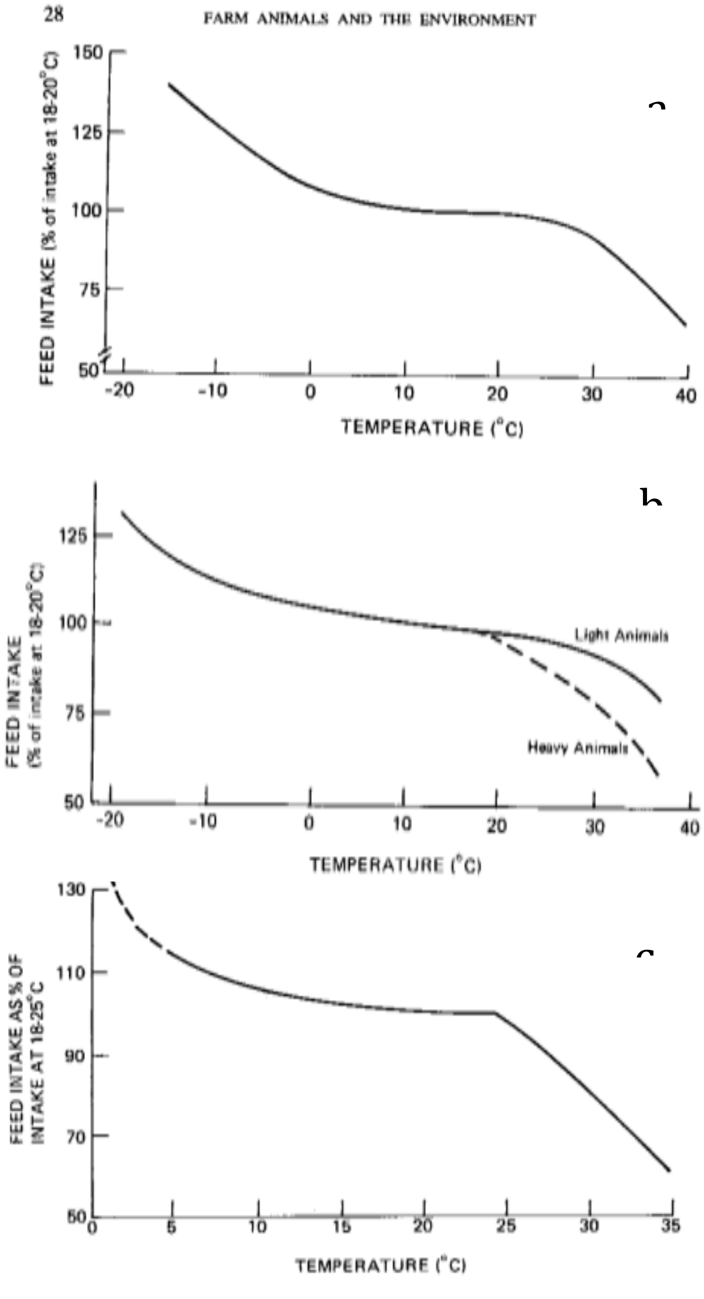
Source: Calculations based on data from FAO (2009b).

Biological vulnerability to climate change

The impacts of climate change on livestock are multiple and can be both direct and indirect. Direct impacts, mostly mediated via increases in temperatures, include reductions in feed intake that in turn have an impact on productivity (milk production and weight gain) and in some cases on increased mortality. Figure 2.12.3 shows the typical responses of feed intake to increases in temperature for cattle, pigs and poultry. Most livestock species have comfort zones between 10 and 30 °C. At lower temperatures, animals try to eat more to maintain their body temperature. However at temperatures higher than 25–30 °C depending on animal species (lower end for monogastrics), animals experience reductions in feed intake of around 3–5% per additional degree of temperature. The physiological explanation for the reduction in intake is that at higher temperatures, livestock cannot dissipate enough heat from the digestive processes, hence they reduce intake to try to maintain their body temperature constant. These reductions in intake translate into productivity losses of 10–20% per additional degree of temperature, with the range depending on diet quality and others. Other aspects affected by increases in temperature are reproduction and grazing patterns. Reproduction becomes impaired at higher temperatures because livestock cycle irregularly or do not show signs of oestrus, implantation is impaired and conception rates decrease. In some extreme cases, at very high temperatures (over 45 °C) increased rates of abortions have also been observed. Grazing patterns are affected as reductions in diurnal grazing are observed (Humphreys 1991).

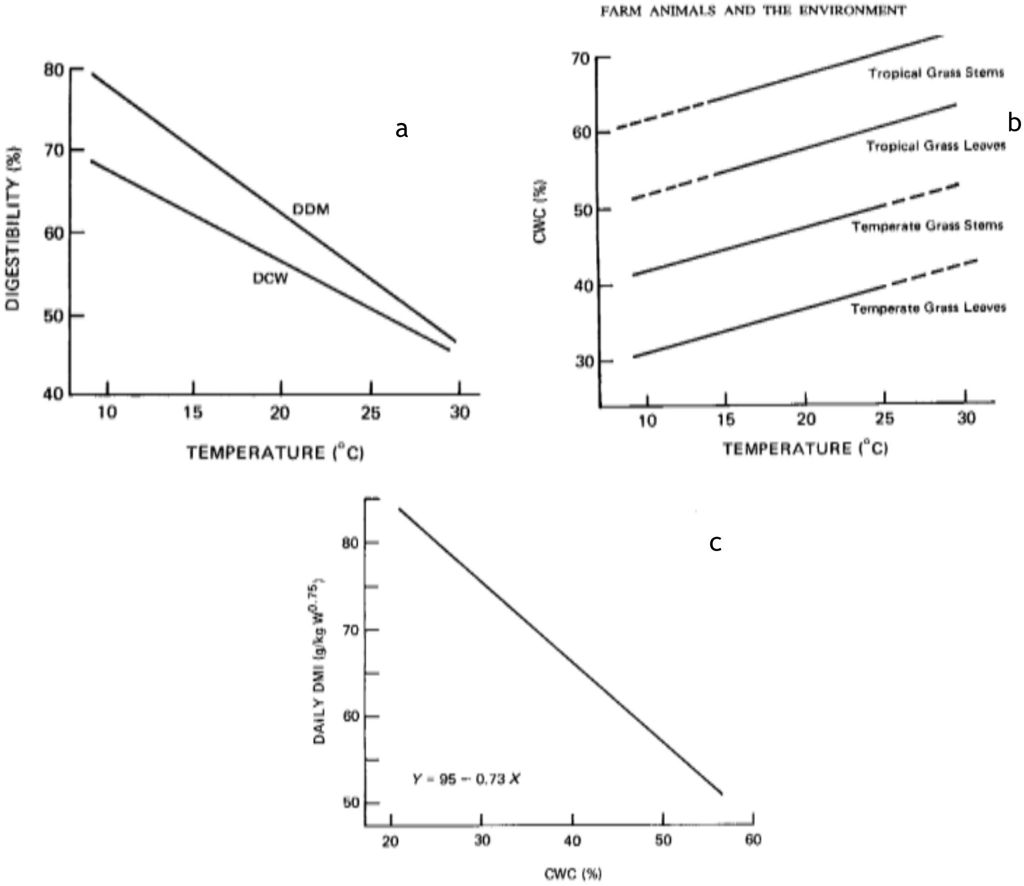
The impacts of climate change on the quantity and quality of feed resources can be significant, and this is one of the key impacts of climate change on livestock systems. The impacts on feed quantity are mostly mediated by changes in rainfall and its variability. Droughts and extreme rainfall variability can trigger periods of severe feed scarcity, especially in dryland areas. These in turn can have devastating effects on livestock populations. Thornton and Herrero (2009) found that increases in drought frequencies to a drought every three years could decimate herds of Kenya pastoralists if they increased from the historical 1 in 5 year droughts, which maintained herd sizes constant.

Figure 2.12.3. The impacts of increasing daily temperature on the feed intake responses of a) cattle, b) pigs and c) poultry (adapted from NRC 1981).



Increased temperature can also have impacts on the productivity of pastures. In some cases, these impacts are positive, by reducing temperature constraints on the growth of tropical pastures in some highland areas, but in others, higher temperatures reduce water availability for pasture growth by increasing evapotranspiration. Increases of temperature in the temperature range 15–35 °C increase the rate of leaf appearance and stem elongation in tropical grasses, suggesting that management of grazing systems needs to be adjusted to ensure high production and quality of biomass for the animals. The quality of tropical pastures is also significantly affected by increases in temperature over wide temperature ranges (Figure 2.12.4). The changes are mediated via reductions in cell wall and organic matter digestibility, and increases in cell wall content and lignification of both leaves and stems. The overall result is more fibrous and less digestible grasses, which are consumed in lower quantities by the animals, thus reducing animal performance.

Figure 2.12.4. The impacts of increased temperature on a) forage digestibility and b) cell wall contents and c) the resulting impacts on dry matter intake. Adapted from NRC 1981.



The species composition of rangelands can also be affected by climate change. Differential growth responses to temperature and carbon dioxide concentrations can change the balance between grasses and browse species in rangelands, with C_3 browse species benefiting from CO_2 fertilization.

While there are important differences in the responses of different breeds to increased temperature, the triple impacts of climate change on the quantity and quality of feed, plus the intrinsic reductions in animal feed intake and increased mortality, could make the impacts of climate change on livestock systems severe in certain places.

Other dimensions of the biological vulnerability of livestock to climate change include changes in the distribution of livestock vector-borne diseases. These are mediated via changes in the ranges in which ticks, mosquitos, flies and others can be distributed. Examples of these include East Coast fever, babesiosis, anaplasmosis, and trypanosomiasis. Less is known about other types of diseases (Thornton 2010). The water needs of livestock are also likely to increase with increasing temperatures. This, together with potential reductions in water availability, could pose a serious constrain on livestock development options in certain places.

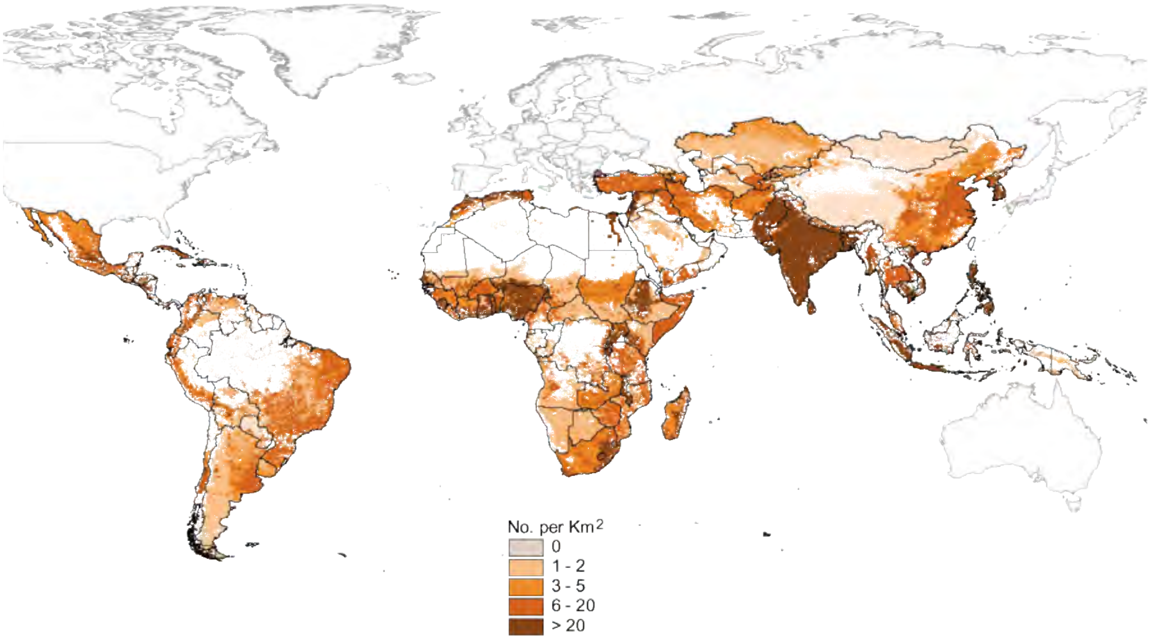
Socioeconomic vulnerability to climate change

Livestock play multiple socioeconomic roles in developing countries. Nearly 1 billion people living on less than two dollars a day in South Asia and sub-Saharan Africa keep livestock (Figure 2.12.5), and of these, it has been estimated that two thirds are women. Livestock are an important source of household income, with income ranging from 15 to 80% depending on the type of system, the level of diversification, and off-farm income, for example.

Livestock production in the developing world is also an important economic activity. Livestock products are high-value products, especially when compared to crops. Milk and meat rank as some of the agricultural commodities with the highest gross value of production (VOP) in the developing world (data from FAOSTAT). In the last decade, livestock have represented between 17 (Southeast Asia) and 47 (Central America) percent of the total agricultural VOP in developing-country regions.

At the same time, some groups of livestock keepers are among the most vulnerable of all human groups to the impacts of climate change. For example, pastoralists and agro-pastoralists in Africa, poorly supported by services, public and private safety nets and with little access to resources, and some mixed crop-livestock farmers in very poor areas with high population densities, are likely to experience the most severe impacts of climate change, largely as a result of their low capacity to adapt.

Figure 2.12.5. Density of poor livestock keepers in the developing world



Source: Thornton et al. (2002).

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2.13 Maize

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The importance of maize for food and nutrition security

Together with rice and wheat, maize provides at least 30 percent of the food calories to more than 4.5 billion people in 94 developing countries. They include 900 million poor consumers for whom maize is the preferred staple. Maize is currently produced on nearly 100 million hectares in 125 developing countries and is among the three most widely grown crops in 75 of those countries (FAOSTAT 2010). About 67 percent of the total maize production in the developing world comes from low and lower middle income countries; hence, maize plays an important role in the livelihoods of millions of poor farmers. By 2020, the world will have around 7.7 billion people and by 2050 the figure will be approximately 9.3 billion. Between now and 2050, the demand for maize in the developing world will double (Rosegrant et al. 2009).

Maize is an important source of food and nutritional security for millions of people in the developing world, especially in Africa and Latin America. The role of maize for human consumption, expressed in terms of the share of calories from all staple cereals, varies significantly across regions (Table 2.13.1). This ranges from 61 percent in Mesoamerica, 45 percent in Eastern and Southern Africa (ESA), 29 percent in the Andean region, 21 percent in West and Central Africa (WCA), and 4 percent in South Asia. The contribution of maize as a source of protein from all the cereal staples is very similar to its contribution of calories. Its use as a source of food accounts for 25 percent and 15 percent of the total daily calories in the diets of people in the developing countries and globally. The remainder is used mainly in animal feed and for various industrial applications including food processing and bioethanol production (FAOSTAT 2010, Shiferaw et al. 2011).

Maize is a particularly important crop to the poor in many developing regions of Africa, Latin America and Asia to overcome hunger and improve food security. Its high yields (relative to other cereals) make maize particularly attractive to farmers in areas with land scarcity and high population pressure (Shiferaw et al. 2011).

Table 2.13.1. Maize production and consumption statistics by region

Region	Average production per year ('000 Mt)	Per capita production (kg)	Average area (1000 ha)	Average yield (kg/ha)	Quantity (kg/ person/ year)	Calories (kcal/ person/	Protein (g/person/day)
Year	2001/10	2001 /10	2001/ 10	2001/ 10	2007	2007	2007
Africa (Total)	50,401	54.4	27,933	1,798.	41.0	357.7	9.2
Eastern Africa	17,854	61.3	12,739	1,404.	54.4	474.4	11.9
Northern Africa	6,939	35.8	1,154.	6,012.	34.2	303.3	7.9
Middle Africa	3,338	29.5	3,467.	960.6	26.5	238.8	6.3
Southern Africa	10,268	185.	3,187.	3,273.	100.7	863.7	22.1
Western Africa	12,000	43.8	7,385.	1,613.	26.2	225.3	5.9
Americas (Total)	394,867	442.	59,860	6,576.	34.4	286.0	6.8
Northern	295,968	893.	31,719	9,305.	13.3	96.5	1.8
Central America	24,620	167.	8,950.	2,753.	106.0	912.4	23.5
Caribbean	585	14.5	453.8	1,301.	18.5	172.5	4.5
South America	73,692	196.	18,736	3,914.	27.2	223.6	5.1
Asia (Total)	202,330	50.8	48,245	4,170.	8.8	69.2	1.6
Central Asia	1,181	20.4	241.8	4,887.	5.5	42.8	1.0
Eastern Asia	145,061	94.0	28,167	5,127.	7.9	61.3	1.2
Southern Asia	22,525	14.1	9,933.	2,253.	6.4	55.2	1.4
South-Eastern	28,863	51.0	8,903.	3,212.	16.2	116.1	2.9
Western Asia	4,698	22.3	999.7	4,691.	14.7	122.2	2.8
Europe (Total)	81,285	111.	14,182	5,727.	7.1	53.0	1.2
Eastern Europe	33,392	112.	8,072.	4,113.	5.7	43.2	1.0
Northern Europe	15	.2	3.7	3,426.	3.0	25.0	.6
Southern Europe	26,277	174.	3,706.	7,099.	7.6	60.6	1.4
Western Europe	21,600	115.	2,398.	9,006.	11.0	76.8	1.8
Oceania (Total)	572	16.9	89.2	6,441.	4.3	35.3	.8
Australia and New Zealand	558	22.5	84.4	6,639. 7	4.7	38.4	.8
Melanesia	14	1.8	4.7	3,032.	.3	2.7	.1
Micronesia	.1	.2	.1	1,600.	.1	.6	
Polynesia	-	-	-	-	.0	.0	
World	729,456	111.	150,31	4,837.	16.8	138.9	3.4

Source: FAOSTAT, 2012

Biological vulnerability to climate change

Using CIMMYT data from more than 20,000 historical maize trials in Africa, combined with daily weather data, Lobell et al. (2011) estimated that each degree day spent above 30°C reduced the final yield by 1 percent under optimal rain-fed conditions and by 1.7 percent under drought conditions. The outputs of temperature simulations for 2050 in sub-Saharan Africa show a general trend of warming, with maximum temperatures predicted to increase by 2.6°C and minimum temperatures by 2.1°C (Cairns et al. 2012). Overlaying temperature simulations with drought susceptibility maps show Southern Africa will likely be most affected.

In some regions such as the East African highlands, increased temperatures may see improved conditions for maize production, however temperatures will increase beyond the threshold of highland maize and new germplasm will be required to achieve the predicted yield gains. The challenge will be to provide maize farmers with the means to respond both to the threats and opportunities posed by climate change.

Regional variation in yield response of maize to climate change

The potential impact of a 1˚C warming on maize yields in sub-Saharan Africa was mapped from field trial data (Figure 2.13.1) using the following approaches:

- Empirical crop/weather relationships derived from extensive field trials in Africa (1999–2007) from a network of 123 research stations managed by CIMMYT, National Agricultural Research Programs and private seed companies.
- Two water treatments (i) 'optimal' management to minimise nutrient, drought, disease and other stresses and (ii) managed 'drought stress' to induce drought stress during flowering and grain-filling.
- Varieties currently grown or advanced breeding lines intended for farmers' fields throughout Africa.

Main conclusions from the Lobell et al. (2011) study are:

- Increased temperature significantly effects maize yield ($P < 0.01$).
- Possible gains in yield with warming at relatively cool sites.

- Significant yield losses at sites where temperatures commonly exceed 30˚C (corresponding to areas where the growing season average temperatures = 23˚C or maximum temperatures = 28˚C).
- Daytime warming is more harmful to yield than night-time warming.
- Drought increases yield susceptibility to warming even at cooler sites.
- Under ‘optimal’ conditions yield losses occur over ca. 65% of the harvested area of maize.
- Under ‘drought stress’ yield losses occur at all sites, with a 1˚C warming resulting in at least a 20% loss of yield over more than 75% of the harvested area.

Factors underpinning temperature-induced yield loss in maize

Warmer temperatures and more frequent exposure to high temperature events are the major drivers of yield loss with climate change. In maize, this can be mainly attributed to:

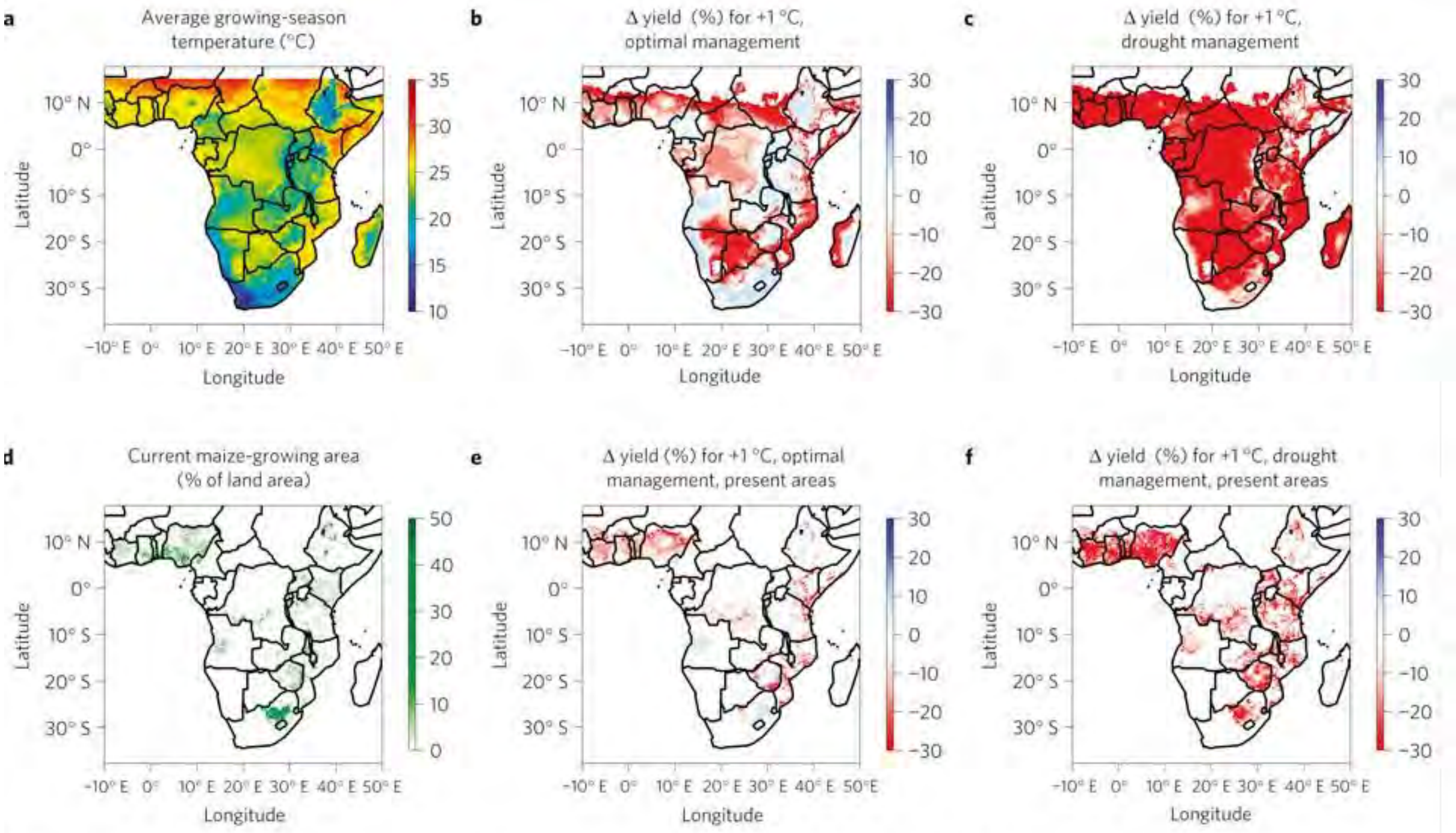
- More rapid crop development: warmer temperatures will reduce the size and duration of organs, and consequently resource capture (light, water and nutrients) and assimilate production for growth and grain fill.
- Reproductive failure: high temperatures can harm crop growth at different stages of development, with reproductive tissues being the most sensitive to damage by heat stress.
- Harmful effects of daytime warming: high temperature damage to maize yields is associated with increased pollen sterility.

Impacts of elevated CO_2 on maize yield

There is no mechanistic basis for a direct effect of CO_2 on C_4 photosynthesis and the weight of evidence indicates that in plants, such as maize, C_4 photosynthesis is not directly stimulated by elevated CO_2. However, growth and yield may benefit indirectly through a reduction in stomatal conductance. Free-Air CO_2 Enrichment (FACE) experiments indicate that elevated CO_2 improves C_4 water relations and so indirectly enhances photosynthesis, growth, and yield by delaying and reducing drought stress (Leakey at al. 2009). In addition, a meta-analysis conducted by Taub et al. (2008) suggests that the increasing CO_2 concentrations of the 21st century are likely to decrease the protein concentration of many human plant foods.

By 2050 atmospheric CO_2 levels are expected to be around 550 ppm. Recent open-air experiments for maize have demonstrated no increase in yield in field level experiments under well-watered conditions and CO_2 levels of 550ppm, although there was substantial reduction in water use (Leakey et al. 2009).

Figure 2.13.1. Changes in maize yield (%) for a 1°C warming. Source: Lobell et al. (2011).



a Average growing-season temperature (°C)

b Δ yield (%) for +1 °C, optimal management

c Δ yield (%) for +1 °C, drought management

d Current maize-growing area (% of land area)

e Δ yield (%) for +1 °C, optimal management, present areas

f Δ yield (%) for +1 °C, drought management, present areas

a–c, Present growing-season average temperature (a) and estimated impacts of 1°C warming for all areas for optimal (b) and drought (c) management. d–f, Present maize-growing area (fraction of grid cell; ref. 23; d) and estimated impacts of 1°C warming for areas with at least 1% of maize (e,f).

These types of findings have implications for irrigation needs in C_3 versus C_4 crops under elevated CO_2, i.e., if growth is stimulated in C_3 crops, then more water may be required to maintain additional leaf area, and in dry areas, there may be an increased risk of drought impact through the exhaustion of stored soil water compared with 'slower' growing crops.

Socioeconomic vulnerability to climate change

Modeling impacts on human welfare

The impact of climate change on agricultural production will be greatest in the tropics and subtropics, with Africa particularly vulnerable due to the range of projected impacts, multiple stresses and low adaptive capacity. Compared to the situation without climate change, climate change is projected to reduce maize production globally by 3% to 10% by 2050 (Rosegrant et al. 2009).

Due to higher temperature and reduced rainfall, Jones and Thornton (2003) estimate that crop yields in Africa may fall by 10–20% by the 2050s. However this figure masks variation since in some areas crop reductions will be greater (northern Uganda, southern Sudan, and the semi-arid areas of Kenya and Tanzania) while in other areas crops yields may increase (southern Ethiopia highlands, central and western highlands of Kenya and the Great Lakes Region) (Thornton et al. 2009). Analysis of climate risk identified maize in southern Africa as one of the most important crops in need of adaptation investments (Lobell et al. 2008). The adverse effects on maize production in southern Africa by the 2030s are projected to reach 50% of the average yield levels in 2000.

Based on simulated effects of crop productivity changes using crop growth models, the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) is being used to estimate the impact of climate change on global food and nutrition security. Preliminary results from IMPACT indicate that climate change will negatively affect global food production and hence will reduce calorie availability in the developing world. The decrease in calorie availability will worsen food and nutritional security. By 2050, the population at risk of hunger in the developing world would increase by more than 30% due to climate change (Figure 2.13.2). The regions that will experience the highest increase in the number of people at risk of hunger are SSA, South Asia and LAC. Similarly, the number of malnourished children would increase by more than 7% in the developing world by 2050, as a result of climate change (Figure 2.13.3).

Figure 2.13.2. Impact of climate change (across crops) on the number of people at risk of hunger in the developing world - Results from IMPACT*

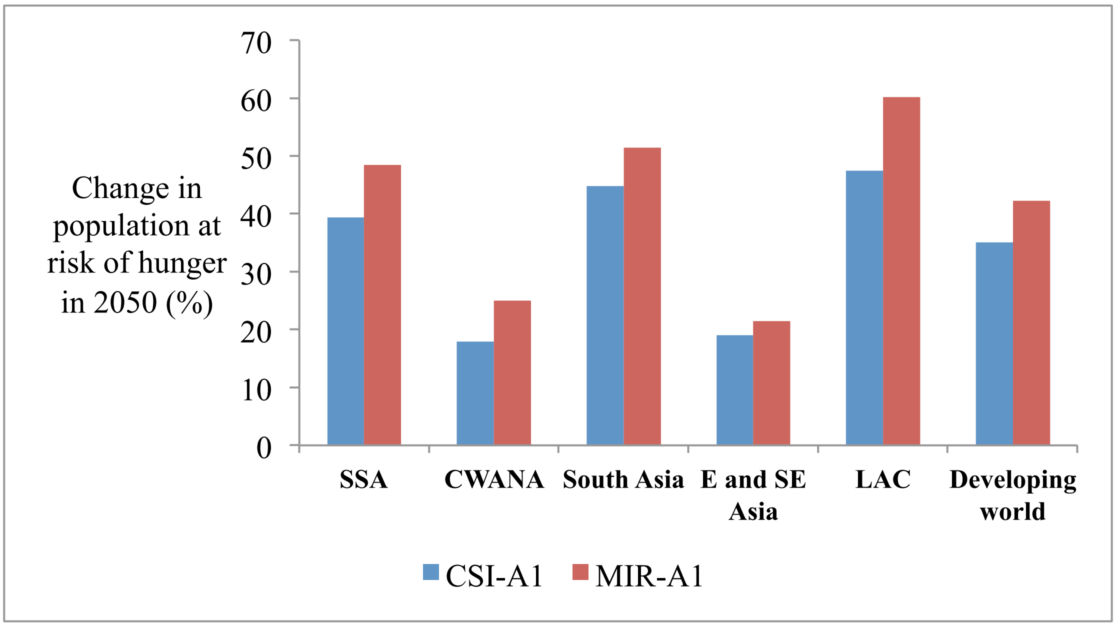
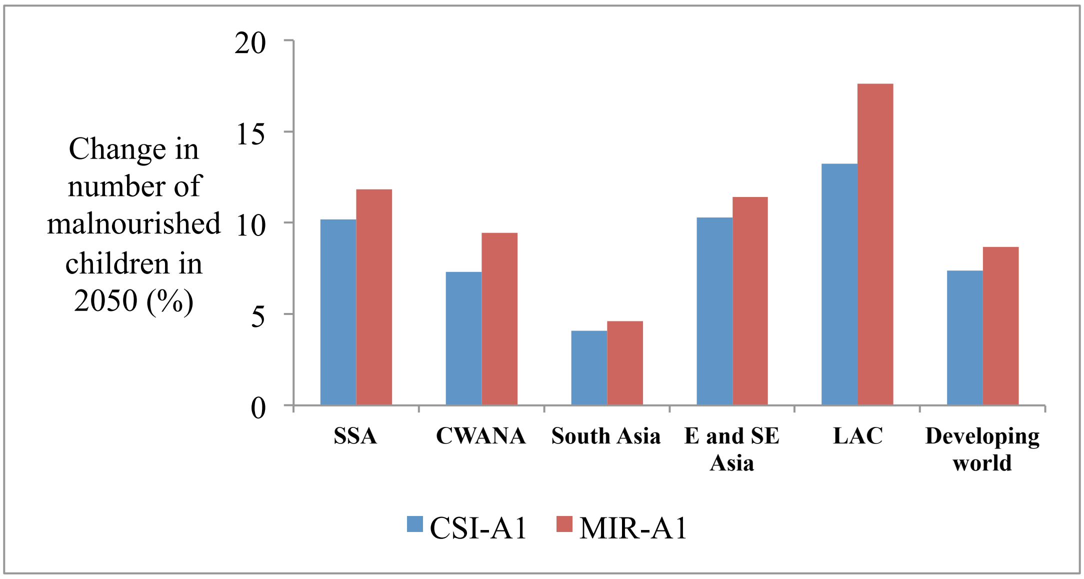


Figure 2.13.3. Impact of climate change (across crops) on the number of malnourished children in 2050 in the developing world - Results from IMPACT*



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* Two GCMs are considered: CSIRO-Mk3.0 and MIROC 3.2. They are combined with the 'A1' scenario (CSI-A1 and MIR-A1, respectively) from the Special Report on Emissions Scenario (SRES) (Nakicenovic et al., 2000) which carries the highest level of greenhouse gas emissions for the period 2000-2050. Of these two cases, the future climate is projected to be hotter and wetter under the MIR-A1 model while under the CSI-A1 model it is expected to be drier than that of MIR-A1.

Focus on role of information in risk management

Farmers are usually exposed to risks and uncertainties and due to changing climatic factors, these uncertainties have further increased. Risk is defined as an adverse outcome which occurs due to uncertainty and imperfect knowledge in decision-making (Drollette 2009). Availability of precise and timely information can help in reducing risk for both production and market linked risks (Drollette 2009). Access to information is one of the enablers to productivity growth and reducing yield gaps and also helps in mitigating risks. Information networks play an important role in the flow of information to the farming communities. However, information on the existing information networks or individual sources of information is not well documented. Also there exists a gap in the information that is available and what farmers actually require.

An assessment of farmer's information needs and sources of information has been carried out in the Indo Gangetic plains (IGP) of India. The survey was conducted in five states—Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal—across 20 districts covering 120 villages and 1200 households. This survey captures the information on the various information sources and networks available to farmers and focuses especially on the role of mobile phones to help deliver information efficiently. The survey results show farmers are using multiple sources to obtain the information. This is because no one source gives farmers all that they need.

However, use of information received on mobile phones is slowly gaining importance. Farmers are using information through mobile phones to mitigate risks related to price information and weather variability. Almost all the sampled farmers have access to mobile phones. Almost all reported that the information obtained from mobile phones is timely as well as useful. Farmers need information about seed variety selection, best cultivation practices, protection from weather-related damage, and handling plant disease. About 35 percent of farmers seem to have experienced an increase in yields due to the availability of such information (see Table).

Benefits of mobile-based information (Unit: Percent of farmers)

States	Percent of farmers using mobile phone for agricultural information	Getting better connected to markets	Getting better price information	Increased yields
Bihar	51	99.2	65.9	21.1
Haryana	65	99.4	79.5	42.9
Punjab	26	77.8	82.5	49.2
Uttar Pradesh	45	69.7	69.7	29.4
West Bengal	17	65.9	48.8	34.1
Total	41	87.2	71.7	34.6

Source: CIMMYT survey 2011

Note: This percent of farmers is from the 41% of farmers, who are using mobile phone to access agricultural information (CIMMYT survey 2011). Farmers have multiple responses.

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2.14 Millet

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The importance of millet for food and nutrition security

Finger Millet [*Eleusine coracana* (L.) Gaertn] plays an important role in both the dietary needs and incomes of many rural households in eastern and southern Africa and South Asia, accounting for 10% of the 338 M hectares sown to all three types of millet globally. Finger millet is rich in fiber, iron and calcium (containing 40 times more calcium than maize and rice, and 10 times more than wheat). It is the most important small millet in the tropics and is cultivated in more than 25 countries in Africa (eastern and southern) and Asia (from the Near East to the Far East), predominantly as a staple food grain. The major producers are Uganda, Ethiopia, India, Nepal and China. Finger millet has high yield potential (more than 10 t/ha under optimum irrigated conditions) and its grain stores very well. Still, like most so-called small millets, finger millet is grown mainly in marginal environments as a rainfed crop with low soil fertility and limited moisture. Finger millet is originally native to the Ethiopian highlands and was introduced into India approximately 44,000 years ago. It is highly adapted to higher elevations and is grown in the Himalayan foothills and East Africa highlands up to elevations of 2300 m.

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is the world's hardiest warm season cereal crop. It can survive even on the poorest soils of the driest regions, on highly saline soils and in the hottest climates. It is annually grown on more than 29 M hectares across the arid and semi-arid tropical and sub-tropical regions of Asia, Africa and Latin America. Pearl millet is the staple food of more than 90 million people who live in the drier areas of Africa and Asia, where its stover is also a valued fodder resource. This crop is principally used for feed and forage in the Americas, and as the mulch component of conservation tillage soya production systems on acid soils in the sub-humid and humid tropics of Brazil.

Globally, production has increased during the past 15 years, primarily due to increased yields. India is the largest single producer of pearl millet, both in terms of area (9.3 M hectares) and production (8.3 Mt). Compared to the early 1980s, the country's pearl millet area has declined by 19%, but production increased by 28% owing to a 64% increase in productivity (from about 450 kg/ha to 870 kg/ha in 2005–07). This has been largely due to adoption of high-yielding hybrids, mostly cultivated in areas receiving more than 400 mm of rainfall annually.

The West and Central Africa (WCA) region has the largest area under millets in Africa (15.7 million hectares), of which more than 90% is pearl millet (Table 2.14.1). Since 1982, the millet area in WCA has increased by over 90%, and productivity has risen by 12% (up from 800 to 900 kg/ha). Production has increased by about 130% (up from 6.1 to 14.1 Mt), most of which has come from increases in cultivated area. Lack of seed production in the region, however, is a major bottleneck in the spread of improved cultivars. In Eastern and Southern Africa (ESA), pearl millet is cultivated on about 2 M hectares. Still, as in WCA, a lack of commercial seed production and distribution continues to be the major bottleneck in the spread of improved seed.

Table 2.14.1. Millet statistics by region

Region	Area harvested (ha)	Yield (kg/ha)	Production (t)	Food supply quantity (kg/capita /yr)	Food supply (kcal/capita/day)
Year	2010	2010	2010	2007	2007
Eastern Africa	1776847	1074	1907577	3.98	31.91
Middle Africa	1281448	605	775676	5.26	42.91
Northern Africa	2022000	239	484000	3.34	31.1
Southern Africa	280300	174	48700	1.33	11.54
Western Africa	15746809	768	12096275	36.36	283.11
Northern America	146900	1781	261610		
Central America	1900	947	1800		
Caribbean	0		0	0	0
South America	6675	1365	9115	0	0
Central Asia	29804	842	25099	0.16	1.26
Eastern Asia	768500	1735	1333020	0.43	3.38
Southern Asia	12372763	941	11646753	7.28	62.1
South-Eastern Asia	210500	902	189800	0.26	2.16
Western Asia	149007	880	131139	0.7	5.96
Eastern Europe	278364	1016	282793	0.74	5.82
Northern Europe					
Southern Europe	659	1945	1282	0	0
Western Europe	16300	2730	44500	0.06	0.59
Australia and New Zealand	38200	966	36900		
Melanesia				0.05	0.46
Micronesia					
Polynesia					

Source: FAOSTAT, 2012.

Besides being highly adapted to abiotic stresses such as heat, drought, high levels of soil aluminium saturation and low levels of soil macro- and micronutrients, pearl millet has been found to be highly responsive to improved management. For instance, when cultivated as an irrigated summer season crop under intensive management conditions in parts of India, hybrids of 80–85 day duration give grain yields as high as 4–5 t/ha of grain yield. Pearl millet is a highly nutritious cereal with high protein content (11–12% with a better amino acid profile than maize, sorghum, wheat and rice) and high grain iron contents (60–65 ppm iron in improved varieties and more than 800 ppm iron in germplasm and breeding lines). High levels of dietary fiber with gluten-free proteins and phenolic compounds with antioxidant properties further add to its health value. Research has shown the effectiveness of various processing and food products technologies to produce alternative and health foods. These can be validated for their commercialization potential, and fine-tuned where needed, or new technologies developed.

Opportunities to be explored include: the increased interest in hybrids in Africa building on past successes in India and on the initial heterotic grouping of pearl millet landraces accomplished in West Africa; high levels of micronutrients (iron and zinc); increased use for alternative food products, feed, and fodder; and the availability of genetic and genomic tools for identification and deployment of favorable alleles at genes contributing significantly to biotic stress resistances and abiotic stress tolerances, and nutritional value of grain, green fodder and stover (including micronutrients as well as anti-nutritional factors such as phytate and flavones). Due to its superior adaptation (compared to all other tropical cereals) to drought, soil salinity, soil acidity, and high temperatures, not to mention its food, feed and fodder values, opportunities exist for pearl millet to make inroads in new niches in Central Asia, the Middle East, Australia and the Americas where preliminary trials have yielded encouraging results, especially with respect to its forage value.

Biological vulnerability to climate change

Major biotic constraints to millet production include blast disease, the parasitic weed Striga, and abiotic stresses such as drought, low soil fertility, soil salinity, and high temperatures during seedling establishment and flowering time.

Changes in yields of millet are presented in Table 2.14.2 where yields in 2000 are compared to 2050 with climate change and without climate change (without CO_2 fertilization in both cases). Two climate models, the CSIRO (Commonwealth Scientific and Industrial Research Organization, Australia) model and the NCAR (National Center for Atmospheric Research, US) model for the 2050s were used to evaluate the impacts. Both models project increases in temperature and precipitation by the 2050s. Yields of millet are projected to increase by 141% by 2050 globally in a “no climate change” situation. In both the climate change scenarios millet showed declines in yield globally, with yield increases in some regions and decreases in others. Increases in yields of millet in some regions were not large enough to compensate for the global yield reduction.

Table 2.14.2. Impact of climate change on millet production

Crops/ Scenarios	South Asia	East Asia	Europe And Central Asia	Latin America And The Caribbean	Middle east and north Africa	Sub-Saharan Africa	Developed countries	Developing countries	World
2000 (mmt)	10.5	2.3	1.2	0.0	0.0	13.1	0.5	27.3	27.8
2050 No CC (mmt)	12.3	3.5	2.1	0.01	0.01	48.1	0.8	66.2	67.0
2050 no CC (% change)	16.5	50.1	77.2	113.0	128.0	267.2	60.5	142.5	141.0
CSIRO (% change)	-19.0	4.2	-4.3	8.8	-5.5	-6.9	-3.0	-8.5	-8.4
NCAR (% change)	-9.5	8.3	-5.2	7.2	-2.7	-7.6	-5.6	-7.0	-7.0

Source: Nelson et al. 2009

Socioeconomic vulnerability to climate change

Millet, like sorghum, millet and pigeonpea, is typically part of mixed cropping systems in the Semi-Arid Tropics (SAT) and is rarely grown as a monocrop over large areas. The exception is perhaps groundnut in southern India, where for example Anantapur District of Andhra Pradesh has more than 900,000 groundnut farmers. Also, data on value by commodity are hard to find in Africa. As such, it is hard to ascribe vulnerability to particular crops.

The SAT contains about 160 million rural poor, of whom 100 are in India. Poverty is declining in rural India, but not elsewhere. Rural households are predominantly net buyers of food, so any reduction in production and/or increases in price affect them proportionately more, women headed households especially (Walker 2010). In India, sorghum, millet, groundnut and pigeonpea now account for about 30% of the cropped area and accounts for about 20% of the value of production, so the net effects on vulnerability in India as a whole are less than 50 years ago (Walker 2010). However, more than 70% of the value of production of sorghum, groundnut and pigeonpea (2003–04 figures) is in the Indian SAT. In India agriculture still accounts for about 40% of per capita income in rural areas. In the SAT of WCA, sorghum, millet and groundnut occupy about 40% of arable land and in East and Southern Africa, between 15 and 20%. Compared to 50 years ago, the reliance on agriculture has declined and non-farm income is far more important, increasing resilience.

Long-term village level studies in the Indian SAT have shown that diets are heavily dependent on cereals; in Maharashtra, for example, sorghum provides over 50% of all calories and iron consumed (Chung 1998). The ratio of cereals to legumes consumed in Maharashtra is typically around 8:1.

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2.15 Pigeonpea

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The importance of pigeonpea for food and nutrition security

Pigeonpea [*Cajanus cajan* (L.) Millsp.] is a staple grain legume in South Asian diets and is also widely grown and consumed in household gardens in Africa—and rapidly expanding as an export crop from Eastern and Southern Africa (ESA) to South Asia (SA). Household artisanal production is not well documented in the FAO database, which indicates a total global area of 4.8 M ha (FAO 2008) in 22 countries. India is by far the largest producer with 3.6 M ha although this is insufficient to meet all its consumption needs; it imports from neighbor Myanmar (560,000 ha) and other regions, notably ESA. In Africa smallholders are most intensified for dual consumption and export in Kenya (196,000 ha), Malawi (123,000 ha), Uganda (86,000 ha), Mozambique (85,000 ha), and Tanzania (68,000 ha) (Saxena et al. 2010). With protein content totaling more than 20%, almost three times that of cereals, pigeonpea plays an important role in nutrient-balancing the cereal-heavy diets of the poor. Pigeonpea is also important in some Caribbean islands and some areas of South America in which populations of Asian and African heritage have settled (Saxena et al. 2010). In addition to being an important source of human food and animal feed, pigeonpea also plays an important role in sustaining soil fertility by improving physical properties of soil and fixing atmospheric nitrogen. Traditional long-duration pigeonpea expresses a perennial tall bush-like growth habit that conveys additional soil protection and deep-rooted nutrient recycling ability. Shorter-duration varieties will naturally have less time to provide such services. Pigeonpea is generally relay or intercropped with sorghum, cotton, maize and groundnut and thus has to compete with the associated crop for water, nutrients, sunlight and other resources. Recently, ICRISAT has developed hybrid pigeonpea cultivars that produce 35% higher yields and are currently being multiplied through the private sector for dissemination to farmers.

Table 2.15.1. Pigeonpea statistics by region

Region	Average production per year ('000 Mt)	Average area (1000 ha)	Average yield (kg /ha)
Year	2001/10	2001/ 10	2001/10
Africa (Total)	366.0	498.4	734.2
-- Eastern Africa	359.4	488.7	735.4
-- Middle Africa	6.6	9.7	676.9
Americas (Total)	32.5	40.4	804.1
-- Central America	1.9	4.3	465.4
-- Caribbean	28.5	33.6	849.2
-- South America	2.0	2.5	792.9
Asia (Total)	3015.3	4070.0	739.3
-- Southern Asia	2446.0	3538.4	690.3
-- South-Eastern Asia	569.4	531.5	1056.6

Source: FAOSTAT 2012

Biological vulnerability to climate change

Major abiotic constraints for pigeonpea are drought and in some areas intermittent waterlogging. Major biotic stresses include diseases especially sterility mosaic, *Fusarium* wilt, and *Phythophthora* blight in the Indian subcontinent; wilt and *Cercospora* leaf spot in eastern Africa; and witches' broom in the Caribbean and Central America (Reddy et al. 1990). The major insect pests are pod fly (*Melanagramyza* sp), pod borers (*Helicoverpa armigera* and *Maruca vitrata*), and pod sucker (*Clavigralla* sp) (Joshi et al. 2001). Both abiotic and biotic stresses are influenced by climate and potentially aggravated by climate change.

A recent study (Sahaa et al. 2012) investigated the impact of elevated carbon dioxide (580 ppm) on canopy radiation interception and its use in relation to yield components of two pigeon pea cultivars Pusa-992 and PS-2009. The lead area index and above-ground biomass were significantly higher during most of the growth stages for plants exposed to higher CO_2 concentration. In cultivar Pusa-992, seed yield increased by 12% under elevated CO_2 because of increase in pod numbers and weight. But in this cultivar, the significant increase (41%) in biomass under elevated CO_2 did not translate into a corresponding increase in seed yield due to lower harvest index and fewer numbers of seed per pod. Under elevated CO_2, the other cultivar PS-2009 became indeterminate and did not mature, resulting in undeveloped pods. Hence in PS-2009, elevated CO_2 resulted in poor seed yield, pod numbers and pod weight even though the biomass produced was higher. Elevated CO_2 in the future may result in higher biomass production and higher radiation use efficiency in pigeonpea due to carbon fertilization, but may not cause a corresponding gain in grain yield because it may lower harvest index.

Socioeconomic vulnerability to climate change

Pigeonpea, like sorghum, millet and groundnut, is typically part of mixed cropping systems in the Semi-Arid Tropics (SAT) and are rarely grown as a monocrop over large areas. Data on value by commodity for these crops are hard to find in Africa, and there is little information on how household vulnerability may change in the future as a result of climate-induced changes in the production and productivity of these crops.

The SAT contains about 160 million rural poor, of whom 100 are in India. Poverty is declining in rural India, but not elsewhere. Rural households are predominantly net buyers of food, so any reduction in production and/or increases in price affect them proportionately more, women headed households especially (Walker 2010). The SSA and SA regions, where 99% of the world's pigeonpea is grown, are characterized by high levels of undernourishment and poverty. Currently there are more undernourished people in both of the two regions than there were 20 years ago (FAOSTAT 2010). The total number of undernourished people in the two regions accounts for approximately 63% of the world total. Estimates from various sources suggest that more than 1.6 million rural households (about 8 million people) in SSA and more than 5 million households in SA (about 30 million people) grow pigeonpea for their use as sources of improved nutrition, animal feed, for income generation and for maintaining soil fertility (Abate et al. 2012). When abiotic and biotic constraints to pigeonpea production are aggravated by climate change, the poorest households of SSA and SA are particularly vulnerable.

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2.16 Potato

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The importance of potato for food and nutrition security

Potato is an important food crop (Walker et al. 1999, Hijmans 2001) that feeds more than a billion people worldwide from a global total crop production that exceeds 300 Mt on 18.5 million ha (FAOSTAT 2012). Two subspecies of the cultivated potato, *Solanum tuberosum tuberosum* and *S. tuberosum andigena*, account for nearly all of the world's production. Potato ranks as the fourth largest food crop in the world, following rice, wheat, and maize and it is fundamental to the food security of millions of people across South America, Africa, and Asia, including Central Asia. Currently more than half of global potato production comes from developing countries. The largest potato production continents are Europe and Asia with 43% and 38% of world's production, respectively. Country-wise, China, Russian Federation, India, United States of America, and Ukraine are the largest producers. Rapid expansion of potato production over the past 20 years has occurred in developing countries, particularly in Africa and Asia where production has more than doubled. Potato remains an essential crop in developed countries where per capita production is still the highest in the world.

Potato is particularly suited to cool climates. It is widely cultivated in the temperate, subtropical, and cool tropical regions where it is grown as a monoculture, in crop rotation, or via multiple cropping. Rotation with other crops is often necessary to ameliorate problems of disease and other pests. In temperate regions, cold temperatures and short frost-free periods limit potato production to one growing season per year, as a monoculture or in a three-year or longer crop rotation with maize, soybean, sorghum, or sugar beet in areas with high rainfall or irrigation; and with wheat, maize, millet, barley, and oats in arid and semi-arid environments, such as the water deficit areas of northern China where potato is a rain-fed and short-season crop (90–110 days). In northern Europe and North America, potato production is generally carried out with intensive agricultural practices, including high rates of fertilization, pesticide use, and irrigation where necessary. Two-to-four-year rotations include oilseeds, cereals and legumes. In the subtropics, potato is found in a range of cropping systems. In the cool tropics, potato is commonly a once a year (in a couple of countries twice-a-year) rain-fed crop grown as a long-season (180 days) monoculture or as part of a rotation with maize, legumes, quinoa, or vegetables, as in the Andean and East Africa highlands. Two crops per year are not uncommon at lower elevations. Regional information on potato is summarized in Table 2.16.1.

Based on past projections and historical trends, estimated growth rates in potato production in developing countries for the period 1993–2020 are between 2.02% and 2.71%. As these projections were done as part of a global model for the world's major food commodities, they also permit estimates of the future value of production. These calculations show that the potato will most likely maintain, if not increase, its relative economic importance in the food basket for developing countries in the decades ahead. However, climate change could pose a serious threat to potato production worldwide.

Biological vulnerability to climate change

The effects of climate change on crop production can be complex. The potato crop is very sensitive to changes in temperature and relative humidity. These changes have both direct and indirect effects on productivity. The first expression of climate change relates to higher temperatures. The response of the crop to changes in temperature is driven by changes in emergence, metabolic, photosynthesis and respiration rates, and total dry matter production. Higher temperatures bring about reduced tuber initiation, debased photosynthetic efficiency, a reduced translocation of photosynthates to the tuber, and increased dry matter (DM) partitioning to stems but reduced root, stolon, tuber and total DM and total tuber number. Potato yields will suffer whenever temperatures at critical growth and development stages depart from their optimum range. Some of these responses are depicted in Figure 2.16.1.

CIP has assessed the expected impact of climate change on global potato production (Hijmans 2003). Average monthly data for current and future climate were used. Scenarios from five Global Climate Models (GCMs) were used: CGM1 (Canadian Center for Climate modeling and analysis), CSIRO-Mk2 (Australian Commonwealth Scientific and Industrial Research Organization), ECHAM4 (German Climate Research Center), GFDL-R15 (US Geophysical Fluid Dynamics Laboratory), and HadCM2 (UK Hadley Center for Climate Prediction). Data were supplied by the Intergovernmental Panel on Climate Change Data Distribution Center (1999). Global average temperatures for the current climate and the five scenarios were calculated for terrestrial cells only, without considering Antarctica. The potential potato yield was calculated using the LINTUL simulation model (Van Keulen and Stol 1995).

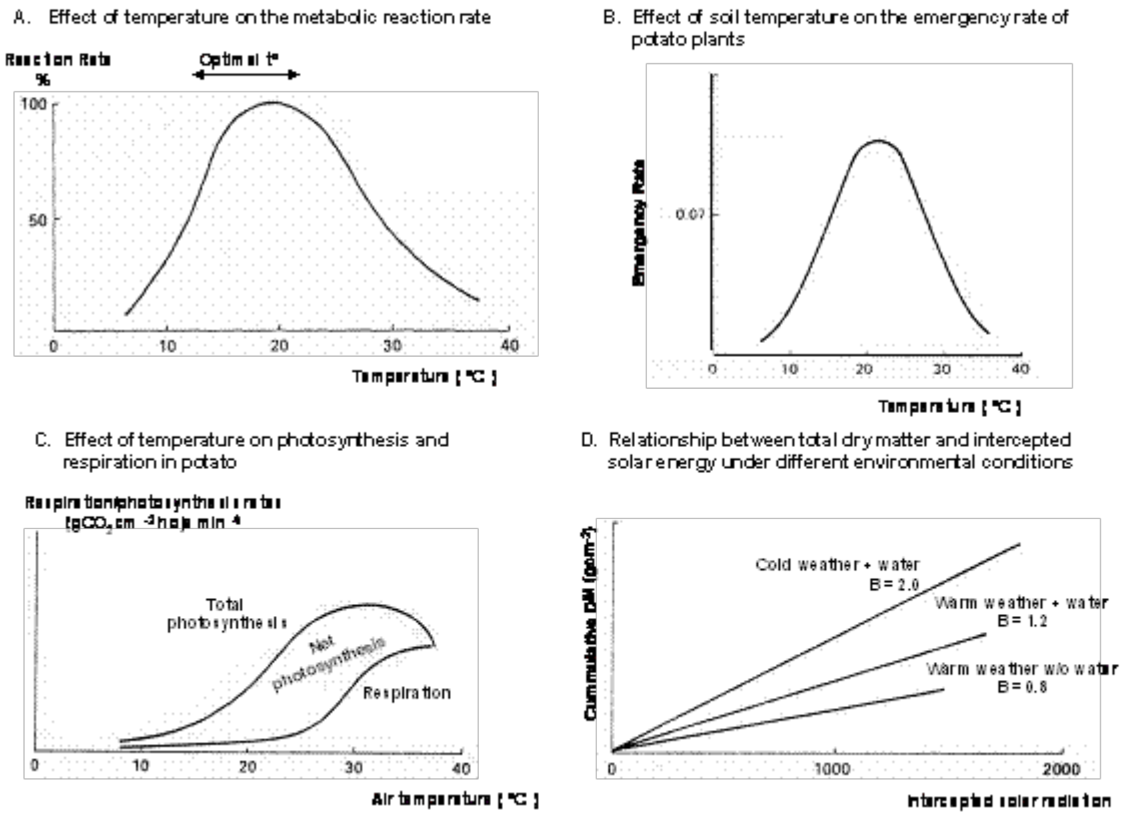
Table 2.16.1. Potato statistics by region

	Average productior per year (1000 Mt)	Per capita productior (kg)	Average area (1000 ha)	Yield (kg/ha)	Apparent consumptior per person (kg)	Quantity (kg/person/year	Calories (kcal/person/day	Protein (g/person/day
Year	2005-2010	2005-2010	2005-2010	2005-2010	2007	2007	2007	2007
Africa	19018	20	1646	12	19	14	27	0.6
Eastern Africa	7244	24	813	9	24	16.6	32	0.7
Middle Africa	818	7	170	5	8	6	12	0.2
Northern Africa	7934	39	336	24	33	27	54	1
Southern Africa	2041	36	68	30	38	30.3	59	1.2
Western Africa	981	3	260	4	3	2.2	4	0.1
Americas	40347	45	1578	26	46	36.5	64	1.7
Northern America	24009	70	585	41	70	57	92	2.5
Central America	2203	15	85	26	20	15.6	27	0.5
Caribbean	301	8	14	21	10	8.2	14	0.3
South America	13834	36	894	15	38	28.9	59	1.7
Asia	138191	35	8559	16	33	23.7	45	1
Central Asia	5957	100	372	16	100	60.4	111	2.6
Eastern Asia	73283	48	5009	15	47	31.4	61	1.4
Southern Asia	47233	29	2586	18	27	20.2	38	0.9
South-Eastern Asia	2251	4	162	14	5	4.3	8	0.2
Western Asia	9467	51	430	22	48	37.6	72	1.6
Europe	123524	169	6793	18	178	91.4	166	3.9
Eastern Europe	75738	257	5335	14	282	121.1	222	5.3
Northern Europe	11172	115	364	31	137	97.1	173	4
Southern Europe	7698	51	405	19	73	57.6	102	2.4
Western Europe	28916	154	690	42	121	69	127	2.9
Oceania	1759	64	47	37	67	53.3	85	2.1
Australia and New Zealand	1756	70	47	37	71	56.4	90	2.3
Melanesia	3	1	-	7	20	20	36	0.8
Micronesia	-	-	-	-	-	5	8	0.2
Polynesia	1	1	-	9	25	22.9	34	0.7

Source: FAO 2012

The results show that potential potato yield can be severely affected if no adaptation to the variation is allowed (18–32%) whereas with adaptation the potential yield decreases by 9–18 % but large differences between regions exist. Results by country are summarized in Table 2.16.2, which shows yield changes to 2050. Current and projected potential yield were compared for two cases: with and without adaptation. Adaptation is narrowly defined as changes in the month of planting or in the maturity class of the cultivar. This is sometimes referred to as ‘autonomous adaptation’ in the sense that these are inexpensive and can be carried out at the farm level (McCarthy et al. 2001). In the case of ‘without adaptation,’ potential yield for projected conditions is calculated for the combination of cultivar and month of planting that gave the highest yield for the current climate.

Figure 2.16.1. Potato response to changes in temperature



A. Effect of temperature on the metabolic reaction rate

B. Effect of soil temperature on the emergency rate of potato plants

C. Effect of temperature on photosynthesis and respiration in potato

D. Relationship between total dry matter and intercepted solar energy under different environmental conditions

Source: Midmore 1988

In addition to a direct physiological effect on potato yield, climate change may indirectly affect potato production and productivity through the negative impact of pest and diseases. Among them, potato late blight caused by the pathogen *Phytophtora infestans* is the most important disease affecting the crop worldwide. Temperature is very important in late blight.

For instance, CIP data show that if temperatures increase at the higher altitudes in the tropical highlands, fungicides will be needed in areas where no application is required now. Besides late blight, there are several emerging potato diseases, which could be exacerbated by climate change. Various re-emerging and newly emerging viruses are threatening the crop and these viruses have the potential to severely limit potato production if new climate conditions favor their vectors.

Table 2.16.2. Simulated changes in potato yields to 2050 for selected countries

Country	Potato area Ha x 1000	Change in potential yield (%)		Areas with yield increase (%)	
		Without adaptation	With adaptation	Without adaptation	With adaptation
China	3430	-22.2	-2.5	8.5	30.7
Russia	3289	-24	-8.8	12.4	48.4
Ukraine	1534	-30.3	-24.8	0	2.7
Poland	1290	-19	-16.1	0	2.4
India	1253	-23.1	-22.1	0.4	2
Belarus	692	-18.8	-16.6	0	0
United States	548	-32.8	-5.9	1.4	20.1
Germany	300	-19.6	-15.5	0	0
Peru	263	-5.7	5.8	8.3	13.9
Romania	262	-26	-9.9	0	19.2
Turkey	207	-36.7	-17.1	9	10.4
Netherlands	181	-20	-10.9	0	0
Brazil	177	-23.2	-22.7	0	0
United Kingdom	169	-6.2	8.1	50	57.1
France	168	-18.7	-6.9	4.5	29.9
Colombia	167	-32.5	-30.6	4.5	4.5
Kazakhstan	165	-38.4	-12.4	2.3	9.4
Iran	161	48.3	-13.3	0	21.4
Canada	155	-15.7	4.6	17.9	55.5
Spain	142	-31.4	-6.6	0	37.5
Bangladesh	140	-25.8	-24	0	0
Bolivia	131	8.4	76.8	22.6	29
Lithuania	126	-13.7	-9.2	0	0
Argentina	115	-12.9	0.5	11.4	35.2
Nepal	115	-18.3	-13.8	0	16.7
Japan	102	-17.4	-0.9	8.8	41.2

Source: Hijmans 2003

Socioeconomic vulnerability to climate change

A case study is described here that shows a typical pattern of climate vulnerability in a potato-based farming household. This study was conducted in the center of origin of the potato, in the Andes (Sietz et al. 2011). Given the strong relationship between climate risks and food security, this study analyzed how the constitution of agro-pastoral production systems and people's management capacity translate into vulnerability when being exposed to climate extremes. Following an overview of the study region in the Andes, the study describes the underlying mechanisms and quantitative indication of climate vulnerability in relation to food security. Food security has four dimensions: food availability, access to food, stability of supply, and access and utilization. Climate extremes in the Andes have an impact on food security primarily in terms of food availability, stability of production systems, and access to food. Climate is an important production factor, which influences food availability through its direct impacts on agricultural production. Besides, climate-related pests and diseases reduce food availability and affect the stability of the production system. Decreased income from reduced crop and livestock production ultimately diminishes the household's access to food. Therefore, households that generate more climate-independent income (such as some non-agricultural income) can better assure their access to food. This income determines the household's purchasing power in times of crop failure. Climate vulnerability with respect to food security in the smallholder systems investigated is based on the household's agricultural production and reserves in food and livestock as well as monetary assets. Climate vulnerability is thus considered to be a condition mediated by the differential distribution of productive assets, climate risk management, and access to monetary assets. By decreasing potato production, climate change can seriously affect food security. In countries where potato is a staple food crop, higher per capita consumption levels are associated with the population strata with the lowest income (Walker et al. 1999). The impacts of climate change on potato production are thus likely to affect the poor, with concomitant increases in malnutrition and mortality if no adaptation measures are taken. It is highly likely that climate change in the future will increase the use of fungicides, herbicides and insecticides, which may also have serious negative effects on human health.

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2.17 Rice

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The importance of rice for food and nutrition security

World paddy rice production, some 672 Mt in 2010, is spread across some 114 countries. Most of the big producers are in Asia, which accounts for 90% of the total, with two countries, China and India, growing more than half the total crop. For most rice-producing countries where annual production exceeds 1 Mt, rice is the staple food. In Bangladesh, Cambodia, Indonesia, Lao PDR, Myanmar, Thailand, and Vietnam, rice provides 40–70% of the total calories consumed. Notable exceptions are Egypt, Nigeria, and Pakistan, where rice contributes only 5–10% of per capita daily caloric intake.

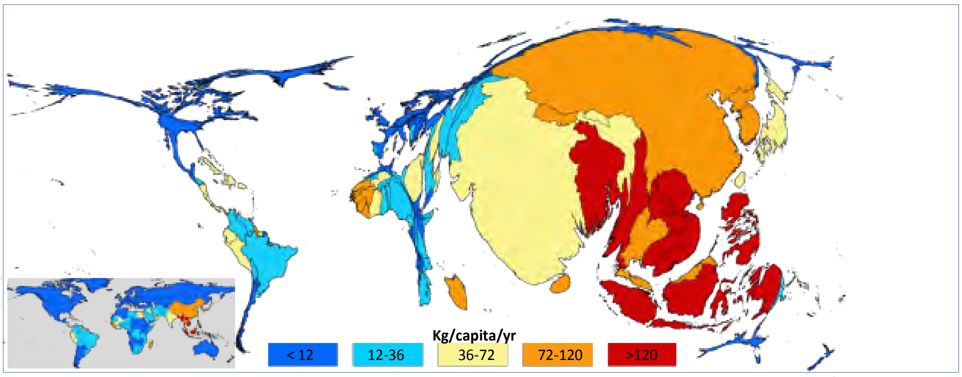
Rice is grown on some 144 million farms worldwide in a harvested area of about 160 Mha, the vast majority in Asia, where it provides livelihoods not only for the millions of small-scale farmers and their families but also to the many landless workers who derive income from working on these farms. The typical Asian farmer plants rice primarily to meet family needs. Nevertheless, nearly half the crop on average goes to market; most of that is sold locally. Only 7% of world rice production was traded internationally during 2000–2009. The world's largest rice producers by far are China and India. Although its area harvested is lower than India's, China's rice production is greater due to higher yields because nearly all of China's rice area is irrigated, whereas less than half of India's rice area is irrigated.

The only countries outside Asia where rice contributes more than 30% of caloric intake are Madagascar, Sierra Leone, Guinea, Guinea-Bissau, and Senegal, excluding countries with populations less than 1 million. Global consumption patterns are shown in Figure 2.17.1. Whilst per capita consumption has always been high in Asia it has more than doubled in the rest of the world over the last 50 years. As global population moves towards 8 billion, such trends in rice consumption reveal new challenges and opportunities for rice production around the world.

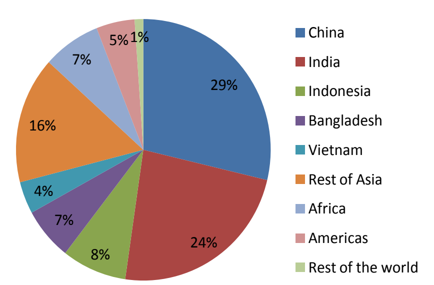
Despite Asia's dominance in rice production and consumption, rice is also very important in other parts of the world. In Africa, for example, rice has been the main staple food for at least

50 years in parts of western Africa (Guinea, Guinea-Bissau, Liberia, Sierra Leone) and for some countries in the Indian Ocean (Comoros and Madagascar). In these countries, the share of calories from rice has generally not increased substantially over time. In other African countries, however, rice has displaced other staple foods because of the availability of affordable imports from Asia and rice's easier preparation, which is especially important in urban areas. In Côte d'Ivoire, for instance, the share of calories from rice increased from 12% in 1961 to 22% in 2007. Rice production in Africa has grown rapidly, but rice consumption has grown even faster, the balance being met by increasing quantities of imports.

Figure 2.17.1. World rice consumption



Territory size represents the proportion of milled rice worldwide that is consumed in that territory. Color shows the per capita consumption of milled rice. Inset map shows a more traditional representation.



Proportion of the world milled rice consumed in each region

The highest rice consuming countries in kg/capita/yr

Brunei Darussalam	245	Sri Lanka	97
Vietnam	166	Guinea	95
Laos	163	Sierra Leone	92
Bangladesh	160	Guinea-Bissau	85
Myanmar	157	Guyana	81
Cambodia	152	Nepal	78
Philippines	129	Korea, DPR	77
Indonesia	125	China	77
Thailand	103	Malaysia	77
Madagascar	102	Korea, Republic of	76

Top 20 per capita rice consuming countries

(1) Food supply quantity data from FAOSTAT - http://faostat.fao.org/site/609/DesktopDefault.aspx?PageID=609#ancor
(2) See http://www.worldmapper.org for more examples of cartograms where territories are re-sized on each map according to the subject of interest

In Latin America and the Caribbean, rice was a preferred pioneer crop in the first half of the 20th century in the frontiers of the Brazilian Cerrados, the savannas of Colombia, Venezuela, and Bolivia, and in forest margins throughout the region. Today, rice is the most important source of calories in many Latin American countries, including Ecuador and Peru, Costa Rica and Panama, Guyana and Suriname, and the Caribbean nations of Cuba, Dominican Republic, and Haiti. It is less dominant in consumption than in Asia, however, because of the importance of wheat, maize, and beans in regional diets. Brazil is by far the largest producer, and it accounts for nearly half (46% in 2006–08) of paddy production in the region.

More than 50% of all calories consumed by humans are provided by rice, wheat, and maize. Human consumption accounts for about 76% of total production for rice compared with 63% for wheat and 14% for maize (Table 2.17.1). Rice is the world's most important food crop for the poor (Dawe et al. 2010). Altogether, rice provides 20% of global human per capita energy and 15% of per capita protein, although rice's protein content is modest, ranging from about 4–18%.

Table 2.17.1. World food picture, 2009-2010

						Per capita/day (2007)	
Crop	Area (Mha) 2009	Area (Mha) 2010	Production (Mt) 2009	Food consumed (million ton) 2007		Calories	Protein (g)
Rice (rough)	158.3	153.7	685.2	522.6		532.6	10.0
Maize	158.6	161.8	818.8	110.3		138.9	3.4
Wheat	225.6	216.8	685.6	433.9		529.9	16.1
Millet and sorghum*	73.7	75.6	82.8	52.0		65.5	1.9
Barley and rye*	60.6	52.9	170.3	11.6		12.9	0.4
Oats	10.2	9.1	23.3	3.5		3.0	0.1
Potato	18.7	18.6	329.6	208.7		58.9	1.4
Sweet potatoes and yams*	13.0	12.9	151.5	77.6		31.7	0.4
					Subtotal	1373.4	33.6
					All foods	2797.6	77.1
* Computed by adding the two crops							

Source: FAOSTAT online database

Biological vulnerability to climate change

Rice cultivation has a wide geographic distribution, and climate change is likely to exacerbate a range of different abiotic stresses, including high temperatures coinciding with critical developmental stages, floods causing complete or partial submergence, salinity which is often associated with sea water innundation, and drought spells that are highly deleterious in rainfed systems.

Temperatures beyond critical thresholds not only reduce the growth duration of the rice crop, they also increase spikelet sterility, reduce grain-filling duration, and enhance respiratory losses, resulting in lower yield and lower-quality rice grain (Fitzgerald and Resurreccion 2009, Kim et al. 2011). Rice is relatively more tolerant to high temperatures during the vegetative phase but highly susceptible during the reproductive phase, particularly at the flowering stage (Jagadish et al. 2010). Unlike other abiotic stresses heat stress occurring either during the day or night have differential impacts on rice growth and production. High night-time temperatures have been shown to have a greater negative effect on rice yield, with a 1°C increase above critical temperature (>24 °C) leading to 10% reduction in both grain yield and biomass (Peng et al. 2004, Welch et al. 2010). High day-time temperatures in some tropical and subtropical rice growing regions are already close to the optimum levels and an increase in intensity and frequency of heat waves coinciding with sensitive reproductive stage can result in serious damage to rice production (e.g., Zou et al. 2009, Hasegawa et al. 2009).

Floods are a significant problem for rice farming, especially in the lowlands of South and Southeast Asia. Since there were no alternatives, subsistence farmers in these areas depend on rice which—in contrast to other crops—thrives under shallow flooding. Complete or partial submergence is an important abiotic stress affecting about 10–15 Mha of rice fields in South and South East Asia causing yield losses estimated at US$1 billion every year (Dey and Upadhyaya 1996). These losses may increase considerably in the future given sea level rise as well as an increase in frequencies and intensities of flooding caused by extreme weather events (Bates et al. 2008).

Rice is a moderately salt sensitive crop (Maas and Hoffman 1977). As for drought tolerance, salt stress response in rice is complex and varies with the stage of development. Rice is relatively more tolerant during germination, active tillering, and toward maturity but sensitive during early vegetative and reproductive stages (Moradi et al. 2003, Singh et al. 2008). The increasing threat of salinity is an important issue; as a result of sea level rise, large areas of coastal wetlands may be affected by flooding and salinity in the next 50 to 100 years (Allen et al. 1996). Sea level rise will increase salinity encroachment in coastal and deltaic areas that have previously been favourable for rice production (Wassmann et al. 2004).

Drought stress is the largest constraint to rice production in the rainfed systems, affecting 10 million ha of upland rice and over 13 million ha of rainfed lowland rice in Asia alone (Pandey et al. 2007). Dry spells of even relatively short duration can result in substantial yield losses, especially if they occur around flowering stage. Drought risk reduces productivity even during favourable years in drought-prone areas, because farmers avoid investing in inputs when they fear crop loss. Inherent drought is associated with the increasing problem of water scarcity. In Asia, more than 80% of the developed freshwater resources are used for irrigation purposes, mostly for rice production. Thus, even a small savings of water due to a change in the current practices will translate into a significant bearing on reducing the total consumption of fresh water for rice farming. By 2025, 15–20 million hectares of irrigated rice will experience some degree of water scarcity (Bouman et al. 2007). Many rainfed areas are already drought-prone under present climatic conditions and are likely to experience more intense and more frequent drought events in the future.

The abiotic stresses outlined above are responsible for significant annual rice yield losses. However, their occurrence is often in combination in farmers' fields, causing incremental crop losses (Mittler 2006). Breeding for abiotic stresses has typically been pursued individually. A 'stress combination matrix' illustrates the interactions between different abiotic stresses such as heat and drought, and heat and salinity (Mittler 2006). Combined stresses have been observed to increase negative effects on crop production—for example, combined heat and salinity stress (Moradi and Ismail 2007). This suggests the need to develop crop plants with high levels of tolerance for combinations of stresses. Indeed, recent research has highlighted the physiological, biochemical, and molecular connections between heat and drought stress (Barnabas et al. 2008, Rang et al. 2011).

Socioeconomic vulnerability to climate change

Sustainable growth in rice production worldwide is needed to ensure food security, maintain human health, and sustain the livelihoods of millions of small farmers. Demand for rice has been steadily increasing over the years due to population and income growth in major rice-consuming countries, and global demand for rice may increase by about 90 Mt (paddy equivalent) by 2020 (Mohanty 2009). One of the most serious long-term challenges to achieve sustainable growth in rice production is climate change (Vaghefi et al. 2011, Wassmann and Dobermann 2007, Adams et al. 1998, IFPRI 2010). Rice productivity and sustainability are already threatened by biotic and abiotic stresses, and the effects of these stresses may be further aggravated by changes in climate in many places.

The net economic benefit of developing and disseminating a combined drought- and flood-tolerant rice variety in South Asia was estimated by Mottaleb et al. (2012) using an ex ante impact assessment framework, a partial equilibrium economic model, and the crop growth simulation model ORYZA2000 (Bouman et al. 2001). The estimated cumulative net benefits of a combined drought- and flood-tolerant variety released in 2016 (for the period 2011–50 and discount rate at 5%) amounted to $1.8 billion for the whole of South Asia. This work also showed that in 2035 rice production, consumption would be higher, and retail prices lower, if such a variety were developed and released in the region, compared with the case where the variety was not developed and released. Production increases range from about 3–5%, compared with the baseline, and the price of rice in India, for example, would be about 22% higher if the variety were not developed and released.

Considering that the change in the global climate will result in more extreme events such as floods, droughts, and cyclones, substantial economic benefits can be achieved from the development of improved rice varieties that are more resilient to climate change. This type of technology would allow rice producers to adapt to a worsening global climate and make them better able to mitigate the adverse effects of climate change in the future. In the long run, the returns to the investment of developing ‘climate change tolerant’ variety are high. Otherwise, resource-poor rice farmers in South Asia will remain highly vulnerable and food safety in the region may be at stake if new multiple stress-tolerant varieties of rice are not available in the near future.

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2.18 Rice in Africa

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The importance of rice for food and nutrition security in Africa

Rice has always been a common staple for some countries in Africa (Table 2.18.1). However, it is now also the most rapidly growing food source across the continent. The rate of urbanization in Africa is greater than in any other region of the world, and this means a shift towards convenience foods such as rice. Rice consumption in Africa is increasing rapidly because of changes in consumer preferences and urbanization. In 2009, the continent imported one-third of what is available on the world market, costing an estimated US$5 billion. Soaring and highly volatile rice prices and relatively low levels of global stocks are predicted to remain the norm over the next 10 years. As witnessed by the food crisis in 2008 this is a very risky, expensive and unsustainable situation, and it may lead to severe food insecurity and civil instability in some African countries. However, Africa has the human, physical and economic resources to produce enough rice to feed itself.

Table 2.18.1. Rice statistics for Africa

Region	Average production per year ('000 Mt)	Per capita production (kg)	Average area (1000 ha)	Average yield (kg/ha)	Apparent consumption per person (kg)	Quantity (kg/ person/ year)	Calories (kcal/ person/ day)	Protein (g/person/ day)
Year	2001/10	2001/10	2001/10	2001/10	2001/2007	2007	2007	2007
Eastern Africa	5,090	20.5	2,300	2,213	14.6	13.58	136.5	2.79
Northern Africa	6,670	43.1	680	9,809	20.7	16.01	167.72	3.23
Middle Africa	540	3.6	600	900	6.8	10.08	100.73	1.88
Southern Africa	10	0.1	10	1,000	8.5	18.35	180.52	3.47
Western Africa	8,570	31.5	5,010	1,711	32.5	32.76	323.62	6.48
Africa (Total)	20,880	22.6	8,610	2,425	19.0	19.65	196.96	3.91

Source: FAOSTAT

Per capita production = Average production per year / estimated average population of the region (2001–2010)

Apparent consumption per person = Food supply quantity / estimated average population of the region (2001–2007)

By 2020, Africa's rice production will have increased by 21.53 Mt and imports will have declined as compared to 2011 by 19%, leading to a situation where the continent is at least 80% self-sufficient in rice. This production enhancement will be due to an increase in average sustainable yields across rice ecosystems (3.96% per annum) and a sustainable increase in harvested area (2.42% per annum). Rice productivity can be enhanced through the adoption of input-efficient, stress-tolerant, higher-yielding, and enhanced-quality rice varieties, small-scale mechanization and improved and sustainable agronomic practices, reduced post-harvest losses, and policy improvements to ensure equitable access for poor rural and urban consumers (Africa Rice Center 2011).

Biological vulnerability to climate change

The impacts of climate change on rice production and productivity can be summarized by the following factors: heat stress, increased night-time temperature, flooding, drought and salt stress. Rice is a tropical crop. It can withstand high temperatures, but unfortunately also rice has its limits. During the vegetative stage rice can withstand night temperatures up to 25 °C and day temperatures up to 35 °C. Higher temperatures will result in reduced photosynthesis.

Another phenomenon related to high daytime temperatures is heat stress. Heat stress causes spikelet sterility, eventually leading to high yield loss. Rice is particularly sensitive to heat stress at the flowering stage, which may occur when the temperature rises above 35 °C. Especially, the time of day when rice opens its flower is very important, because it is at that moment that rice is most vulnerable to high temperatures. The fact that African rice (*Oryza glaberrima*) flowers early in the morning, while Asian rice (*Oryza sativa*) flowers just before noon, unleashed the search for the African rice early flowering trait that enables the rice flower to escape the heat of the day.

The effect of increased CO_2 on rice yield is not yet fully understood. It is generally thought that the positive effects of increased CO_2 levels, or CO_2 fertilization, will disappear through the simultaneous increase in temperature.

Increased night-time temperature has a negative effect on rice grain yield. After analyzing data from Los Banos, Peng et al. (2004) found that the associated grain yield declined by 10% for each 1 °C increase in minimum temperature in the dry season, while there was no clear effect of an increase in maximum temperature.

The latest edition of the Intergovernmental Panel on Climate Change's report on climate change (IPCC 2007) predicts increased droughts for the African continent. Since most of the African agriculture is rainfed, this will have negative consequences on crop yields. The same holds for rice production. An estimated 80% of the rice-growing area in Africa is devoted to rainfed rice production, while 48% is for upland and 32% for rainfed lowland production. While rainfed upland rice production will be hit hardest, the rainfed lowland production may be negatively affected too. Although better protected against drought, rainfed lowlands face an increased probability of being confronted with flooding. While rice can easily withstand flooding it can withstand complete submergence only for a short time. New rice varieties that have been introgressed with the Sub1 gene can stand submergence for three weeks as was reported by IRRI (Wassmann et al. 2009). At AfricaRice, studies are under way on producing rice with less water (Figure 2.18.1).

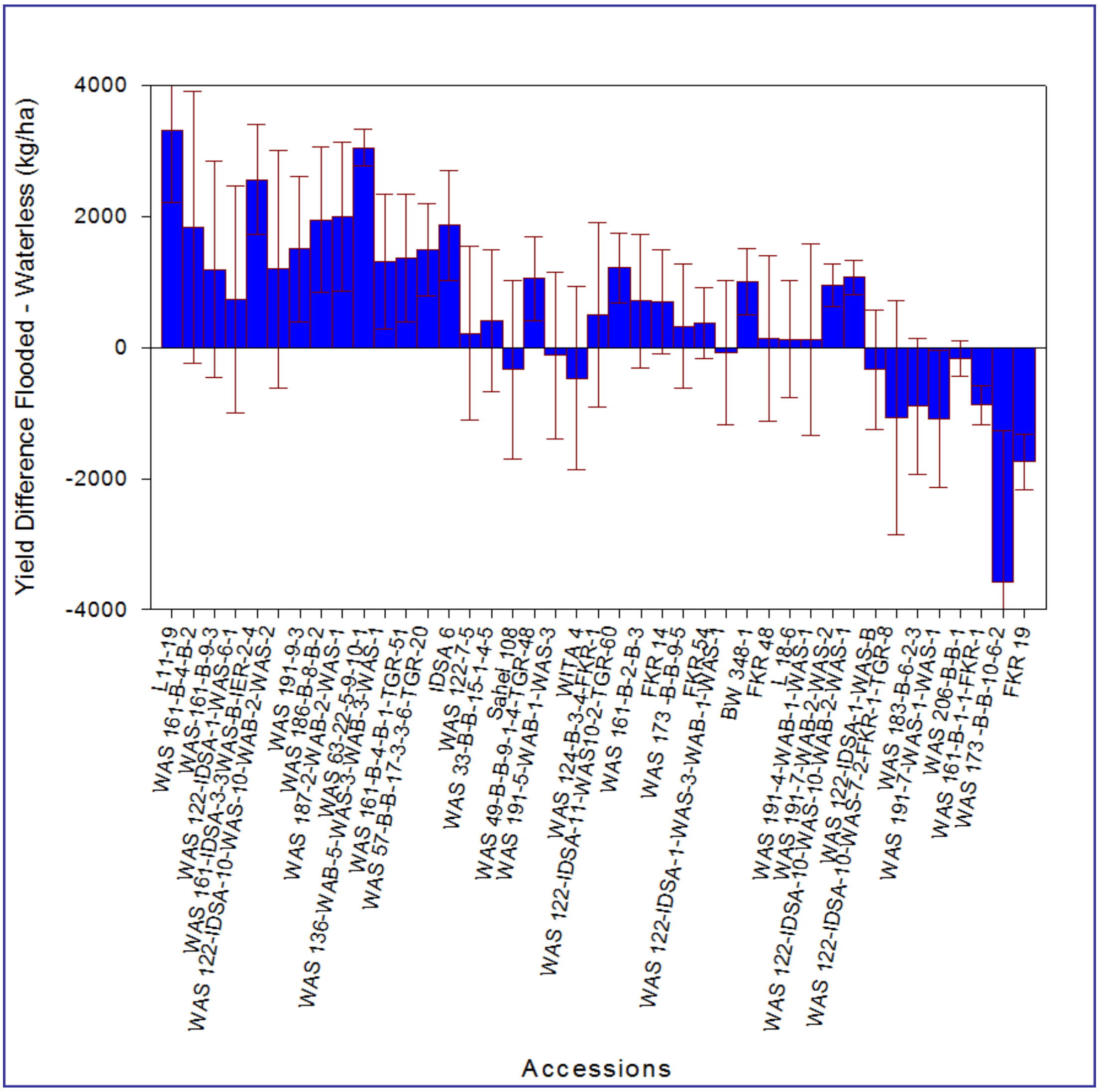
Increased temperature will lead to an increase in evaporation. Increased evaporation may lead to increased salinity and sodicity inland, while in coastal areas sea level rise will increase salinity. As a result, an increase in salt stress associated with climate chance is expected to occur. Rice is moderately tolerant to low levels of salt, while mangrove rice varieties are known to withstand high levels of salt. Efforts are being made to identify the genes that confer salt tolerance.

AfricaRice currently has two research projects studying the effect of climate change on pest and diseases. One is studying the effect of climate change on the virulence and distribution of blast and bacterial leaf blight, while the second is concentrating on the effect of climate change on the vigor and distribution of parasitic rice weeds.

Socioeconomic vulnerability to climate change

Africa is one of the less-researched continents in terms of the potential consequences of global warming. Trends suggest that the variability of rainfall will increase and the monsoon regions may become drier, leading to increases in drought-prone areas in the Sahel and southern Africa. Equatorial zones of Africa may receive more intense rainfall. The overall spatial distribution of future rainfall remains uncertain, however, particularly for the Sahel for which there are a number of contrasting projections. Climate change is expected to lead to major changes in rainfall distribution, increased frequency of extreme weather events, and generally rising temperatures and CO_2 levels. Farmers have great experience in dealing with climate risk, but the fast pace of change means that their local knowledge and technologies may not be sufficient as new conditions emerge.

Figure 2.18.1. Testing of varieties to be grown with less water



Source: AfricaRice, unpublished data

We need to anticipate such changes and provide alternatives or measures for farmers to adapt to lower and erratic rainfall, higher demand for water, changing river discharges, and so on. New climate-resilient varieties and crop-and resource-management technologies and institutional innovations such as insurance against crop failure may help them adapt to these rapidly changing environments. Mitigation opportunities are also important. The impact of the predicted enhanced use of Africa’s lowlands for rice, slash-and-burn practices in upland environments, and increased use of nitrogen fertilizer needs more study to develop as much as possible ways to limit additional release of greenhouse gases into the atmosphere. In short, a global effort to develop targeted technological options to help African farmers to adapt to and mitigate the effects of climate change is needed.

Sub-Saharan Africa represents one of the poorest regions of the world with a high number of people living below the poverty line. It will be very difficult for these people to protect themselves against climate change, because they do not have the means or the knowledge to deal with the threats that climate change is posing to them. For this reason AfricaRice is involved in research projects that deal with all the threats listed above.

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2.19 Sorghum

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The importance of sorghum for food and nutrition security

Sorghum [*Sorghum bicolor* (L.) Moench] is cultivated in the drier areas of Africa, Asia, the Americas and Australia. It is the fifth most important cereal after rice, wheat, maize and barley, and is the dietary staple of more than 500 million people in more than 30 countries (Ashok Kumar et al. 2011). It is grown on 42 million hectares in 98 countries of Africa, Asia, Oceania and the Americas (Table 2.19.1). Nigeria, India, the USA, Mexico, Sudan, China and Argentina are the major producers. Other sorghum-producing countries include Burkina Faso, Chad, Ethiopia, Gambia, Ghana, Mali, Mauritania, Mozambique, Niger, Senegal, Somalia, Tanzania and Yemen.

Sorghum is a staple cereal in sub-Saharan Africa, its primary center of genetic diversity. It is most extensively cultivated in zones of 600–1000 mm rainfall, although it is also important in the areas with higher rainfall (up to 1200 mm), where poor soil fertility, soil acidity and aluminum toxicity are common. Sorghum is extremely hardy and produces even under very poor soil fertility conditions (where maize fails). The crop is adapted to a wide range of temperatures, and is thus found even at high elevations in East Africa, overlapping with barley. It has good grain mold resistance and thus has a lower risk of contamination by mycotoxins. The cultivated species is diverse, with five major races identified, many of them with several subgroups. This reflects farmer selection pressure applied over millennia for adaptation to diverse production conditions, from sandy desert soils to waterlogged inland valleys, growing to maturity with only residual moisture, as well as in standing water. The grain is mostly used for food purposes, consumed in the form of flat breads and porridges (thick or thin, with or without fermentation). Sorghum grain has moderately high levels of iron (> 40 ppm) and zinc (> 30 ppm) with considerable variability in landraces (iron > 70 ppm and zinc >50 ppm) and can complement the ongoing efforts on food fortification to reduce micronutrient malnutrition globally (Ashok Kumar et al. 2012). In addition to food and feed it is used for a wide range of industrial purposes, including starch for fermentation and bio-energy. Sorghum stover is a significant source of dry season fodder for livestock, construction material and fuel for cooking.

Sweet sorghum is emerging as a multi-purpose crop. It can provide food, feed, fodder and fuel (ethanol) without significant trade-offs among any of these uses in a production cycle. ICRISAT has pioneered the sweet sorghum ethanol production technology and its commercialization (Reddy et al. 2008, 2011; Ashok Kumar et al. 2010).

Table 2.19.1. Sorghum statistics by region

Region	Average production per year ('000 Mt)	Average area (1000 ha)	Average yield (t/ha)
Year	2008	2008	2008
Eastern Africa	4.59	4.29	1.07
Middle Africa	1.24	1.48	0.83
Northern Africa	4.73	6.79	0.70
Southern Africa	0.32	0.17	1.85
Western Africa	14.32	14.86	0.96
Northern America	12.00	2.94	4.08
Central America	7.02	2.09	3.36
Caribbean	0.10	0.12	0.87
South America	5.95	1.82	3.27
Central Asia	0.02	0	4.07
Eastern Asia	2.53	0.60	4.21
Southern Asia	8.09	8.03	1.01
South-Eastern Asia	0.06	0.03	1.70
Western Asia	0.66	0.56	1.18
Eastern Europe	0	0	0
Northern Europe	0	0	0
Southern Europe	0	0	0
Western Europe	0	0	0
Australia and New Zealand	0	0	0
Melanesia	0	0	0

Source: FAOSTAT 2008

Globally, sorghum production has remained more or less stable over the past 30 years, although there are notable regional differences. Area of production has decreased overall, but has remained essentially constant during the past five years on a global basis. West Africa, which produces roughly 25% of the world's sorghum, has seen a steady increase in total production over the past 25 years. Most of the increase up to 1995 is attributed to increases in area, although productivity increases also contributed; after 1995, yield increases explain most of the rise in sorghum production in the region. Recent global trends also show both grain yield and production increases. These gains may reflect increased use of improved varieties and better crop management practices (such as fertilizer micro-dosing), as well as increased demand due to population growth and higher world prices for major cereals. The yields of post-rainy season sorghum have steadily increased in India, and are in demand for their superior grain and stover quality.

Major constraints to sorghum production include shoot fly, stem borer, head bug and aphid insect pests; grain mold and charcoal rot diseases; weed competition and the parasitic plant Striga (in Africa); and abiotic stresses such as drought (especially terminal drought), high temperatures, acid soils (resulting in high levels of aluminium saturation) and low soil fertility (in terms of both macronutrients like nitrogen and phosphorus and micronutrients such as iron and zinc).

Opportunities for the future include developing hybrids to increase yields for a wider range of production systems in Africa, building on successes in India, Mali and elsewhere; and exploiting photoperiod sensitivity and temperature insensitivity to adapt to variable climates and developing new, improved plant types for ‘dual purpose’ sorghums for grain, feed and fodder uses that would increase the value of the crop. These new sorghum types would strengthen the integration of animal husbandry with crop production, resulting in higher and more stable incomes while improving soil health through increased organic matter cycling. The availability of the full genome sequence and other genetic and genomic tools will enable efficient use of the crop’s rich genetic diversity for the improvement of sorghum and other cereals.

Sorghum has been an important staple in the semi-arid tropics of Asia and Africa for centuries. It is still the principal sources of energy, protein, vitamins and minerals for millions of the poorest peoplein these regions. While total food consumption of all cereals has risen considerably during the past 35 years, world food consumption of sorghum has remained stagnant, mainly because, although nutritionally sorghum compares well with other grains, it is regarded in many countries as an inferior grain. Per caput consumption of sorghum is high in countries or areas where climate does not allow the economic production of other cereals and where per caput incomes are relatively low. These include especially the countries bordering the southern fringes of the Sahara, including Ethiopia and Somalia, where the national average per caput consumption of sorghum can reach up to 100 kg per year. Other countries with significant per caput consumption include Botswana, Lesotho, Yemen and certain provinces in China and states in India (per caput consumption is up to 75 kg per year).

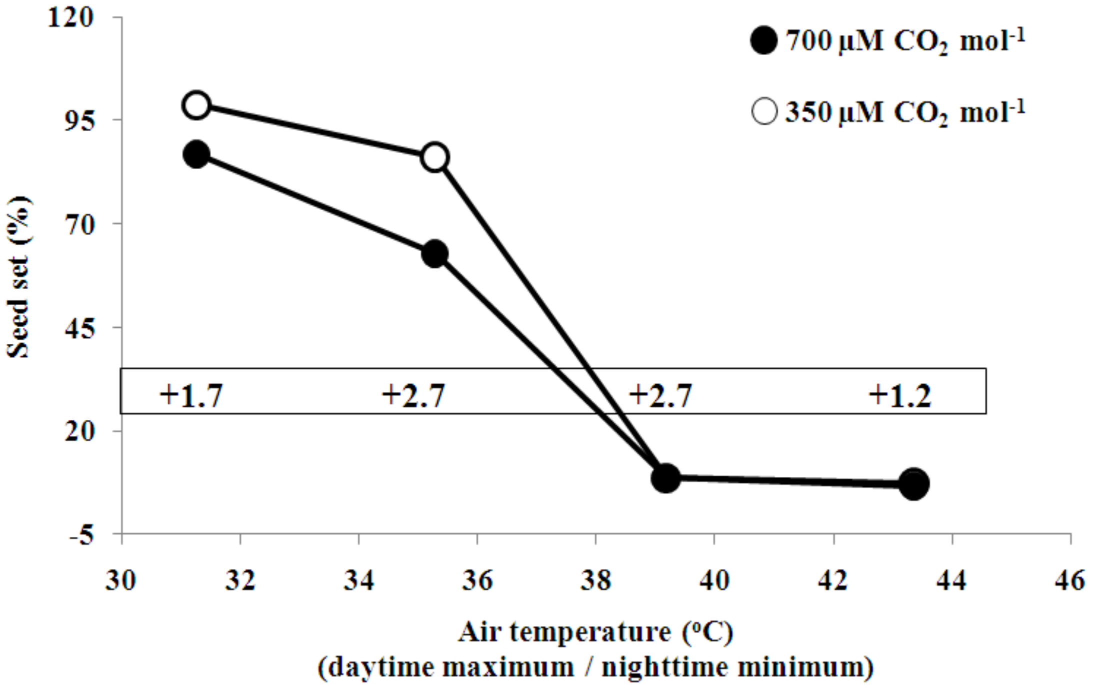
Grain use for animal feed has been a dynamic element in the stimulation of global sorghum consumption. The demand for sorghum for feed purposes has been the main driving force in raising global production and international trade since the early 1960s. The demand is heavily concentrated in the developed countries, where animal feed accounts for about 97 percent of total use, and in some higher-income developing countries, especially in Latin America where 80 percent of all sorghum is utilized as animal feed. The United States, Mexico and Japan are the main consuming countries, followed by Argentina, the former Soviet Union and Venezuela. These countries together account for over 80 percent of world use of sorghum as animal feed

Biological vulnerability to climate change

Sorghum is one of the major rainfed crops for food and fodder in tropics and subtropics of the world. These regions are already towards the higher side of the tolerant range of temperature. Thus, a small change in climate could reduce the production of the crop drastically.

Optimum temperature for reproductive growth of sorghum plants is 25 to 28 °C (Maiti 1996). High temperature (HT) stress during reproductive processes can affect the crop substantially as the reproductive processes are more sensitive to HT stress compared to vegetative processes of development (Downes 1972, Craufurd et al. 1998, Hammer and Broad 2003, Prasad et al. 2006). Growth temperatures of 40/30 °C (day/night) delay panicle exsertion by about 30 days, while panicle exsertion is completely inhibited at growth temperature of 44/34 °C (Prasad et al. 2006). As temperature increases from 32/22 to 36/26 °C, panicle length and panicle diameter decreases significantly. Beyond 36/26 °C, panicle length and panicle diameter decreases linearly. High temperatures (33/28 °C) at later stages of panicle development and at flowering induce floret and early embryo abortion, which result in lower grain yield compared to 27/22 °C (Downes 1972). Pollen viability decreases above 36/26 °C (Prasad et al. 2006). Increases in temperature from 32/22 to 36/26 °C decrease pollen germination by 26% at ambient CO_2 (350µmol mol^{-1}) and by 48% at elevated CO_2 (700µmol mol^{-1}) whereas, at elevated CO_2 pollen germination decreases by 9% at 32/22 °C and 36% at 36/26 °C (Prasad et al. 2006, see Figure 2.19.1). Prasad et al. (2008) suggested that the pre-flowering phase (10 d before flowering) is highly sensitive to HT stress (40/30 °C) as the phase coincides with microsporogenesis. The effect of temperature, CO_2 and their interaction were found to be significant on pollen germination.

Figure 2.19.1. Effect of temperature on seed-set in sorghum at two levels of CO_2. The difference in tissue temperature between ambient and high CO_2 is also shown.



Redrawn from Prasad et al., 2006.

Increase in temperature from 25 to 33.5 °C increases the rate of seed growth, which decreases both seed size and seed yield (Chaudhury and Wardlaw 1978). Similarly, Kiniry and Musser (1988) also reported increased grain growth rate and reduced grain filling duration from 22.5 to 30 °C, which resulted in lower yields.

A simulation study from India reported the sensitivity of increasing temperature and impact of the A2a emissions scenario and HADCM3 global climate model outputs for 2020, 2050 and 2080 compared to the baseline conditions (1961–1990) (Srivastava et al. 2010). The study found that a 1 °C increase in average air temperature could decrease the yield of sorghum from 4 to 8% in the rainy season in sorghum-growing regions of India. Winter sorghum suffered yield losses of 8–15% with a 2 °C rise in temperature. Results of the simulations using the A2a scenario and the HADCM3 global climate model for 2020, 2050 and 2080 indicated yield decreases of 3–76% for the rainy season and 7–32% for the winter crop (Srivastava et al. 2010).

Mastrorilli et al. (1995) observed the impact of water stress at critical stages of sorghum and reported that water stress at flowering reduces seed numbers significantly per paniculum and also reduces grain yield compared to the plants in well-watered conditions, while water stress at seed setting and seed ripening does not show any significant difference. Water stress at flowering reduces final biomass by 52%, number of seed per panicle by 58%, and grain yield by 61%.

Simulated changes in yields of sorghum are presented in Table 2.19.2 where yields of the crop in 2000 are compared to 2050 with climate change and without climate change (without CO_2 fertilization in both the conditions). Two climate change models, the CSIRO (Commonwealth Scientific and Industrial Research Organization, Australia) model and the NCAR (National Center for Atmospheric Research, US) model for 2050 were used to simulated yield impacts. Both the scenarios project increase in temperature and precipitation by 2050. Yields of sorghum are projected to increase by 106% by 2050 globally in the 'no climate change' situation. Sorghum showed a global decline in yield in both the climate change scenarios. Increases in yields of both model runs in some regions were not large enough to compensate for the global yield reduction.

Table 2.19.2. Simulated impact of climate change on sorghum production

Crops/Scenarios	South Asia	East Asia	Europe And Central Asia	Latin America And The Caribbean	Middle east and north Africa	Sub-Saharan Africa	Developed countries	Developing countries	World
2000 (mmt)	8.4	3.1	0.1	11.4	1.0	19.0	16.9	43.0	59.9
2050 No CC (mmt)	9.6	3.4	0.4	28.0	1.1	60.1	20.9	102.6	123.5
2050 no CC (% change)	13.9	11.6	180.9	145.3	12.2	216.9	23.6	138.7	106.2
CSIRO (% change)	-19.6	1.4	-2.7	2.3	0.3	-2.3	-3.1	-2.5	-2.6
NCAR (% change)	-12.2	6.7	-10.4	4.3	0.7	-3.0	-7.3	-1.5	-2.5

Source: Nelson et al., 2009

Socioeconomic vulnerability to climate change

Sorghum, like millet, groundnut and pigeonpea, is typically part of mixed cropping systems in the Semi-Arid Tropics (SAT) and it is rarely grown as a monocrop over large areas. There is little information available as to how changes in the production and productivity of sorghum may affect households in the SAT.

The SAT contains about 160 million rural poor, of whom 100 are in India. Poverty is declining in rural India, but not elsewhere. Rural households are predominantly net buyers of food, so any reduction in production and/or increases in price affect them proportionately more, women headed households especially (Walker 2010). In India the sorghum, millet, groundnut and pigeonpea area now accounts for about 30% of the cropped area and about 20% of the value of production, so the net effects on vulnerability in India as a whole are less than 50 years ago (Walker 2010). In India agriculture still accounts for about 40% of per capita income in rural areas, and in the SAT of sub-Saharan Africa, it will account for considerably more than this. Most rural households are still substantially reliant on rainfed agriculture for their livelihoods, and their resilience is generally low.

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2.20 Soybean

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The importance of soybean for food and nutrition security

Soybean is a relatively new crop in sub-Saharan Africa (SSA). This notwithstanding, some farmers in the region have adopted the crop especially in the moist savannahs. Research into the development of improved varieties of soybean has been continuing for some years and the efforts have resulted in new lines that farmers now grow in their fields. Side by side with the development of new improved high-yielding varieties was research into how soybean could be processed for consumption in SSA. The grains are rich in protein and vegetable oil. Some recipes have been developed which have facilitated the adoption of soybean in peoples' diet. Oil millers have also taken up the processing of soybean into vegetable oil and the cake that remains after oil extraction is used for compounding food for poultry and some other livestock. The availability of ready markets for soybean grains has enhanced the remarkable increases being recorded in the quantity being produced and the land area planted to the crop in SSA (Table 2.20.1 and Table 2.20.2)

Biological vulnerability to climate change

The effect of average temperature on yields has been widely studied in econometric analyses, and generally has a negative effect on soybean (Kucharik and Serbin 2008) and crop (Lobell and Field 2007) yields. The productivity of crop and livestock systems is extremely vulnerable to climate change. For example, US crop yields could decrease by 30–46% over the next century under slow global warming scenarios, and by 63–82% under the most rapid global warming scenarios. Temperature influences crop growth and development through its impact on enzyme and membrane controlled processes. Crop yields increase gradually between approximately 10–30 °C, but when temperature levels go over 30°C, soybean yields fall steeply. Carbon acquisition by photosynthesis typically has a temperature optimum close to the normal growth temperature for a given crop, while the carbon loss via respiration increases with temperature (Lambers et al. 1998). Therefore, crop growth will be indirectly controlled by temperature due to the balance between photosynthesis and respiration rates. Temperature also serves as a controlling factor for developmental processes, and the accumulation of low or high temperatures often serves as cues for flowering and fruit

Table 2.20.1. Soybean statistics by region

Region	Average Area Harvested per year (1000 ha)	Average Production per year (1000 t)	Average Yield (kg/ha)	Food supply quantity (1000 t)	Food supply quantity (kg/capita/yr)	Food supply quantity (g/capita/day)	Food supply (kcal/capita/day)	Protein supply quantity (g/capita/day)	Fat supply quantity (g/capita/day)
Year	2001-2010	2001-2010	2001-2010	2001-2007	2001-2007	2001-2007	2001-2007	2001-2007	2001-2007
World (Total	90,712	212,794	2,342	9,707	1.5	4.2	14.3	1.371	0.5
Africa (Total	1,152	1,275	1,104	567	0.6	1.7	6.8	0.600	0.3
Eastern Africa	334	364	1,095	85	0.3	0.9	3.4	0.297	0.2
Middle Africa	44	24	555	20	0.2	0.5	1.9	0.181	0.1
Northern Africa	10	31	2,912	17	0.1	0.2	0.8	0.094	0.0
Southern Africa	178	307	1,686	45	0.8	2.3	7.7	0.873	0.4
Western Africa	585	547	950	397	1.5	4.1	16.6	1.391	0.7
Americas (Total)	68,837	182,205	2,643	689	0.8	2.2	4.6	0.551	0.1
Northern America	30,715	84,140	2,737	33	0.1	0.3	0.7	0.076	0.0
Central America	97	172	1,797	28	0.2	0.5	1.8	0.196	0.1
Caribbean				10	0.3	0.8	2.6	0.296	0.1
South America	38,023	97,892	2,578	617	1.7	4.6	9.3	1.144	0.2
Asia (Total)	19,004	26,403	1,390	8,382	2.2	6.0	21.0	1.996	0.8
Central Asia	38	65	1,603	0.1	0.0	0.0	0.0	0.000	0.0
Eastern Asia	9,683	16,202	1,673	6,714	4.4	12.2	43.0	3.981	1.5
Southern Asi	8,130	8,560	1,044	990	0.6	1.8	5.9	0.667	0.3
South-Eastern Asia	1,133	1,515	1,334	583	1.1	2.9	10.8	0.977	0.4
Western Asia	18	58	3,214	93	0.5	1.5	2.9	0.314	0.1
Europe (Total)	1,693	2,861	1,719	63	0.1	0.2	0.7	0.073	0.0
Eastern Europe	1,268	1,662	1,288	16	0.1	0.2	0.4	0.050	0.0
Northern Europe				5	0.1	0.2	0.3	0.029	0.0
Southern Europe	342	991	2,884	4	0.0	0.1	0.2	0.029	0.0
Western Europe	81	207	2,570	37	0.2	0.6	1.6	0.179	0.1
Oceania (Total)	25	49	2,003	4	0.2	0.5	1.0	0.094	0.0
Melanesia				0.3	0.2	0.5	0.8	0.087	0.0
Micronesia				0.1	0.5	1.4	2.4	0.237	
Polynesia				0.3	0.6	1.7	3.0	0.291	0.0

Source: FAOSTAT 2012

maturation stages (Atkinson and Porter 1996). Because of the importance of temperature an increment could lead to longer growing seasons (this means a major quantity of accumulated heat or degree days in the period, but a minor chill hour), reduction of cycles of crops (so the rate of heat will be faster), and changes in the efficiency of photosynthesis (negative or positive). Temperature changes also vary both regionally and seasonally. In this sense, Schlenker and Roberts (2009) studied the nonlinear temperature effects in the USA under climate change in: corn, soybean and cotton, and find that yields increase with temperature up to 29 °C for corn, 30 °C for soybeans, and 32 °C for cotton but that temperatures above these thresholds are very harmful resulting in an reduction on yields. The relationship between temperatures and crop yields was used to derive the effects of changes in average weather on crop yields.

They found important impacts under climate change for corn, soybeans, and cotton: 79, 71, and 60% reductions in yields, respectively, under the rapid warming scenario and 44, 33, and 25% reductions under the slower warming scenario. In a warming world, this spells problems for the agricultural industry globally. The United States produces 41% of the world’s corn and 38% of the world’s soybeans. These crops comprise two of the four largest sources of caloric energy produced and are thus critical for world food supply. As indicated by Schlenker and Roberts (2009), the 2008 nonlinear temperature effects indicate severe damages to US crop yields under climate change. They also find that yields increase with temperature up to 29 °C for corn, 30 °C for soybeans, and 32 °C for cotton but that temperatures above these thresholds are very harmful. The slope of the decline above the optimum is significantly steeper than the incline below it. By 2070, the area suitable for soy plantations could drop by 60% compared to the current production area, because of water deficiency and more intense summers. Soybean will be one of the crops that suffer most from climate change, if current production practices stay the same.

Another example, the southern and northern Brazilian Cerrado (a biodiversity hotspot larger than Mexico covered by soybean agriculture) faces the most damage, with costs up to $7.6 billion (almost US$4 billion) until 2070, in the worst case scenario. In addition, warmer temperatures are expected to lead to more extreme rainfall events, with erosion and soil degradation more likely to occur. Global warming would also affect soil fertility.

Table 2.20.2. Soybean oil statistics by region

Region	Average production per year ('000 t)	Food supply quantity (1000 t)	Food supply quantity (kg/capita/yr)	Food supply quantity (g/capita/day)	Food supply (kcal/capita /day)	Protein supply quantity (g/capita/day)	Fat supply quantity (g/capita/day)
Year	2001-2010	2001-2007	2001-2007	2001-2007	2001-2007	2001-2007	2001-2007
World (Total)	33,582	21,718	3.4	9.4	82.0	0.010	9.3
Africa (Total)	276	1,141	1.3	3.5	30.8	0.000	3.5
Eastern Africa	41	194	0.7	2.0	17.3	0.000	2.0
Middle Africa	1	82	0.8	2.1	18.4		2.1
Northern Africa	199	550	2.9	7.8	68.9	0.010	7.8
Southern Africa	32	180	3.3	9.0	79.7		9.0
Western Africa	4	133	0.5	1.4	12.2		1.4
Americas (Total)	21,015	10,847	12.4	33.9	294.5	0.076	33.3
Northern America	8,981	6,691	20.1	55.2	473.6	0.170	53.5
Central America	380	625	4.4	12.0	106.3	0.010	12.0
Caribbean (Total)	29	230	6.6	18.0	159.2	0.010	18.0
South America	11,624	3,299	9.0	24.7	218.4	0.030	24.7
Asia (Total)	9,269	7,749	2.0	5.5	48.9	0.000	5.5
Central Asia	12	31	0.5	1.5	13.2		1.5
Eastern Asia	6,926	4,242	2.8	7.7	67.6	0.000	7.6
Southern Asia	1,289	2,375	1.5	4.2	37.6	0.000	4.3
South-Eastern Asia	701	648	1.2	3.3	28.9	0.000	3.3
Western Asia	341	451	2.6	7.0	61.4	0.026	6.9
Europe (Total)	3,012	1,939	2.7	7.3	65.0	0.009	7.3
Eastern Europe	191	384	1.3	3.5	31.2	0.007	3.5
Northern Europe	225	338	3.5	9.6	88.6	0.009	10.0
Southern Europe	1,066	507	3.4	9.4	82.8	0.006	9.4
Western Europe	1,530	709	3.8	10.5	92.6	0.004	10.5
Oceania (Total)	8	40	1.5	4.2	36.7	0.013	4.1
Melanesia		6	3.6	9.7	86.1		9.7
Micronesia		0.03	0.3	0.8	6.7		0.8
Polynesia		0.33	0.8	2.1	18.5		2.1

Source: FAOSTAT 2012

Climate change will modify host physiology and resistance, and alter the stages and rates of the development of pathogens; example of these is: soybean studies carried out by Eastburn et al. (2010). They evaluated the effects of elevated carbon dioxide (CO_2) and ozone (O_3) on three soybean diseases: downy mildew (*Peronospora manshurica*), Septoria (*Septoria glycines*) and sudden death syndrome (*Fusarium virguliforme*). Their results suggested that changes in the composition of the atmosphere altered the expression of the disease, and plant responses to the diseases varied considerably. For instance, the severity of downy mildew damage was significantly reduced at high levels of CO_2. In contrast, high levels of CO_2, alone or in combination with high concentrations of O_3 increased the severity of Septoria glycines. Alternatively the concentration of CO_2 and O_3 did not have an effect on sudden death syndrome. The authors concluded that high levels of CO_2 and O_3 induced changes in the soybean canopy density and leaf age, likely contributed to disease expression modification. Thus, the increase in both CO_2 and O_3 will alter disease expression for import fungal pathogens of soybean.

High CO_2 levels and/or temperature are likely to affect crop development rates. In most cases, elevated CO_2 or temperature seem to hasten development, but it has also been shown in soybean, for example, that increased CO_2 can actually prolong crop duration (Morgan et al. 2005).

Agriculture directly accounts for approximately 14% of global greenhouse gas emissions, mainly in the form of methane and nitrous oxide from fertilized soils, enteric fermentation, biomass burning, rice production, and manure and fertilizer production. Various aspects of soybean production can cause greenhouse gas emissions, including carbon dioxide from fossil fuels, deforestation, and emissions from soil management and tillage practices (PANDA 2012).

Socioeconomic vulnerability to climate change

Agricultural yields are expected to decrease for all major cereal crops in all major regions of production. Land suitability for cultivation will be reduced. Climate change will reduce soybean yield and production—also a major crop that produces protein and oil. A food shortage through climate change could result in tens to hundreds of millions of additional people at risk from hunger. Sub-Saharan Africa is particularly vulnerable in this respect as are some parts of south Asia and Central America. For the global population in 2050 the number of malnourished children could total around 24 million (AVOID 2012).

In general, African countries are particularly vulnerable to climate change because of their dependence on rainfed agriculture, high levels of poverty, low levels of human and physical capital, and poor infrastructure. The vast majority of the poor reside in rural areas and depend on agriculture for their livelihoods (Fan et al. 2009). Irrigation water supply reliability, the ratio of water consumption to requirements, is expected to worsen in sub-Saharan Africa due to climate change. Without climate change, calorie availability is expected to increase in sub-Saharan Africa between 2000 and 2050. With climate change, however, food availability in the region will average 500 calories less per person in 2050, a 21 percent decline (Nelson et al. 2009). In a no-climate change scenario, only sub-Saharan Africa (of the 6 regional groupings of developing countries studied in the report) sees an increase in the number of malnourished children between 2000 and 2050, from 33 to 42 million; climate change will further increase this number by over 10 million, resulting in 52 million malnourished children in 2050 (Nelson et al. 2009). Other regions will also be affected: Latin America and the Caribbean face average yield declines of 3 percent for soybean to 2050, while soybean yields may decline by 13 percent in East Asia and the Pacific. While additional investments to increase agricultural productivity can compensate for many of the adverse effects of climate change, Nelson et al. (2009) estimated that sub-Saharan Africa would need 40 percent of the estimated 7 billion USD per year in additional global agricultural investments, mostly for rural roads.

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2.21 Wheat

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The importance of wheat for food and nutrition security

The global annual average area under wheat during the 2008–2010 period was about 221 million ha while the corresponding production was 674 Mt (Table 2.21.1). This translated into an annual average yield of about 3 t/ha, whereby the average yield in less developed countries (LDC) and developed countries (DC) is about the same. The main difference in wheat production between LDCs and DCs is that wheat in DCs is mainly produced rain-fed while around 90% or all irrigated wheat is produced in LDCs. Wheat is the most important plant-derived protein source globally and in developing countries. In terms of food security, the mean annual per capita wheat consumption in the 2008–2010 period was about 76 kg with notable variation across different regions of the world.

The highest per capita consumption with 190–230 kg per year is in North Africa, Eastern Europe, the former Soviet Union and West Asia, where wheat provides 35–60% (Tajikistan) of daily calories. The biggest wheat producers are China and India, which together produce 200 Mt, or around 30% of all wheat. On the other hand, regions like the Pacific, Andean region of South America, Mexico, Central America and the Caribbean have per capita wheat consumption of less than 50 kg per year. These are regions where rice and maize dominate diets, but they include some of the major wheat importers like Bangladesh, Brazil, Indonesia, Malaysia, Mexico, Nigeria and the Philippines (FAOSTAT 2012).

Biological vulnerability to climate change

Summary of average yield response to climate change

Recent evidence for wheat in India suggests that current crop growth models such as CERES and APSIM are probably underestimating yield losses for + 2 °C by as much as 50% for some sowing dates, if there is exposure to temperatures greater than 34 °C (Lobell et al. 2012).

Table 2.21.1. Wheat production and consumption statistics by region

Region	Average production per year ('000 Mt)	Per capita production (kg)	Average area (1000 ha)	Average yield (kg / ha)	Quantity (kg/ person / year)	Calories (kcal/ person/ day)	Protein (g/person/day)
Year	2001/10	2001/10	2001/10	2001/10	2007	2007	2007
Africa (Total)	21,188	22.9	9,425	2,242	45.6	359.5	10.8
Eastern Africa	3,057	10.5	1,716	1,770	20.7	168.3	5.0
Northern Africa	16,047	82.7	6,849	2,332	15.8	124.0	3.6
Middle Africa	18	0.2	12.8	1,445	133.	1,051.	31.7
Southern Africa	1,993	36.3	789.2	2,548	57.2	467.7	14.5
Western Africa	72	0.3	57.4	1,296	19.1	142.4	4.0
Americas	105,426	118.3	39,13	2,694	63.2	459.4	13.7
Northern	80,406	242.9	29,63	2,708	85.2	615.4	19.9
Central	3,337	22.7	679.3	4,896	34.9	259.2	7.0
Caribbean					41.9	312.9	8.9
South America	21,679	58.2	8,827	2,464	56.3	411.1	11.3
Asia (Total)	269,933	68.0	97,90	2,754	63.6	533.5	16.2
Central Asia	22,688	391.4	15,19	1,491	172.	1,305.	38.8
Eastern Asia	103,218	66.9	23,91	4,313	64.4	563.0	18.0
Southern Asia	113,538	71.1	45,22	2,507	64.2	541.2	15.6
South-Eastern	146	0.3	94.6	1,541	19.3	140.5	3.8
Western Asia	30,341	146.1	13,46	2,255	152.	1,168.	36.6
Europe (Total)	205,467	280.7	57,40	3,569	108.	819.4	25.5
Eastern Europe	96,344	323.5	38,19	2,502	122.	945.5	28.7
Northern	25,929	267.9	4,010	6,464	94.3	722.7	23.2
Southern	19,012	126.3	6,168	3,099	113.	819.1	25.8
Western	64,181	343.9	9,031	7,098	89.0	671.6	21.5
Oceania (Total)	20,066	592.6	12,72	1,567	70.7	567.1	19.7
Melanesia	0.0	0.0	0.0	1,523	73.3	539.1	15.0
Micronesia			0.0		50.6	372.6	10.8
Polynesia					62.9	480.7	12.7
World	622,083	95.0	216,5	2,869	65.9	529.9	16.1

Source: FAOSTAT 2012

For wheat, an increase of 1 °C average temperature during the growing season in semi-tropical wheat growing areas reduces the yield potential on average by 10% (Lobell et al.

2007). Lobell et al. (2012), using nine years of data from North West India, found that crop models underestimate yield losses from high temperature as much as 50% for some sowing dates. These results imply that warming presents an even greater challenge to wheat than implied by previous modelling studies, and that the effectiveness of adaptations will depend on how well they reduce crop sensitivity to very hot days. The dominant predicted response of wheat to climate change is a reduction in yield. Knox et al. (2011) reviewed 17 studies from South Asia and 20 studies from Africa and found a significant (-7.2%) mean variation in wheat yield for Africa but no significant difference for Asia.

Regional variation in yield response of wheat to climate change

Average yield responses mask some large inter- and intra-regional variation as shown by a recent study of the effects of global warming. Using two Global Climate Models, CSIRO–Mk3.0, and MIROC 3.2 combined with the 'A1' scenario from the Special Report on Emissions Scenarios (SRES) (Nakicenovic et al. 2000), the study involves simulated benchmark wheat varieties (varieties commonly used by farmers) for each wheat mega-environment in the crop models. (The 'A1' scenario involves the highest level of greenhouse gas emissions for the period under study, 2000–2050; future climate is projected to be hotter and wetter using the MIROC model and drier using the CSIRO model.) Moreover, the only stresses considered are the additional abiotic stresses (heat and drought) brought by climate change.

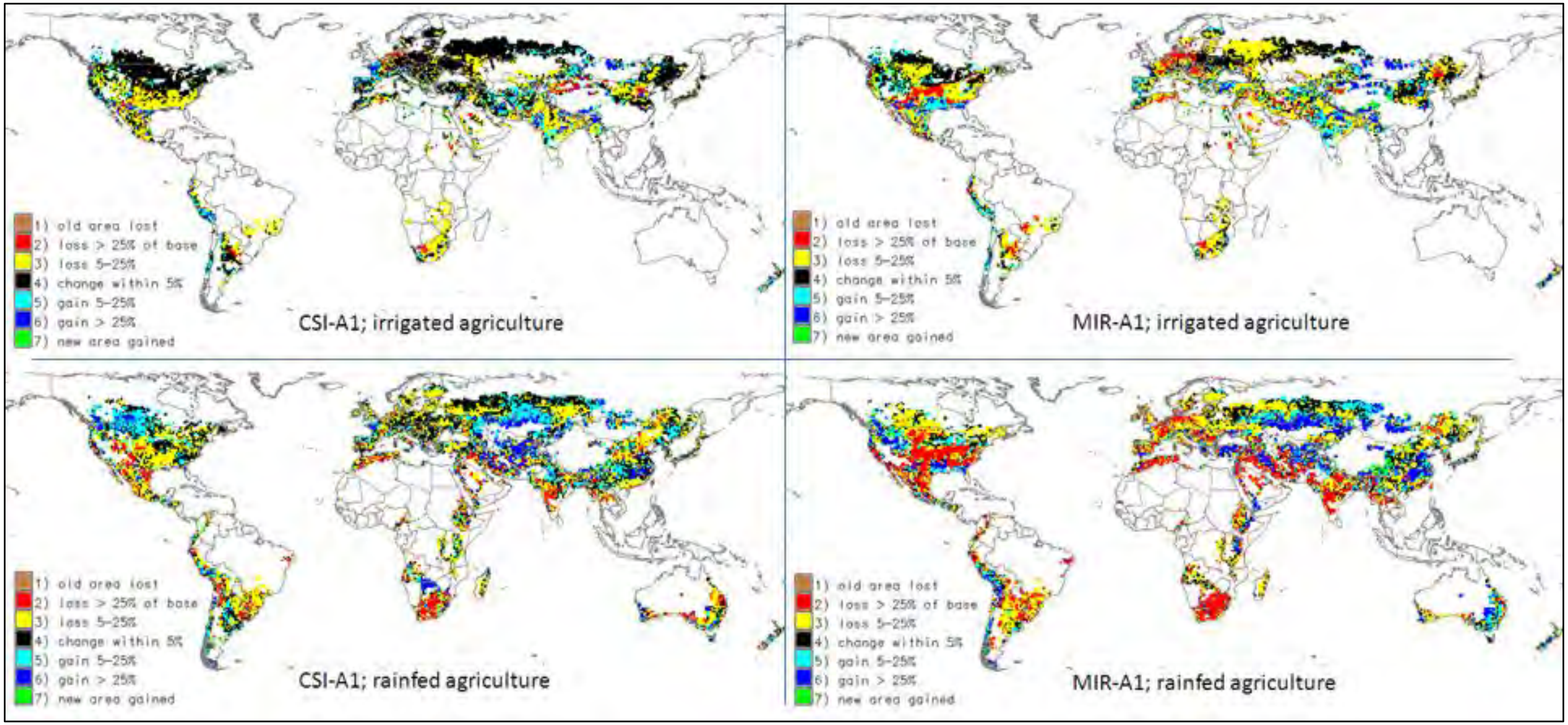
Results of this ongoing modelling effort (Gbegbelegbe et al. 2012) indicate that wheat yields in most parts of the developing world are expected to decrease due to climate change (Figure 2.21.1 and Table 2.21.2). For irrigated and rain-fed agriculture, the table reports the average yield change for wheat grown with a 2050s climate compared to a 2000 climate. Moreover, global yields for irrigated wheat production are expected to decrease more using the CSIRO climate model compared with the MIROC climate model. For rainfed wheat production, global yields are expected to decrease more using the MIROC model. The changes in global wheat yields are mainly driven by the yield changes among the major wheat producers.

Table 2.21.2. Simulated impact of climate change on wheat yields in selected regions, 2050s, for the SRES A1FI emissions scenario and two climate models

Region		CSIRO GCM	MIROC GCM
Irrigated agriculture			
	World	-2.79	-0.82
	Developed	-1.73	-11.10
	Developing	-2.88	0.02
	Major wheat producers	-4.01	0.86
Rainfed agriculture			
	World	-0.82	-5.97
	Developed	-1.11	-15.08
	Developing	-0.57	0.95
	Major wheat producers	-0.73	-10.56

Source: Gbegbelegbe et al. (2012) Promising wheat technologies and the impact of climate change (draft paper)

Figure 2.21.1. Simulated impact of climate change on wheat grain yield with current/ benchmark wheat cultivars.



Source: Gbegbelegbe et al. 2012.

The case of wheat in the dry areas

In 2011, the International Center for Agricultural Research in the Dry Areas (ICARDA) conducted a simulation activity of the impact of a regionally downscaled changing climate on wheat growth and yield under rainfed, Mediterranean conditions using the CropSyst cropping systems simulation model (Stöckle et al. 2003). CropSyst was calibrated to historic, multi-year data sets on crop growth, biomass accumulation, nitrogen uptake and water use of major wheat varieties grown at ICARDA headquarters in the north of Syria. Subsequently, researchers analyzed the impact of climate change considering the future periods 2011–2030, 2046–65 and 2080–99 as provided by 15 GCMs within the framework of the IPCC CC-studies (IPCC 2007), and quantified possibilities for mitigating the negative impact of climate change by means of application of supplemental irrigation (Sommer et al. 2011). Simulation results indicated that compared to historical (1980–2010) conditions, under climate change scenario SRES A1B wheat yield (ICARDA variety Cham-1) is projected to change by on average (of 15 GCMs; long-term future: 13) +2% (0.04 Mg/ha), -7% (-0.13 Mg/ha) and -23% (-0.44 Mg/ha) considering the periods 2011–2030, 2046–65 and 2080–99, respectively (Figure 2.21.2).

Thus, after a negligible increase in yields in the immediate future, yields in the mid- and long-term future will be negatively affected by climate change. Year-to-year variability of agricultural production will also increase. Simulations revealed that the percentage of years with yields below 0.78 Mg/ha will increase from 10% historically to 16, 22 and 34% in the three considered futures. This means in one out of three years yields will be heavily affected by climate change in the long-term future.

Simulations highlighted the beneficial effect of elevated CO_2 concentrations on water use efficiency, i.e., the amount of grain produced per unit of water consumed. This is visualized in Figure 2.21.3, where grain yields are higher towards the long-term future under comparable rainfall amounts.

Not surprisingly, given the fact that water is the most growth-limiting factor, supplemental irrigation could mitigate these negative impacts, in part by allowing for earlier planting of wheat and thus avoidance of (terminal) heat stress during grain filling period. However, more irrigation water would be required in the future—on average 181 mm per season in 2080–99 compared with only 134 mm historically—to satisfy basic crop water requirements. As irrigation water resources are limited, policies on where to allocate water and how much will have to be adapted in a climate change future. Growing summer crops under full irrigation might be a less viable option.

Figure 2.21.2. Rainfed yields of wheat (Cham-1) in response to climate change as projected by some major GCM models (for GCM details see http://www.ipcc-data.org/ar4/gcm_data.html).

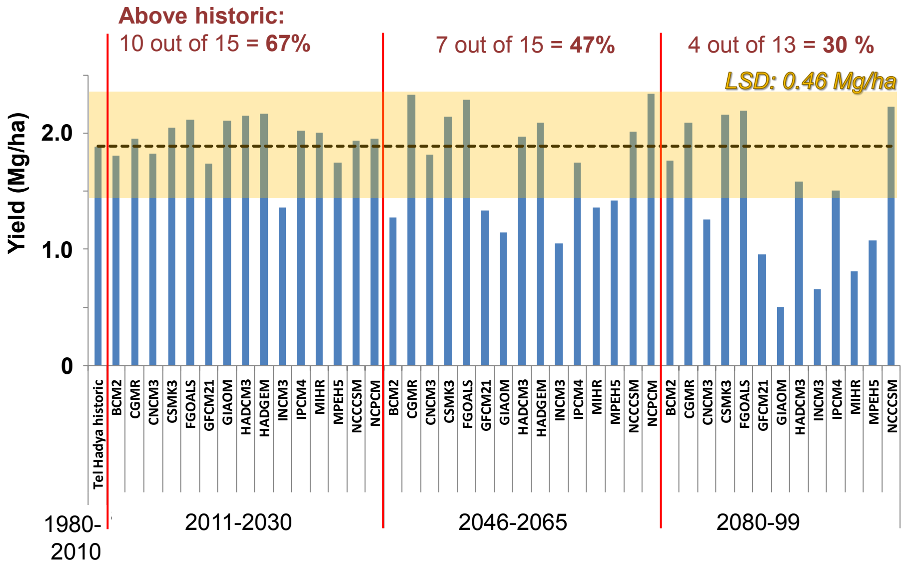
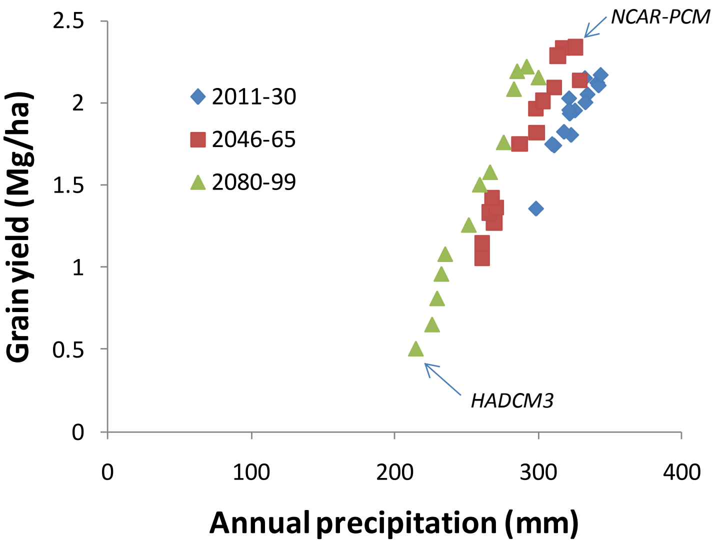


Figure 2.21.3. Average wheat grain yields plotted against annual precipitation for the future periods 2011-30, 2046-65 and 2080-99 under SRES A1B in response to climate as predicted by 15 (2080-99: 13) major GCM models in Northern Syria.



Factors underpinning temperature-induced yield loss in wheat

Warmer temperatures and more frequent exposure to high temperature events are major drivers of yield loss with climate change. In wheat, this can be mainly attributed to the following:

- More rapid crop development: warmer temperatures will reduce the size and duration of organs, and consequently resource capture (light, water and nutrients) and assimilate production for growth and grain fill.
- A 2 °C warming (at an ambient mean temperature of 10 ˚C) reduced the duration of wheat from 254 to 212 days and the reproductive phase from 130 to 114 days (Batts et al. 1997).
- Reproductive failure: high temperatures can harm crop growth at different stages of development, with reproductive tissues being the most sensitive to damage by heat stress.
- Grain fertilisation and grain set in wheat are highly sensitive to heat stress during mid-anthesis resulting in a drastic reduction in grain number and yield (Ferris et al. 1998).

Impacts of elevated CO_2 on wheat yield

There is considerable on-going debate concerning the effects of elevated CO_2 on crop growth and yield. Whilst there is a clear mechanistic basis for a direct CO_2-induced stimulation of C_3 photosynthesis, the scale of the response observed in the field has been much less than expected based on greenhouse studies only (Leakey et al. 2009). A meta-analysis of Free-Air CO_2 Enrichment (FACE) experiments gave a general trend towards increases in wheat yield (ca. 15%) under elevated CO_2, but these increases were not statistically significant (Ainsworth and Long 2005).

By 2050 atmospheric CO_2 levels are expected to be around 550 ppm. In C_3 species like wheat and rice, the elevated CO_2 level is expected to increase productivity through the improvement of CO_2 diffusion through stomata and a consequent effect on photosynthesis. However, a complex of interactions can arise among plant development, growth and environment variables. Plants that have acclimated to high CO_2 and grown new leaves over time (with typically fewer and smaller stomata) do not show the same high photosynthesis rates as a ‘normal CO_2’ plant will under short periods of exposure (Leakey et al. 2009, Parry and Hawkesford 2010). Consequently, the observed increases in yield have been only in the order of 10 to 20% for crops like wheat, when grown in open-top chambers with elevated CO_2.

Analysis of impact of elevated CO_2 on yield of wheat in India using CropSyst model showed increases in yield up to 2 °C rise in temperature at doubled (375 to 750 ppm) CO_2 condition. The increased growth response with increasing CO_2 concentration was attributed to greater tillering and more grain-bearing panicles due to increased net assimilation rate and canopy net photosynthesis under elevated CO_2 concentration. The photosynthetic acclimation to elevated CO_2 concentration in wheat occurred because of down regulation of Rubisco, through limitation imposed on Rubisco SSU gene expression, as a consequence of sugar accumulation in the leaves (Pandurangam et al. 2006). In an another study in central India, Naidu and Varshney (2011) reported that the negative effect of drought and weeds on wheat yield under rising temperatures can be ameliorated by the elevated CO_2 levels of 550±30 ppm compared to ambient (370±20 ppm) CO_2.

Socioeconomic vulnerability to climate change

Wheat farming systems, particularly those in South Asia, North Africa and West Asia, are projected to suffer most from heat stress and water scarcity due to climate change. Future food security in the densely populated countries with fast growing populations and countries that rely on imports of wheat therefore depends on reversing the stagnating productivity trends and addressing the alarming threats from climate change. Wheat is increasingly being pushed into more marginal areas due to higher prices or yields for other crops like maize, cotton, rice, soybeans, and canola. With increasing drought incidence and water scarcity, wheat is likely to be grown increasingly under rain-fed conditions. This will escalate the risks faced by farmers and expose consumers to extreme price fluctuations. At the same time, farmers can expect sharp increases in the price of fertilizers, driven by rising costs for fossil fuels and depleting reserves of phosphorus and potassium.

Slowing productivity growth from biotic and abiotic stress is further complicated by changing consumption patterns and a growing demand for wheat. The food demand for wheat has been increasing in many countries including Africa and is projected to grow by 2.6% per annum until 2020. Except in a few developing countries, the demand for wheat is being met increasingly through imports; wheat now accounts for the largest food imports (43%) to developing countries. Demand for wheat in the developing world is projected to increase 60% by 2050 (Rosegrant et al. 2009). Achieving the productivity increases needed to ensure regional and global food security will require more than a repeat performance of the Green

Revolution, because conditions have changed since the 1960s. The spread of new varieties particularly needs to go hand in hand with sustainable management practices to prevent worsening water scarcity and soil degradation, which keep farmers from realizing the benefits of new technologies and thus undercut their incentive to adopt them.

While the impact of current climatic variability and the gap between current and potential wheat yields can be reduced by investments in breeding and good agronomy, farmers will not be able to benefit from existing and future technology options if they are unable to access the improved seeds and the technologies for improved farm management as well as markets and services that facilitate wider adaptation. This suggests that there will be a need to address multiple market and government failures in the delivery of technologies, inputs and services that enhance adaptation. Many farmers currently lack access to information and services to leverage available technologies and mitigate the negative impacts of climate change on livelihoods and food security. There is a need to enhance access to available technologies–including seeds and complementary crop and resource management options–to boost the ability to manage current climatic variability as an essential first step in adapting to progressive climate change (Cooper et al. 2008). This requires new institutional arrangements and policy instruments to enhance local capacity and stimulate the adoption of improved technologies for adaptation, managing risks and protection of vulnerable livelihoods.

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2.22 Yam

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The importance of yam for food and nutrition security

Yam (*Dioscorea* spp.) plays a very important part of the food security and livelihood systems of at least 60 million people in West Africa. It is cultivated mostly in the Derived and Southern Guinea Savanna. About 48 Mt of yams (about 93% of global production) are produced on 4 million hectares annually in this sub-region, mainly in five countries, that is, Benin, Côte d'Ivoire, Ghana, Nigeria and Togo (Table 2.22.1). Nigeria alone accounts for 68% of global production (36 Mt on 3 million hectares). Yams rank as the most important source of calories in Côte d'Ivoire and among the top three contributors in Benin and Ghana (Table 2.22.2). The crop also makes a substantial contribution to protein in the diet, ranking as the third most important source of supply. This is much greater than the more widely grown cassava, and even above animal protein sources (Table 2.22.3).

Table 2.22.1. Basic statistics on production of yam in West Africa in 2008

Region / Country	Area harvested (million ha)	Yield (t/ha)	Production (million t)	% of World Production	Population (million)	Production per capita (kg)
Western Africa	*4.44*	*10.83*	*48.10*	*92.99*	*291.27*	*165.1*
Benin	0.20	8.81	1.80	3.49	8.66	208.1
Côte d'Ivoire	0.82	8.45	6.93	13.40	20.59	336.7
Ghana	0.30	11.87	3.55	6.86	23.35	152.0
Nigeria	3.05	11.50	35.02	67.69	151.21	231.6
Togo	0.06	10.20	0.64	1.23	6.46	98.8
World	*4.93*	*10.50*	*51.73*	*100*		

Source: FAOSTAT Updated December 2009

Table 2.22.2. Yam as a staple food crop in West Africa (calorie supply from major crops and ranking) for 2005 (latest available year)

Crop	Benin		Côte d'Ivoire		Ghana		Nigeria		Togo	
	Kcals/ day	Rank	Kcals/ day	Rank	Kcals/ day	Rank	Kcals/ day	Rank	Kcals/ day	Rank
Cassava	398	2	320	3	596	1	252	3	303	2
Maize	459	1	191	4	357	2	202	5	463	1
Millet	23	6	13	7	49	8	281	2	35	7
Plantain			159	5	272	4	45	8		
Rice (milled equiv)	295	4	413	2	192	5	222	4	223	3
Sorghum	127	5	12	8	72	7	340	1	173	5
Sweet Potato	18	7	6	9	10	9	42	9	1	8
Wheat	7	8	128	6	133	6	134	7	89	6
Yams	317	3	502	1	298	3	200	6	193	4

Source: FAOSTAT, Updated December 2009, Food Balance Sheet

Table 2.22.3. Yam as a protein source in West Africa (protein supply from plant and animal sources and ranking) for 2005 (latest available year)

	Benin		Côte d'Ivoire		Ghana		Nigeria		Togo		West Africa	
Item	(g/cap/ day)	Rank	(g/cap/ day)	Rank	(g/cap/ day)	Rank	(g/cap/ day)	Rank	(g/cap/ day)	Rank	(g/cap/ day)	Rank
Grand Total	54		50.4		56.8		59.8		46.8		53.56	
Wheat	0.2	10	3.7	6	3.7	7	3.8	7	2.6	6	2.8	10
Rice (milled equiv)	5.7	3	8.5	1	3.6	8	4.4	6	4.6	4	5.36	2
Maize	12.1	1	5	4	9.4	1	5.3	4	12.2	1	8.8	1
Millet	0.6	12	0.3	10	1.3	10	7.2	2	1	11	2.08	11
Sorghum	3.9	7	0.3	10	2.2	9	10.6	1	5.1	3	4.42	4
Cassava	3.3	8	2.6	7	4.9	3	1.2	11	2.5	8	2.9	9
Sweet Potatoes	0.2	10	0.1	12	0.1	12	0.6	12	0	12	0.2	12
Pulses	5.6	4	1.2	9	0.3	11	5.5	3	5.7	2	3.66	8
Oil crops	5.8	2	1.6	8	3.9	6	5.3	4	2.6	5	3.84	7
Meat	4.5	6	5.7	3	4.2	5	2.8	9	2.5	8	3.94	6
Fish, Seafood	2.8	9	4.6	5	8.8	2	2.5	10	2.4	10	4.22	5
Yams	5.1	5	8	2	4.8	4	3.2	8	3.1	5	4.84	3

Source: FAOSTAT, Updated December 2009, Food Balance Sheet

Biological vulnerability to climate change

Yam is a multispecies crop, indigenous to Africa, Asia and South America; *Dioscorea rotundata* and *Dioscorea cayenensis* are the two main species of yam crops planted without irrigation during the dry season in Africa, Latin America and the Caribbean region. It is considered that these two species have developed considerable drought tolerance strategies, and that is why planting at the beginning of the dry season by farmers is a common practice for exploiting this drought tolerance. Farmers in both the African yam belt and the Caribbean region of South America usually plant *Dioscorea rotundata* and *D. cayenensis* during the beginning of the dry season in November and December. Once the planted seed tubers break dormancy, the buds sprout and develop large vines, but the leaf buds remain in dormancy. As soon as the rainy season starts in late April and early May, the new plant switches on the production of leaves (Njoku 1963, Okezie et al. 1981, Lopez unpublished data). This strategy has been used by farmers to set up production systems that allow the harvesting of tubers at different times of the year, taking advantage of price fluctuations during the off season and consequently increasing income. As a scientific hypothesis, it has been considered that these two species of yam can tolerate extreme temperatures and dry seasons while maintaining a reasonable yield. Many farmers think that yams are best planted during the dry season (personal experience of the author in Africa and Latin America) so that they can get the best prices at early harvest in July and August. One additional strategy of these two yam species is that after the tuber is removed in July and August, the base of the plant is covered with soil and from this time to December, the plant produces another tuber with irregular shape, which is used as seed for planting during the subsequent dry season.

Wounds caused during pre-harvest, harvest and postharvest, combined with infestations of mealy bug, scale insect and beetles, insects and nematodes (*Scutellonema brady* and *Meloidogyne* spp) affect ware and seed tuber quality, and contribute to increase losses in storage. Scale insect and mealy bugs are common pest of tubers during the dry season.

Increases in rainfall could increase the normal infestations of causal agents of diseases such as anthracnose, while more drought could definitively favour the expression of virus diseases in both *Dioscorea alata* and *D. rotundata*. Nwajiuba and Onyeneke (2010) used regression and trend analysis of climate data for a period of thirty years (1978–2007) to predict the future effect of climate change on yam in the southeastern rainforest zone of Nigeria. Results show decreasing trends for rainfall and relative humidity and increasing trends for temperature and sunshine hours, with significant effects on major crop (maize, yam, and cassava) yields. In the near future, the growing of such crops in this area may be increasingly difficult if these trends continue. More recently, Odoh et al. (2012) found that clones of *D. rotundata* differed in their response to imposed water stress conditions and concluded that in view of a significant response to different water stress levels, the genetic variability available in IITA's core yam collection could be of great importance for developing drought tolerant varieties. Another concern is erratic rainfall with increased rain intensity and water logging, which will cause rot and potentially the death of the plant.

Colletotrichum gloesosporioides is a major pathogen of yam with a broad diversity of strains and a broad range of hosts in West Africa. The coincidence of susceptible crop stages with wet conditions is necessary for epidemic development of anthracnose (Emehute et al.1998); however, the pathogen has the ability to survive in host tissues when environmental conditions are unfavourable (i.e., during the dry season), bridging the gap between susceptible stages of the cropping cycle (Waller 1992), thus increasing the vulnerability of the crop.

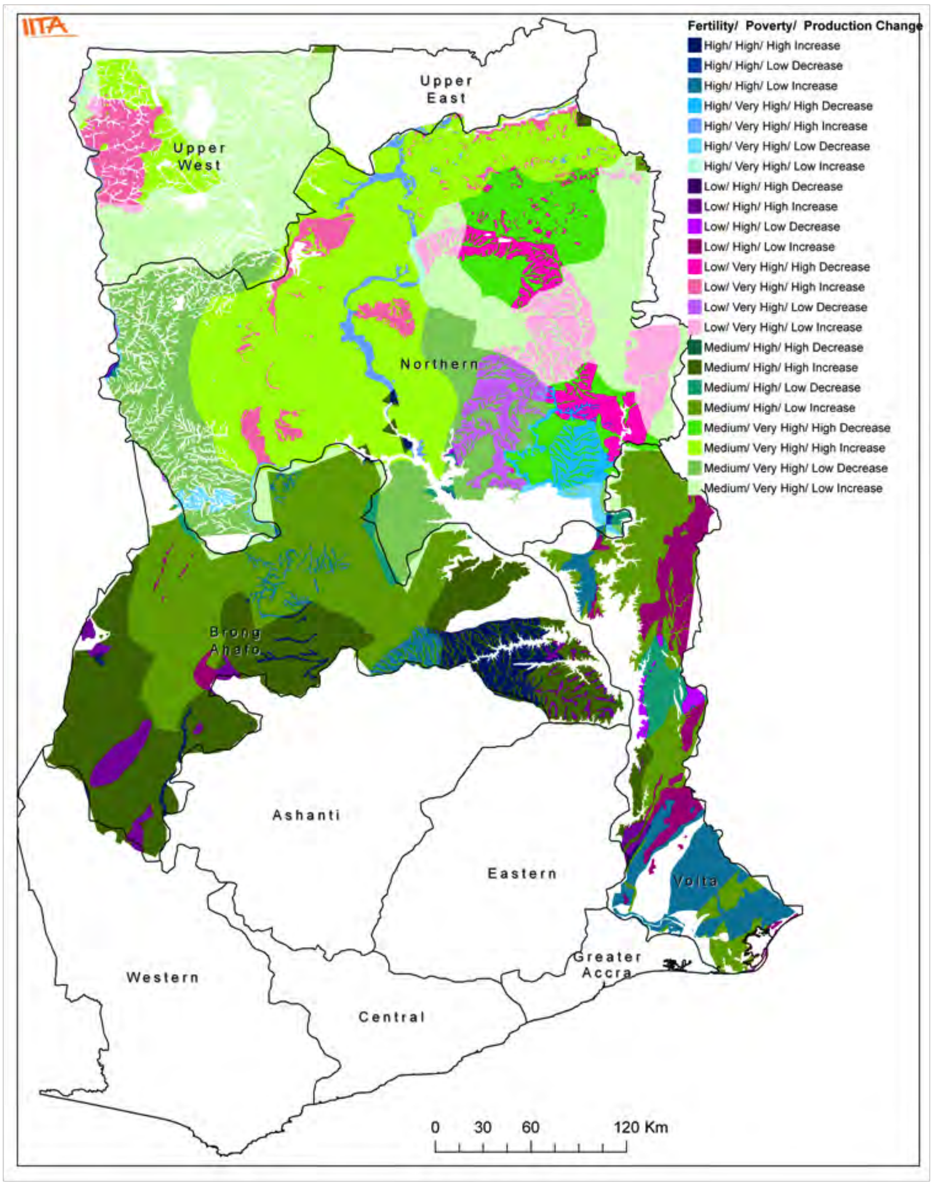
The cooler morning hours are the best time for successful pollination of yam; after this time high temperatures negatively affect the efficiency of the process. Accordingly, significant increases of temperatures could affect considerably the breeding process.

Socioeconomic vulnerability to climate change

While significant amounts of yam are being grown, productivity per hectare has remained stagnant or is declining. Since 2000, the rate of annual increase in yam production has been slowing (less than 1% per year increase in Nigeria, for example) compared with earlier dramatic increases associated with area expansion into the savannas. This decrease could be catastrophic unless steps are taken soon to change the situation (Manyong and Nokoe 2001). The decline in productivity is attributed to a combination of factors mostly associated with the intensification of cultivation due to shortened fallow periods. The constraining factors include the following: deteriorating soil structure and fertility; inadequate yield potential of popular varieties; prevalence of noxious weeds such as speargrass (*Imperata cylindrica*); increasing levels of field and storage pests and diseases (such as nematodes, mealybugs, scales, anthracnose and viruses); and high tuber losses in storage.

Production of yam in soils with low fertility and high to very high poverty levels will be extremely vulnerable. In fact there are some areas in Nigeria (Ebonyi state) where farmers have had to grow other crops as a consequence of very low yields of yam after continued cultivation in soils of low fertility. Mapping the combination of soil fertility level, high to very high poverty levels and changes in yam production during the last 15 years in Ghana (Figure 2.22.1) indicates that yam production areas with moderate soil fertility are the areas likely to be most exposed to climate change, particularly drought and increases in soil temperature (IITA, 2012).

Figure 2.22.1. Yam production systems based on changes in yam production, soil fertility and poverty in Ghana



Source: IITA, 2012

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3 Natural resource summaries

3.1 Agroforestry

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The importance of agroforestry for food and nutrition security

Local people in large parts of the tropics rely on a wide range of both indigenous and exotic tree species, overall in approximately equal proportions, to meet their needs for various products and services (Table 3.1.1). The importance of smallholder cultivation of exotic species is considerable: surveys of distribution and use clearly demonstrate the past and future importance of cross-border transfer of tree germplasm to better meet smallholders' needs. At the same time, the dangers of new introductions, due to the weedy and potentially invasive characteristics of many trees, are also obvious; these have not always been sufficiently considered, and potential problems need to be guarded against (Ewel et al. 1999).

Data on global export values for a range of 12 tree commodities that are grown primarily in the tropics are shown in Figure 3.1.1, amounting to more than US$66 billion based on figures for 2009. One notable feature of Figure 3.1.1 is the rise in palm oil export value in the last two decades, to overtake green coffee exports. The actual value of other tree commodities may be considerably higher than shown because much of the crop is sold in local markets rather than exported, perishable fruit such as mango being a good example (Mohan Jain and Priyadarshan, 2009). Nevertheless, export values provide an indication of the overall importance of a crop, with on average significant jumps in commodity prices evident in recent years.

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[3] This is a shortened version of Neufeldt H, Dawson IK, Luedeling E, Ajayi OC, Beedy T, Gebrekirstos A, Jamnadass RH, König K, Sileshi GW, Simelton E, Montes CS, Weber JC. 2012. *Climate Change Vulnerability of Agroforestry*. ICRAF Working Paper No 143. Nairobi: World Agroforestry Centre http://dx.doi.org/10.5716/WP12013.PDF

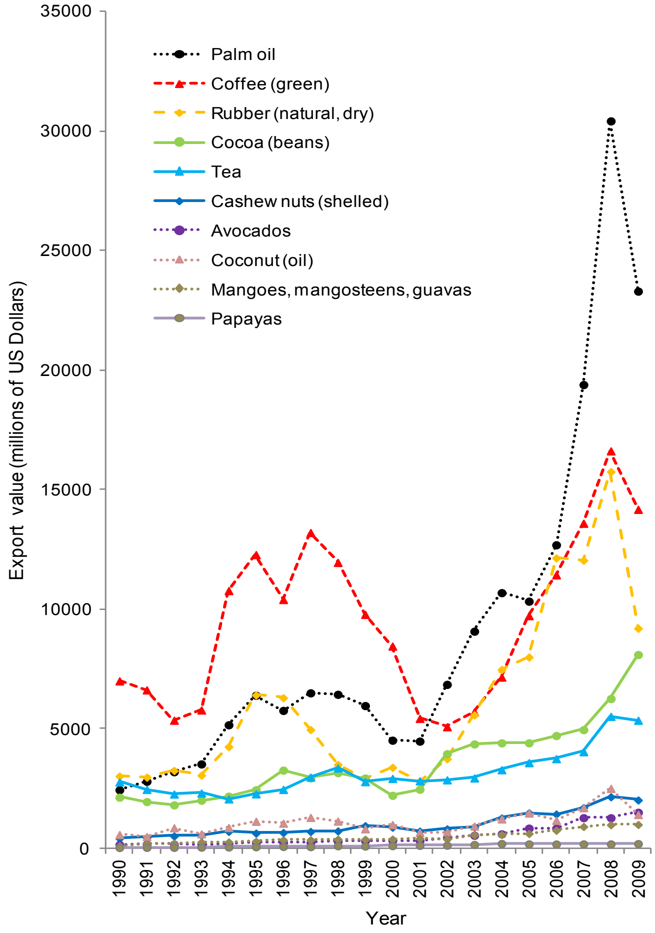
Table 3.1.1. The number of tree species mentioned in the Agroforestree Database (AFTD) as providing various functions in different regions of the tropics

		Region [2]						
Function [1]	**Origin**	Africa	Oceania	South America	South Central Asia	South East Asia	Western Asia and Middle East	Sum 6 regions
Apiculture	E	89	58	51	74	75	18	**365**
	I	88	26	32	34	46	16	**242**
	E+I	177	84	83	108	121	34	**607**
Erosion control	E	81	50	34	63	61	15	**304**
	I	94	20	23	57	56	17	**267**
	E+I	175	70	57	120	117	32	**571**
Fibre	E	85	58	40	73	82	14	**352**
	I	56	35	20	60	67	18	**256**
	E+I	141	93	60	133	149	32	**608**
Fodder	E	134	71	53	105	102	26	**491**
	I	161	30	43	112	89	35	**470**
	E+I	295	101	96	217	191	61	**961**
Food	E	137	81	68	113	115	28	**542**
	I	158	43	51	107	110	34	**503**
	E+I	295	124	119	220	225	62	**1045**
Fuel	E	167	96	73	133	133	27	**629**
	I	190	51	53	110	116	35	**555**
	E+I	357	147	126	243	249	62	**1184**
Medicine	E	167	101	86	149	158	30	**691**
	I	223	58	58	149	156	37	**681**
	E+I	390	159	144	298	314	67	**1372**
Shade/shelter	E	139	78	60	109	105	20	**511**
	I	142	53	44	84	97	26	**446**
	E+I	281	131	104	193	202	46	**957**
Soil improvement	E	95	56	40	83	84	14	**372**
	I	99	27	33	60	70	12	**301**
	E+I	194	83	73	143	154	26	**673**
Timber	E	199	119	91	160	172	34	**775**
	I	220	73	67	153	175	36	**724**
	E+I	419	192	158	313	347	70	**1499**
Sum 10 functions	**E**	**1293**	**768**	**596**	**1062**	**1087**	**226**	**5032**
	I	**1431**	**416**	**424**	**926**	**982**	**266**	**4445**
	E+I	**2724**	**1184**	**1020**	**1988**	**2069**	**492**	**9477**

[1] The AFTD contains data on a wide range of products and services provided by trees; a range of 10 of the most important functions is given here. Data are presented on the number of species given in the database as used for a particular purpose based on whether they are indigenous (I) or exotic (E) in origin to a particular geographic region. The database contains more species indigenous to Africa than to other geographic regions, which is a factor determining the greater number of total references to the African continent.

[2] The AFTD contains data on use across the globe; mentions of uses for a range of six important regions are given here. The regions of Africa, Oceania and South America were defined here according to en.wikipedia.org/wiki/List_of_sovereign_states_and_dependent_territories_by_continent. The regions of South Central Asia, South East Asia and Western Asia and Middle East were defined according to www.nationsonline.org/oneworld/asia.htm

Figure 3.1.1. Global export values of a range of tree commodity crops for the years 1990 to 2009 (combined figures for all nations providing data)



Data from the TradeSTAT database of FAOSTAT (faostat.fao.org/).

Data for mangoes, mangosteens and guava are reported together. Values include re-exports (i.e., import into one nation followed by export to another). Some commodities, such as coffee, cocoa and coconut, are exported in more than one form; for each crop, only the most important form by export value is given here.

Smallholders account for considerable proportions of production. In Indonesia, around 40% of palm oil production has been reported to come from smallholders (IPOC 2006), while some 30% of land planted to oil palm in Malaysia is reported to be under the management of small farmers (Basiron 2007). More than two-thirds of coffee production worldwide is on smallholdings (www.ico.org). With natural rubber, there has been a trend toward increased smallholder production, partly because estates have switched to less labour-intensive crops such as oil palm (see www.unctad.info/infocomm).

Many people in low-income nations are at danger from poor nutrition, with a lack of micronutrients, leading to poor health consequences for hundreds of millions. Solving malnutrition requires a range of interconnected approaches that include the bio-fortification of staple crops such as maize and rice, greater spending on food supplementation programmes, and the use of a wider range of edible plants for more diverse diets (UNICEF 2007, Negin et al. 2009). The further promotion of edible indigenous fruits, nuts, vegetables, etc., including those provided by trees, is an attractive option, as it allows consumers to take responsibility over their diets in culturally relevant ways (Keatinge et al. 2010). Furthermore, the biochemical profiles of these indigenous species in supplying micronutrients, fat, fibre and protein are often better than staple crops (Leakey 1999). The nutritional value of many forest foods is however unknown, including what genetic variation in nutritional quality is present within species, and further testing and the compilation of data are required (Colfer et al. 2006).

Communities in many parts of the tropics already incorporate many edible products harvested from forests into their diets as an important component, and a few depend on them; it has been reported that the role of these products is especially important for filling seasonal and other cyclical food gaps (Arnold et al. 2011). In addition, forests provide woodfuel needed to cook food to make it safe for consumption and palatable, and income from the sale of other products that can then be used to purchase food.

The cultivation of trees for foods once obtained from forests has the potential to improve health and incomes though local consumption and sale. Special potential for cultivation lies in the great biological diversity of indigenous foods found growing in forests that are important locally but have to date been under-researched by the scientific community. At the same time as supporting livelihoods, the cultivation of these species in farmland allows them to be conserved outside threatened forests, helping to maintain resources for future use and further development as food crops.

Biological vulnerability to climate change

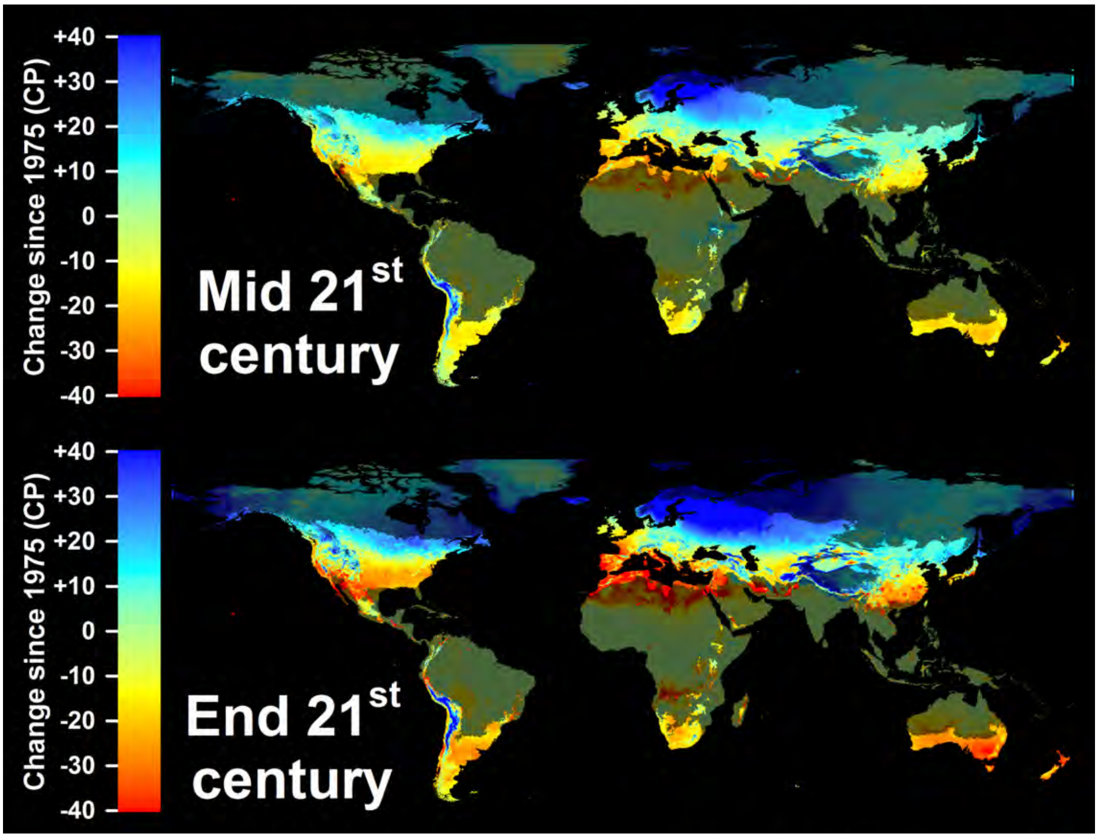
Compared to simpler agricultural systems, very little research has been done on the impacts of climate change on agroforestry systems. Experimental trials of agroforestry systems are difficult to implement and maintain in the field. Some experimental research is possible and has been conducted to investigate the possible consequences of climate change during the early stages of establishment of agroforestry systems. Provenance trials, in which tree specimens originating from different locations are grown in common gardens, can also be used to derive information on species' climate responses. For many exotic agroforestry species (such as *Calliandra calothyrsus* and *Gliricidia sepium*), such trials have been conducted, but results have yet to be systematically evaluated with a view to climate change. For most tree species grown in agroforestry systems, virtually no information on climate responses is available. The same is true for tree responses to elevated CO_2. Appropriate process-based models of agroforestry systems are yet to be developed.

Some information exists on system components. Esmail and Oelbermann (2011) analyzed the response of seedlings of the agroforestry species *Cedrela odorata* and *Glyricidia sepium* under controlled temperature and CO_2 conditions. They showed that elevated temperature accelerated seedling growth. At current temperature levels, raising CO_2 concentrations to 800 ppm had negative effects on the growth of both species. Increasing temperature had positive effects. When CO_2 concentrations and temperatures were increased, the response of *G. sepium* did not differ much from the elevated temperature treatment. In contrast, *C. odorata* growth was greatly increased in this treatment. Elevated carbon treatments greatly increased the shoot/root ratio and lowered leaf nitrogen concentrations. These results imply that for the species analyzed and for Costa Rican climate conditions (as replicated in a growth chamber in Canada), climate change will likely accelerate growth, but change plant nutrient levels in ways that are likely unfavorable for the productivity of agroforestry systems.

Luedeling et al. (2011) projected climate change effects on winter chill, an agroclimatic factor that affects agroforestry systems that include temperate fruit trees. Winter chill is needed for allowing temperate fruit trees to overcome winter dormancy. Especially for warm growing regions, winter chill was projected to decline progressively throughout the late 20th and 21th centuries (Figure 3.1.2), casting doubt on the potential of subtropical and tropical growing regions of such fruits to maintain production of currently grown tree species and cultivars. Many production regions may become unsuitable for several currently grown tree species and cultivars.

In agroforestry systems, pollinators are instrumental in ensuring system functionality. Since many pollinators of crops and trees are ectothermic organisms, they will likely be impacted by climate change, and if their rate of range shifts differs strongly from that of the plants that rely on them for pollination, ecosystem functions could be impaired. In a recent study focusing on historic shifts in North American plant and pollinator populations, Bartomeus et al. (2011) did not find evidence of such developments, but this may not be true for tropical contexts or for future climate changes. There is a big data gap on climate change effects on pollination in tropical agroforestry systems, and research is urgently needed, in particular for systems that rely on specialized pollinators.

Figure 3.1.2. Projected losses in Safe Winter Chill (in Chill Portions - CP) around the world compared to a 1975 baseline scenario. The two maps show averaged projections for three General Circulation Models, two greenhouse gas emissions scenarios for the 2050s (top map) and the 2080s (bottom map). Safe Winter Chill is the amount of winter chill that is exceeded with 90% probability for a given scenario year. In the 1975 baseline (not shown), Safe Winter Chill estimates range from 0 CP in the Tropics to about 160 CP in maritime climates of Northern Europe.



Source: Luedeling et al., 2011

Jaramillo et al. (2011) projected the likely impact of climate change on the coffee berry borer (*Hypothenemus hampei*), a major pest of coffee agroforestry systems in East Africa. Using two future climate scenarios, they projected that pest pressure will increase substantially in Ethiopia, Uganda, Kenya, Burundi and Rwanda. In some growing regions, the number of possible generations of the coffee berry borer was projected to double. Such studies suffer from the constraint that the ecological interactions in complex ecosystems cannot reliably be modeled. Pest insects may be regulated by other biological processes, which may also be strengthened by climate change.

Besides process-based projections of climate change effects on components of agroforestry systems, we are not aware of process-based attempts to model tree-based cropping systems. Yet some impact projection studies have used species distribution modeling to estimate future suitable ranges for systems; Luedeling and Neufeldt (2012) provide an example.

An indirect measure of the impacts of climate change on agroforestry systems can be derived by projected shifts in vegetation zones. The Vegetation and Climate Change in Eastern Africa (VECEA) project developed a high-resolution map of potential natural vegetation for seven African countries (Ethiopia, Kenya, Malawi, Rwanda, Tanzania, Uganda and Zambia), available in atlas and online formats (Lillesø et al. 2011, van Breugel et al. 2011). Because reliable point-location data remain scarce for the majority of those tree species that can be integrated in forestry and agroforestry systems, the VECEA map is expected to provide a more reliable proxy of habitat suitability for a greater number of species than would be inferred by species distribution models. The VECEA map is also likely the best possible tree seed zonation map for the countries that it covers. By applying the precautionary principle that planting materials (such as seeds, seedlings or cuttings) of the same species should not be transferred across vegetation boundaries, failures of agroforestry or other tree planting projects due to a breakdown of genetic adaptation can possibly be reduced significantly. Another application domain of the VECEA map is to project the possible effects of climate change. Preliminary results from one study showed that the choice of IPCC scenario or choice of General Circulation Model resulted in clear changes in the distribution of vegetation types. However, for many places the same vegetation type was predicted to occur for all scenarios or models (van Breugel et al. 2011). Caution should be applied in interpreting the results from species distribution modeling studies: biotic factors affecting ecosystems, such as pest and disease organisms, pollinators and microsymbionts, are assumed to migrate at rates corresponding to shift in vegetation types. It is also possible that new species assemblages will become established in novel climate regimes.

Socioeconomic vulnerability of agroforestry to climate change

There are relatively few studies that clearly show how agroforestry systems contribute to managing climate risk. Trees on farms may mitigate direct climate impacts, such as providing erosion control (Ma et al. 2009, Mutegi et al. 2008) or reducing the loss of grain production in drought years (Sileshi et al. 2011). But most of the effects are indirect in the sense that agroforestry tends to improve livelihoods and wellbeing and thereby reduces vulnerability to climate impacts as much as development related factors (Neupane and Thapa 2001, Mithöfer and Waibel 2003, Garrity et al. 2010). For example, smallholder farmers in western Kenya plant trees mainly as a living 'savings account' that allows them to pay for regular expenses (e.g. school fees) and emergencies. They prefer *Grevillea robusta* as a boundary tree over most other species because of its high growth rates, lack of competition with annual crops and the ability to prune it regularly for firewood (Neufeldt unpublished data).

For an example of direct effects, soil erosion is a serious problem in cultivated areas of the central highlands of Kenya as there is strong negative correlated to maize production parameters (Mutegi et al. 2008). They estimated how crop yields might be affected by introducing different erosion control measures into the conventional maize monocropping system. Their results showed that Napier grass (*Pennisetum purpureum*) alone had the highest erosion mitigating effects but that this was accompanied by a loss in maize production whereas a combination of Napier grass with leguminous shrubs (*Leucena trichandra* or *Calliandra calothyrsus*) led to a reduction of erosion and an enhancement of maize production and soil fertility, particularly in the second year of establishment of the hedges.

Most effects of agroforestry are expected to be indirect in the sense that agroforestry increases farmers' food security, livelihoods and income and thereby reduces climate vulnerability and raises the adaptive capacities. There are few quantitative results so far and few provide specific evidence on reduced climate vulnerability beyond a general increase in improved livelihoods and income. Nonetheless, for resource poor farmers being able to manage their daily challenges better with agroforestry is a clear indicator of reduced climate risk. As an example, Thorlakson and Neufeldt (submitted) analyzed coping strategies in western Kenya during a drought in 2009 and flooding in 2010. Results showed that farm productivity dropped by 60% and 39% in the Lower and Middle Nyando catchment areas, respectively, which led to on average at least one month of food shortage in addition to the 4.5 and 2.3

hunger months experienced in normal years. During the hunger periods coping strategies consist of restriction of size, diversity and number of meals taken each day. Selling of livestock at between 75% and 50% of market prices was also a typical measure. Farmers were also forced to use coping strategies that had detrimental effects in the long term such as selling oxen, which would not be available for plowing; consuming seeds reserved for planting; leasing land; and engaging in casual labor. Farmers practising agroforestry typically used fewer of these detrimental coping strategies during hunger periods. Farmers with mature trees were able to sell seedlings, timber and firewood and consume fruit from their trees (Table 3.1.2). Farmers explained that the most effective way to reduce their vulnerability to the climate-related hazards was to diversify income, including off-farm income activities. Higher farm productivity also contributed to reducing the overall climate risk.

Table 3.1.2. Proportion of farmers using coping strategies to deal with flood and drought in 2009-2010

	Lower Nyando		**Middle Nyando**	
	Treated (%)	*Control (%)*	*Treated (%)*	*Control (%)*
Reduce quantity, quality or # of meals	82	66	54	86
Help from gov, NGO, church	40	47	11	25
Borrow money	31	40	29	46
Casual labor	24	40	32	18
Sell possessions or livestock	73	66	36	43
Consume seeds	67	80	50	71
Consume or sell fruit from trees	40	25	68	38
N=	*45*	*15*	*28*	*28*

To overcome some of their vulnerabilities, poor farmers often rely on social safeguard systems, as opposed to financial safeguards. Chaudhury et al. (2011) described how social protection improves farmers' adaptive capacity and risk management in agroforestry contexts. Through case studies from Zambia and Honduras the paper demonstrated that linkages between social protection and adaptive capacity reinforce each other such that natural resource management through agroforestry leads to improved social protection and boosts adaptive capacity.

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3.2 Forests

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Biological vulnerability to climate change

Changes in climate have already begun to affect forests and their biodiversity, for example through the timing of reproduction in animals and plants and migration of animals, the length of the growing season, species distributions and population sizes, and the frequency of pest and disease outbreaks (Root et al. 2003). Climate change is projected to affect all aspects of biodiversity: individual organisms, populations, species distributions, and ecosystem composition and function both directly (e.g., through increases in temperature and changes in precipitation and in the case of coastal ecosystems also changes in sea level and storm surges) and indirectly (e.g., through climate changing the intensity and frequency of disturbances such as wildfires) (Williams et al. 2008).

The distribution, functioning and disturbance patterns of tropical rainforests are expected to be affected by climate change (Fischlin et al. 2007). For example, climate change could enhance drought in the Amazon and increase wildfire, climate-induced forest dieback, and large-scale conversion of tropical rainforest to savannah, with important implications for the global climate (Cox et al. 2004, Scholze et al. 2006, Nepstad et al. 2008). Biogeographical studies have shown that climate change could induce biodiversity losses in tropical forests in Africa and Latin America (Miles et al. 2004, McClean et al. 2005). In the humid tropics of north Queensland (Australia), tropical forests have been shown to be highly sensitive to warming and changes in precipitation (Hilbert et al. 2001).

Tropical mountain humid forests are particularly vulnerable to shifts in temperature and precipitation as these forests are located in areas with steep gradients and highly specific climatic conditions (Foster 2002) and because atmospheric warming raises the altitude of clouds that provide these forests with prolonged moisture (Pounds et al. 1999). In tropical dry forests, changes in rainfall and temperature can affect vegetation productivity and plant survival. A slight annual decrease in precipitation can make these forests subject to greater risk from forest fires. In tropical mangroves, the principal threat comes from sea level rise and its consequences on sediment dynamics, erosion, and salinity. Mangroves can be also affected by temperature or carbon dioxide increase, and storms (Locatelli et al. 2010).

The general effect of projected human-induced climate change is that the habitats of many species will move from their current locations (Moser et al. 2011). Species will be affected differently by climate change: They will migrate at different rates through fragmented landscapes, and ecosystems dominated by long-lived species (e.g., trees) will often be slow to show evidence of change. Thus, the composition of most current ecosystems is likely to change, as species that make up an ecosystem are unlikely to shift together. The most rapid changes are expected where they are accelerated by changes in natural and anthropogenic non-climatic disturbance patterns. Changes in the frequency, intensity, extent, and locations of disturbances will affect whether, how, and at which rate the existing ecosystems will be replaced by new plant and animal assemblages. Disturbances can increase the rate of species loss and create opportunities for the establishment of new species.

Processes such as habitat loss, modification and fragmentation, and the introduction and spread of non-native species can enhance the impacts of climate change of ecosystems (Root et al., 2003). For example, in the Amazon, the interactions between agricultural expansion, forest fires, and climate change could accelerate the degradation process (Nepstad et al. 2008).

The risk of extinction will increase for many species that are already vulnerable (Thomas et al. 2004). Species with limited climatic ranges and/or restricted habitat requirements and/or small populations are typically the most vulnerable to extinction (Ohlemuller et al. 2008), such as endemic mountain species and biota restricted to islands, peninsulas (e.g., Cape Floral Kingdom), or coastal areas (e.g., mangroves and coastal wetlands). In contrast, species with extensive, non-patchy ranges, long-range dispersal mechanisms, and large populations are at less risk of extinction. While there is little evidence to suggest that climate change will slow species losses, there is evidence it may increase species losses. In some regions there may be an increase in local biodiversity—usually as a result of species introductions, the long-term consequences of which are hard to foresee (Willis et al. 2010).

Case study: Impacts of climate change on forests and water in Central America

The definition of adaptation plans for ecosystems and people depending on them requires understanding of the likely impacts of climate change on ecosystems and their services. The Central American region will be heavily affected by climate change (Giorgi 2006). As result, changes in the availability of natural resources (e.g. water, biodiversity and biomass) will affect the 60 million people who depend heavily on them (DeClerck et al. 2010). Precipitation is expected to decrease in the future but this trend is uncertain, given the different outcomes of Global Circulation Models under different emission scenarios (Neelin et al. 2006). Assessing uncertainties is crucial for informed decision making.

Climate change will affect ecosystems and hydrology through non-linear and complex interactions between soils, vegetation and climate. A process-based model was applied in Central America to simulate the vegetation and hydrological responses to changes in climate (Imbach et al. 2012). In order to assess uncertainties in the future of ecosystems and water in the region, several climate scenarios were used to estimate the likelihood of changes in vegetation and water cycle. Different greenhouse gas emission scenarios were coupled with 23 general circulation models (GCMs) and resulted in a total of 136 climate scenarios, grouped according to emissions (low, intermediate and high emissions). The biogeographic soil-vegetation-atmosphere model MAPSS (Mapped Atmosphere Plant Soil System) was applied for simulating changes in leaf area index (LAI), vegetation types (grass, shrubs and trees), evapotranspiration, and runoff at the end of the 21st century.

LAI is likely to decrease in most of the region (from 77% to 89% of the area, depending on climate scenario groups). This shows that potential vegetation will likely shift from humid to dry types. Most of the region is expected to experience a decrease in water runoff under more than 75% of the scenarios and some areas (central Yucatan Peninsula and the mountain ranges of Nicaragua, Honduras and Guatemala) are likely to experience a decrease in runoff of more than 80%. Some small areas are likely to have a large increase in runoff, but they currently have very low runoff and therefore will remain dry in the future relative to the rest of Central America (Imbach et al. 2012). Runoff is likely to decrease even in areas where precipitation will increase, because temperature change will increase evapotranspiration. The analysis of uncertainties shows that, even though future trends in precipitation are uncertain, the impacts of climate change on vegetation and water cycle are predicted with relatively low uncertainty. This is due to the high certainty in temperature increase (Imbach et al. 2012).

Where significant ecosystem disruption occurs (e.g., loss of dominant species or a high proportion of species, or much of the species redundancy), there may be losses in net ecosystem productivity (NEP) at least during the transition period (Turner et al. 2011). However, in many cases, loss of biodiversity from diverse and extensive ecosystems due to climate change does not necessarily imply loss of productivity, as there is a degree of redundancy in most ecosystems; the contribution to production by a species that is lost from an ecosystem may be replaced by another species (Turner et al. 2011). Globally, the impacts of climate change on biodiversity and the subsequent effects on productivity have not been estimated. Modeling the changes in biodiversity in response to climate change presents some significant challenges (Sala et al. 2000). The data and models needed to project the extent and nature of future ecosystem changes and changes in the geographical distribution of species are incomplete, meaning that these effects can only be partially quantified.

Identified information needs and assessment gaps include (Gitay et al. 2002):

- Enhanced understanding of the relationship between biodiversity, ecosystem structure and function, and dispersal and/or migration through fragmented landscapes.
- Improved understanding of the response of biodiversity to changes in climatic factors and other pressures.
- Development of appropriate resolution transient climate change and ecosystem models especially for quantification of the impacts of climate change on biodiversity at all scales, taking into account feedbacks.
- Improved understanding of the local to regional scale impacts of climate change adaptation and mitigation options on biodiversity
- Further development of assessment methodologies, criteria, and indicators to assess the impact of climate change mitigation and adaptation activities on biodiversity and other aspects of sustainable development
- Identification of biodiversity conservation and sustainable use activities and policies that would beneficially affect climate change adaptation and mitigation options.

Socioeconomic vulnerability to climate change

Climate change will affect smallholder and subsistence farmers, pastoralists and fisherfolk, who depend directly on climate-sensitive activities and may have a limited capacity to adapt to rapid changes in a context of multiple stressors, as well as urban populations who rely on cheap food, fuel, water and other necessities. The impacts of climate change on forest ecosystem services will affect all those who depend on them for their livelihoods (Osman-Elasha et al. 2009).

Well-managed forests can help societies adapt to both current climate hazards and future climate change by providing a wide range of ecosystem services. For example mangroves protect coastal areas against storms and waves, forests regulate water flows and quality, and forests also provide a multiplicity of products that are used as ‘safety nets’ by local communities when agriculture is affected by weather anomalies (Locatelli et al. 2008). Such climate shocks including floods, droughts, and resultant wildfires are apt to increase in frequency and severity due to climate change. Recent spikes in the price of staple foods that reached all-time highs have been linked to climate events that devastated production in several areas of intensive cropping (Ziervogel and Ericksen 2010). Diverse, multi-functional landscapes that include forests, however, are often more resilient to climate shocks and provide the rural poor with a broader set of options for securing both food and income (Sunderland 2011). Forest foods have been shown to be especially crucial in helping the rural poor cope with seasonal shortages and recurrent climate anomalies and economic downturns (Fisher et al. 2010, Arnold et al. 2011, Djoudi et al. 2012).

The sustainable management of forests can contribute in these and many other ways to the adaptation of vulnerable people, particularly in developing countries, through an ecosystem-based approach to adaptation. Despite its name, ‘ecosystem-based adaptation’ (EbA) is a human-centred approach to adaptation. It aims at reducing human vulnerabilities through the provision of ecosystem services. For ensuring that forests continue to provide relevant ecosystem services for society (‘forests for adaptation’), their sustainable management must be a priority. When immediate pressures on forests (e.g. deforestation for land conversion) are eased, a longer term perspective and issues related to climate change can be considered (‘adaptation for forests’) (Locatelli et al. 2010).

The role of ecosystem services in social adaptation is recognized in many National Adaptation Programmes of Action (NAPAs) developed by the least developed countries. Among the 44 NAPAs submitted as of August 2010, more than 50% acknowledge the importance of ecosystem services and 45% of the references to ecosystem services are related to forests (Pramova et al. 2012). Around 22% of the proposed adaptation projects include ecosystem activities for social well-being or adaptation and deal mainly with regulating services (soil rehabilitation, erosion control and water regulation) and provisioning services (food, fibre and fuel wood). As many of them consider multiple ecosystem services and beneficiary sectors, they have the potential to strengthen cross-sectoral adaptation (Pramova et al. 2012).

Case study: Vulnerability of livestock- and forest-based livelihoods to environmental changes in northern Mali

In Northern Mali, local people have always been adapting to climate variability – with more or less success – but climate change will impose an additional burden on them. CIFOR research has shown that current national and sub national institutional arrangements may fail to support local adaptive strategies. Using a participatory approach across levels and genders, scientists have analyzed the vulnerability of livestock and forest-based livelihoods to climate variability and change in Lake Faguibine, northern Mali, where drastic ecological, political and social changes have occurred. For instance, the lake has dried out and evolved from a water-based to a forest ecosystem. This transformation has induced changes in local livelihoods, with new activities emerging as part of an adaptation strategy (Djoudi et al. 2012).

Forests are part of local adaptive strategies; for instance, people use the resources of the new forests for charcoal or fodder. However, these strategies can have adverse impacts on the resource itself, which could lead to increased vulnerability in the future, unless forests are managed sustainably. Sub-national institutions have not yet realized the importance of managing these forests for enhancing local adaptive strategies. The institutions do not help local people to implement strategies that could effectively reduce their vulnerability. For instance, rules for access and control to the new forest are unclear, as well as land tenure in the previously irrigated agricultural lands. National and sub national decision makers generally lack information about local adaptive strategies. The research highlighted the divergent perceptions on adaptation by national, sub national and local stakeholders (Djoudi et al. 2012).

For EbA, it is necessary to understand the coupled vulnerabilities as well as resilience of people and ecosystems and to look at ecosystems in their broader context. However, there are many knowledge gaps on the socioeconomic vulnerability of forest-dependent people due to climate change (Easterling et al. 2007). These gaps can be explained by the site-specific nature of the role of forests in local livelihoods and the impacts of climate change on the services that are relevant to local stakeholders, for example specific non-timber forest products. More integrated research is needed on the impacts of climate change and their socioeconomic implications (Osman-Elasha et al. 2009).

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3.3 Water

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Impacts of climate change on water resources

The observed and likely impacts of climate change (CC) on water resources globally and by region, as well as implications of such impacts for agriculture and food security at large, have been collated and analyzed in the review conducted for the IPCC (Bates et al. 2008). This is the most comprehensive source of information on the subject to date. It states from the start that "Observational records and climate projections provide abundant evidence that freshwater resources are vulnerable and have the potential to be strongly impacted by climate change, with wide-ranging consequences on human societies and ecosystems". The four years since this was published have produced new evidence that confirm this statement (e.g. devastating floods and droughts of increasing frequency and magnitude in different regions, including those where CGIAR works, with severe damages to agriculture, livelihoods of poor farmers and food security of nations). The summary below reproduces, revises, merges or abbreviates some of the messages from Bates et al. (2008), supplemented with additional information where possible, and/or interpreted within the CGIAR regional context.

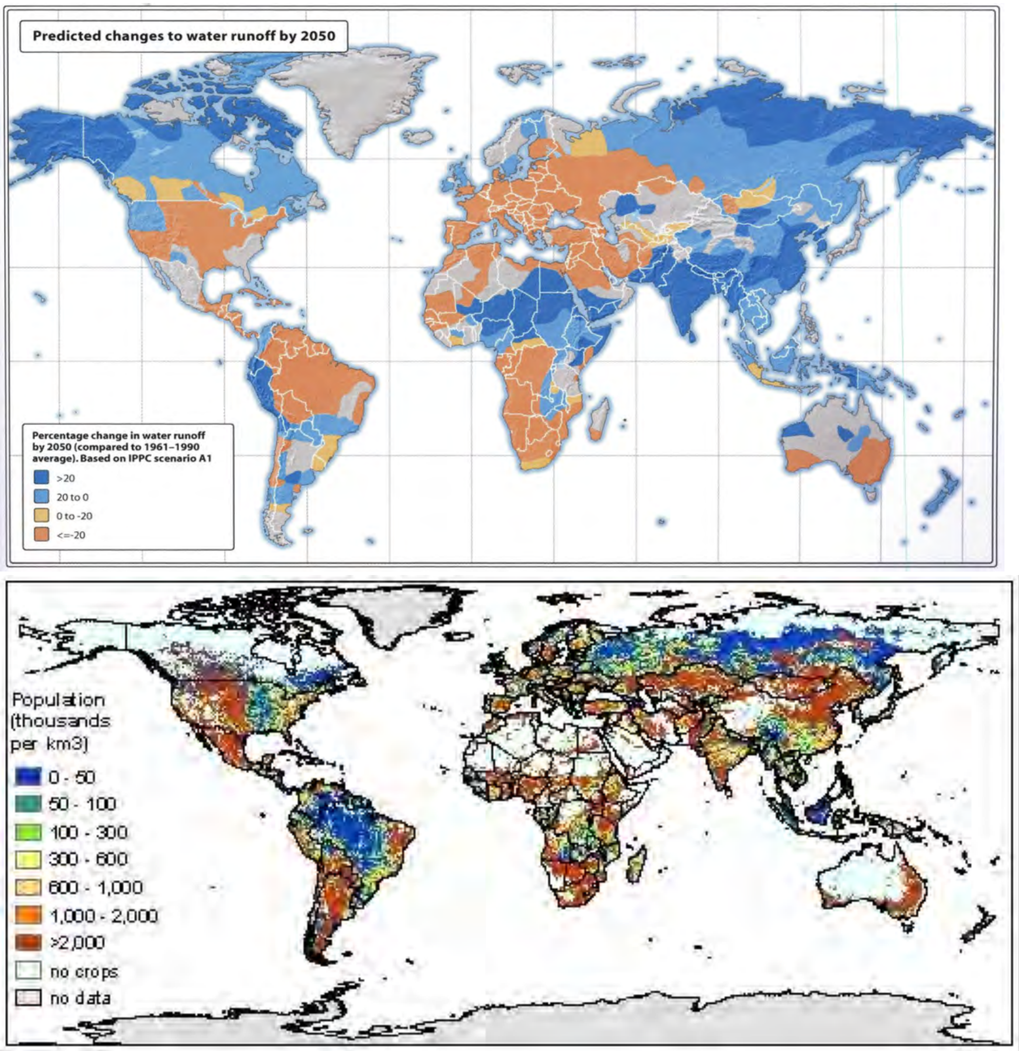
Observed changes: temperature increase in the past few decades is linked to changes in the large-scale hydrological cycle such as: increasing atmospheric water vapor content; changing precipitation patterns, intensity and extremes; changes in soil moisture and runoff. Precipitation decreases have dominated from 10°S to 30°N since the 1970s. The proportion of heavy precipitation events generally increased globally, including in India and southern Africa, with some evidence for decrease in East Africa. Globally, the area of land classified as very dry has more than doubled since the 1970s.

Projected changes in means: climate models consistently project mean precipitation increases in the 21st century in parts of the tropics, and decreases in some subtropical and lower mid-latitude regions. Outside these areas, the sign and magnitude of projected changes remains very uncertain. In the 21st century, annual average river runoff and water availability may increase in some wet tropical areas, and decrease over some dry regions at mid-latitudes and in the dry tropics. Some semi-arid and arid areas (e.g., Middle East-North Africa, southern Africa, northeastern South America) are projected to suffer a decrease in annual runoff, while

India, Southeast Asia and central East Africa are likely to see an increase, while Agricultural Water Crowding is already very high in many regions (Figure 3.3.1). There is very little that is currently known about the possible impacts on groundwater that may be one of the most significant climate change adaptation water sources for poor farmers.

Projected changes in extremes: increased precipitation intensity and variability are projected to increase the risks of flooding and droughts. At the same time, the proportion of land surface in extreme drought at any one time is projected to increase, especially in the sub-tropics, low and mid-latitudes.

Figure 3.3.1. Projected changes to river runoff by 2050 (top) and current Agricultural Water Crowding -the population per km3 of river water available for croplands within each 0.50 grid cell (bottom)



Source: Arnell 2003 (top), Eriyagama et al. 2009 (bottom)

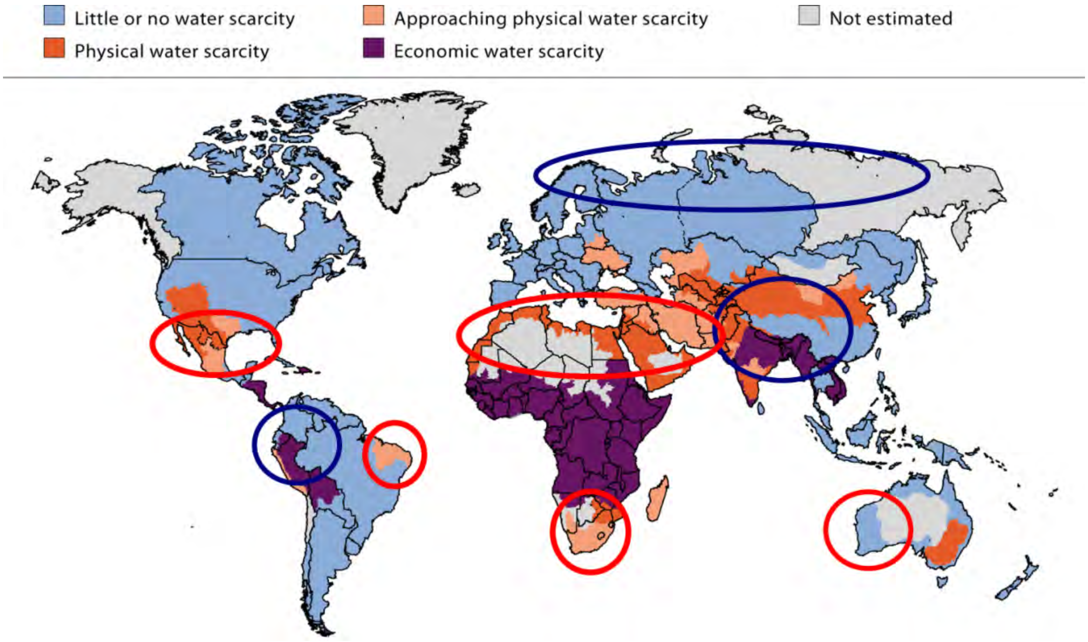
Projected changes in glaciers and sea levels: Water supplies in inland glaciers and snow cover are projected to decline in the course of the century, continuing the trend of the 20th century. This will reduce water availability during warm and dry periods—when irrigation is most needed—in regions supplied by melt water from major mountain ranges, where more than one-sixth of the world's population (mostly poor) currently live. It is however important to explicitly differentiate between glacier melt and snowmelt sources, and to assess these at the basin scale. Glacier contributions to river flow in the large monsoon area basins may not be very significant. Also, large high-altitude glacier systems in basins such as the Indus, which provide water for agriculture in most of the Pakistan, may not be particularly sensitive to temperature increases projected for the 21st century. Sea level rise is projected to extend areas of salinization of groundwater and estuaries, resulting in a decrease of freshwater availability for humans and ecosystems in coastal areas

Socioeconomic vulnerability and implications

Globally, the negative impacts of climate change on freshwater systems are expected to outweigh the benefits. By the 2050s, the area of land subject to increasing water stress is projected to be more than double that with decreasing water stress. Areas in which runoff is projected to decline face a clear reduction in the value of the services provided by freshwater ecosystems on which many poor farmers depend. Where increased runoff is projected to lead to increased total water supply, it is likely to be counterbalanced by increased precipitation variability and seasonal runoff shifts in water supply, water quality and flood risks. Overall, these changes will negatively affect water and food availability and access. This is expected to lead to decreased water and food security and increased vulnerability of poor rural farmers, especially in the arid and semi-arid tropics and Asian and African megadeltas. Figure 3.3.2 illustrates the current distribution of different types of water scarcity pointing to some areas that are projected to become drier or wetter due to climate change. More than one-third of the world's population already lives in river basins that have to deal with water scarcity, and this number will only increase.

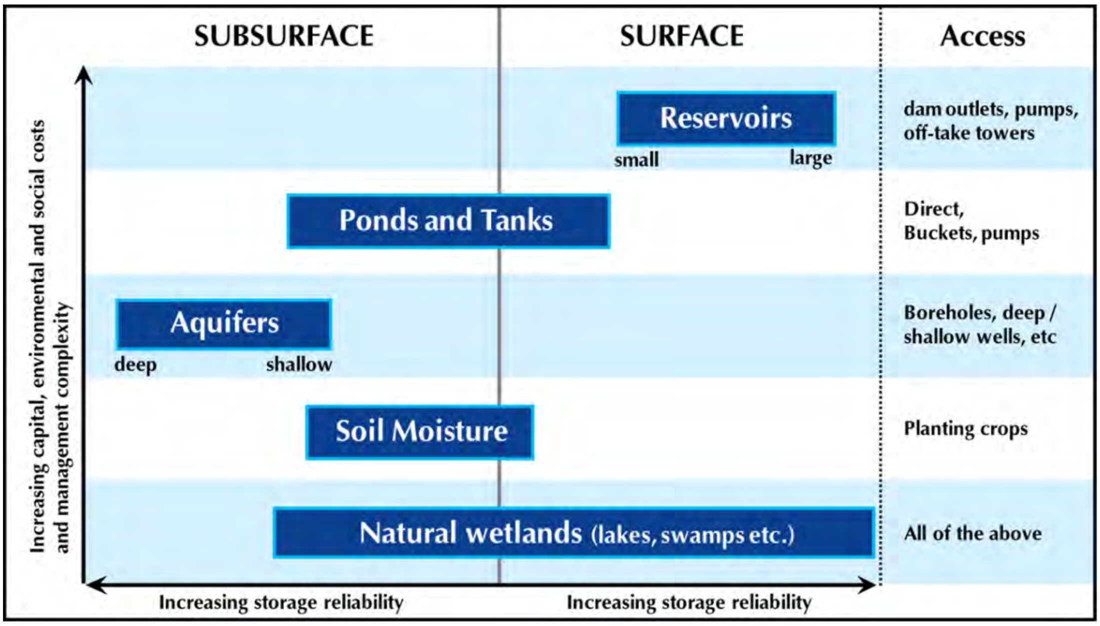
Climate change affects the function and operation of existing water infrastructure and overall water management practices, primarily through increased variability. This includes hydropower, drainage and irrigation systems, as well as water management practices. Adverse effects of climate change on freshwater systems aggravate the impacts of other stresses, such as population growth, changing economic activity, land-use change and urbanization. In many locations, water management cannot satisfactorily cope even with current climate variability, so that large flood and drought damages occur. Overall, management of water resources variability will become the primary societal strategy in the water sector for the 21st century if the adverse effects of climate change on food security are to be avoided. Managing water resources variability at different scales is possible through increased investment in various forms of water storage (Figure 3.3.3).

Figure 3.3.2. Water scarcity and some areas (approximately) projected to experience increase (blue circles) or decrease (red circles) in precipitation.



Source: Comprehensive Assessment of Water Management in Agriculture 2007.

Figure 3.3.3. Water Storage Continuum: storage options and combinations that can be considered for managing increasing water resources variability.

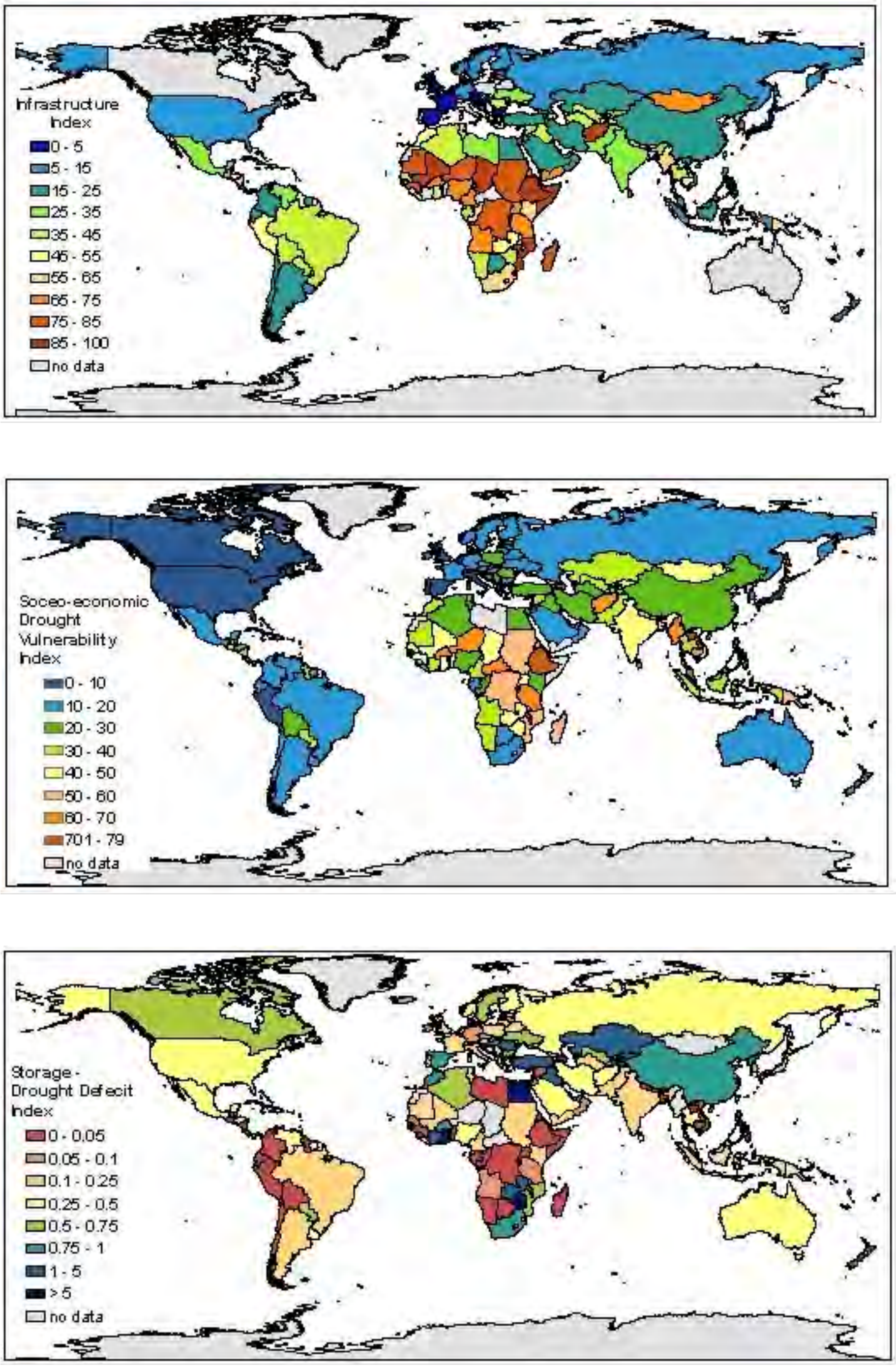


Source: McCartney and Smakhtin 2010.

Adaptation to climate change is largely about water. Following from the above, options designed to ensure water supply during average and drought conditions require integrated demand-side as well as supply-side strategies. The former improve water-use efficiency, such as by recycling water. An expanded use of economic incentives, including metering and pricing, to encourage water conservation and development of water markets and implementation of virtual water trade, holds considerable promise for water savings and the reallocation of water to highly valued uses. Globally, water demand will grow in the coming decades, primarily due to population growth. Large changes in irrigation water demand are expected. Supply-side strategies generally involve increases in water storage capacity, abstraction from water courses, exploitation of unconventional sources of water supply, and water transfers. Adaptation efforts and investments globally and locally will need to be driven by clear knowledge of the most vulnerable regions and locations that can be identified by vulnerability assessments in terms of multiple indicators (Figure 3.3.4).

Climate change mitigation measures can reduce water impacts and thus reduce adaptation needs, but they can have considerable side effects. Clean Development Mechanism (CDM) measures lead to afforestation / reforestation in developing countries to sequester carbon; this has direct impacts on hydrology (low flow reduction in particular). Biofuels is a source of clean energy.

Figure 3.3.4. Examples of global vulnerability mapping: Infrastructure Vulnerability Index based on percentage of people having access to an improved water source and general accessibility of rural areas through the road network (top); Socio-economic Vulnerability Index based on individual countries' crops diversity and their dependence on agriculture for income and employment generation (middle), and Storage-Drought Deficit Index (how much of the long-term annual hydrological drought deficit is satisfied by the existing storage capacity in a county) (bottom).

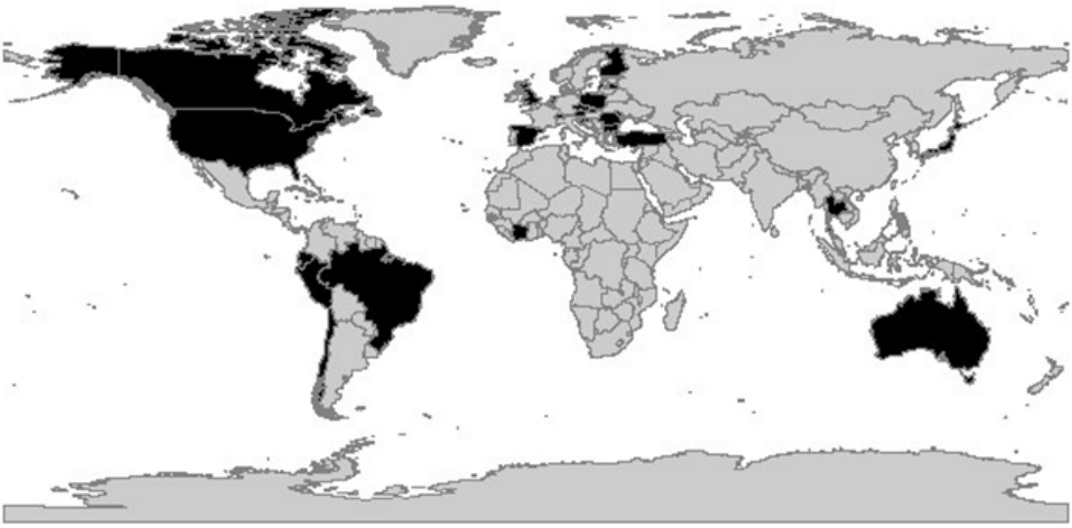


Source: Eriyagama et al. 2009.

But extensive biofuel programs in some countries (India, China) may have significant impacts on hydrology and on food crops (Fraiture et al. 2008), if projects are not sustainably located, designed and managed. Hydropower dams, a source of renewable energy, produce greenhouse gas (GHG) emissions themselves. The magnitude of these emissions depends on specific circumstances and the mode of operation. Agriculture and land-use change contribute over 30% of global GHG emissions. Deforestation and wetland development / degradation associated with it can contribute further carbon dioxide and methane emissions. Drainage of peatlands for agriculture releases carbon (some 30% of global soil carbon is contained in peatlands).

Regarding gaps in knowledge and data for improved water management, information about the water-related impacts of climate change is inadequate, especially with respect to water quality, aquatic ecosystems and groundwater, including their socio-economic dimensions. Improved incorporation of information about current climate variability into water-related management would assist adaptation to longer-term climate change impacts. Observational data and data access are prerequisites for informed agricultural water management and water resources management at large. Yet many observational networks are shrinking, and overall the problems of observed data availability and access that have existed for decades have only become more acute. The data already existing on various components of hydrological cycle are not freely shared (Figure 3.3.5). Without resolving these issues immediately, better understanding of climate change impacts on water resources, managing current water resources variability, and designing water infrastructure—whether large or small—will not be achieved.

Figure 3.3.5. Countries (in black) that share information on what hydro-meteorological data they have (not data themselves).



Source: World Meteorological Organization: www.wmo.int

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4 Summary and conclusions

Climate change affects plants, animals and natural systems in many ways. In general, higher average temperatures will accelerate the growth and development of plants. Most livestock species have comfort zones between 10 and 30 °C, and at temperatures above this, animals reduce their feed intake 3–5% per additional degree of temperature. Rising temperatures are not uniformly bad: they will lead to improved crop productivity in parts of the tropical highlands, for example, where cool temperatures are currently constraining crop growth. Average temperature effects are important, but there are other temperature effects too. Increased night-time temperatures have negative effects on rice yields, for example, by up to 10% for each 1°C increase in minimum temperature in the dry season. Increases in maximum temperatures can lead to severe yield reductions and reproductive failure in many crops. In maize, for example, each degree day spent above 30 °C can reduce yield by 1.7% under drought conditions.

Climate change is already affecting rainfall amounts, distribution, and intensity in many places. This has direct effects on the timing and duration of crop growing seasons, with concomitant impacts on plant growth. Rainfall variability is expected to increase in the future, and floods and droughts will become more common. Changes in temperature and rainfall regime may have considerable impacts on agricultural productivity and on the ecosystem provisioning services provided by forests and agroforestry systems on which many people depend. There is little information currently available on the impacts of climate change on biodiversity and subsequent effects on productivity in either forestry or agroforestry systems. Climatic shifts in the last few decades have already been linked to changes in the large-scale hydrological cycle. Globally, the negative effects of climate change on freshwater systems are expected to outweigh the benefits of overall increases in global precipitation due to a warming planet.

The atmospheric concentration of CO_2 has risen from a pre-industrial 280 ppm to approximately 392 ppm, and was rising by about 2 ppm per year during the last decade. Many studies show a beneficial effect (‘CO_2 fertilization’) on C_3 crops and limited if any effects on C_4 plants such as maize and sorghum. There is some uncertainty associated with the impact of increased CO_2 concentrations on plant growth under typical field conditions, and in some crops such as rice, the effects are not yet fully understood. While increased CO_2 has a beneficial effect on wheat growth and development, for example, it may also decrease the protein concentration in the grain. In some crops such as bean, genetic differences in plant response to CO_2 have been found, and these could be exploited through breeding. Increased CO_2 concentrations lead directly to ocean acidification, which (together with sea-level rise and warming temperatures) is already having considerable detrimental impacts on coral reefs and the communities that depend on them for their food security.

Little is known, in general, about the impacts of climate change on the pests and diseases of crops, livestock and fish, but they could be substantial. Yams and cassava are crops that are both well adapted to drought and heat stress, but it is thought that their pest and disease susceptibility in a changing climate could severely affect their productivity and range in the future. Potato is another crop for which the pest and disease complex is very important—similarly for many dryland crops—and how these may be affected by climate change (including the problems associated with increased rainfall intensity) is not well understood.

Climate change will result in multiple stresses for animals and plants in many agricultural and aquatic systems in the coming decades. There is a great deal that is yet unknown about how stresses may combine. In rice, there is some evidence that a combination of heat stress and salinity stress leads to additional physiological effects over and above the effects that each stress has in isolation. Studies are urgently needed that investigate ‘stress combinations’ and the interactions between different abiotic and biotic stresses in key agricultural and aquacultural systems.

It is clear that the impacts of changes in climate and climate variability on agricultural production will have substantial effects on smallholder and subsistence farmers, pastoralists and fisherfolk in many parts of the tropics and subtropics. Many of these people may have only limited capacity to adapt to climate change or to the many other stressors that may affect them. There have been relatively few studies carried out to date that quantify the impacts of climate change on household food security and livelihoods as well as on the urban populations who rely on cheap food, fuel, water and other necessities. Such studies are needed to help identify and evaluate the trade-offs and synergies associated with particular adaptation and mitigation options in different places. However, this is one focus of a considerable amount of current activity by CGIAR and its partners. Good progress is being made on developing and assembling the tools and databases needed for assessing options at different scales—from the globe to the household—but much remains to be done.

The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) is a strategic initiative of the Consultative Group on International Agricultural Research (CGIAR) and the Earth System Science Partnership (ESSP), led by the International Center for Tropical Agriculture (CIAT). CCAFS is the world's most comprehensive global research program to examine and address the critical interactions between climate change, agriculture and food security.

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